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Chemical Stimulation of Lightwood in Southern Pines

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U.S. DEPARTMENT OF AGRICULTURE

Chemical Stimulation of Lightwood in Southern Pines

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ABSTRACT

When applied to bole zylem tissue, paraquat, a bipyridylium herbicide induces lightwood formation (resin soaking) within the trunk of living pines. All southern pines respond and there is reason to believe that all members of the genus *Pinus* will react similarly. Other coniferous genera, however, show little if any significant reaction to paraquat. The amount and rate of oleoresin enhancement are functions of pine species, wounding method and extent of wounding used in applying paraquat, paraquat cation concentration, and time duration following treatment. Resin-soaking is essentially a wound response much magnified by the paraquat action within the tree. Bark beetles are much more strongly attracted to paraquat-treated trees than to adjacent pines identically wounded but not given paraquat. Fear of creating a bark beetle epidemic has probably hindered widespread application of lightwood technology, but this fear is unfounded. There is no instance where heavily attacked, paraquat-treated stands caused further beetle infestation. Beetle attack varies by season of treatment and wounding method, and is positively correlated with severity of wounding and especially the paraquat cation concentration used. Increases in wounding severity, paraquat concentration, or both, also increase oleoresin yield, but in progressively declining amounts. Therefore, the moderate paraquat treatments that we recommend will produce oleoresin yields only 10 to 15 percent less than those of severe treatments, and incur acceptable, often negligible, losses from beetle attack. These treatments will enhance oleoresin content of the wood from 100 to 150 percent; an increase from about 88 lb/100 ft^3 to 190 lb or more for slash pine, and from about 64 lb/100 ft^3 to 125 lb or more for loblolly pine.

Keywords: *Pinus taeda*, *Pinus elliottii*, paraquat, herbicide, oleoresin, resin soaking.

INTRODUCTION

The general purpose of the research summarized here was to find the means to furnish the economy with an additional supply of oleoresins, which are made up of unsaturated hydrocarbon compounds that are very useful as chemical feedstocks. Because the source is renewable, oleoresin can be produced in perpetuity and the technology has negligible environmental impact. If the treatments proved profitable, we hoped to get them into commercial use as rapidly and efficiently as possible.

The United States has an energy problem that makes new sources of petrochemical substitutes or supplements most welcome. Increased production of oleoresin in living pines could become such a source. Oleoresin is a generic term for those solutions of isoprenoid compounds produced by conifers and other plants, which individually are called resins. Although subject to some oxidation, oleoresins are basically hydrocarbons. Oleoresin is composed primarily of resin acids dissolved in terpenes, which when separated by distillation produce resin and turpentine, respectively. In southern pines, by far the most important source in this country, resin acids of mostly abietic and primaric types constitute the rosin, and the turpentine consists essentially of alpha and beta pinenes (Drew and others 1971; Mirov 1967). Because of their historic use for ship caulking, these commodities from oleoresin are termed "naval stores." The present supply is from three sources: (1) **Gum naval**

stores. Living pines are tapped and oleoresin collected, in this country, exclusively from two southern pines, longleaf (*Pinus palustris* Mill.) and slash (*P. elliottii* Engelm. var. *elliottii*). (2) **Wood naval stores.** Oleoresins are obtained by solvent extraction from the heartwood-rich remains of virgin southern pine stumps. This stump heartwood is resin-soaked and is commonly known as "lightwood" because of its traditional use as kindling in the South. Stumps from the much younger, second-growth timber are mostly sapwood and have little resin accumulation. (3) **Sulfate naval stores.** Oleoresins are obtained as byproducts from the kraft pulping process, which is the most common method for producing paper and cellulose products from southern pines. The gum, wood, and sulfate sources contribute 2, 25, and 73 percent, respectively, of the current United States oleoresin production, which is nearly 1 billion lb (Zinkel 1975b). The sulfate source is clearly the most important, and its production continues to increase while those of the other two decrease due to high labor costs (gum naval stores) and the dwindling supply of virgin pine stumps (wood naval stores). Production from kraft pulpmills is governed, in effect, by the byproduct recovery efficiency, the volume or quantity of pulpwood processed, and especially the oleoresin content of the pulpwood. Production from the wood naval stores industry could also rise if new supplies of wood with sufficiently high oleoresin content were available.

In 1973, our Forest Service naval stores researchers reported a discovery that promises to solve this impasse--a method that can dramatically increase the oleoresin content of young sapwood trees (Roberts 1973; Roberts and others 1973). Such trees account for the overwhelming bulk of our present southern pine timber crops and will become even more important in the future. The bipyridylium herbicides diquat or paraquat, particularly the latter, when applied to bole tissue will induce lightwood formation (resin-soaking) within the trunk of the living pine. All southern pines respond to paraquat by producing lightwood (Peters and Roberts 1976).

All pines of North America tested thus far produced resinosis after paraquat application (Conner and others 1977; Rowe and others 1976). There is reason to believe that all species of the genus *Pinus* will respond, but other coniferous genera such as *Thuja, Abies, Tsuga, Picea, Larix,* and *Pseudotsuga* do not show an economically significant reaction to paraquat (Kiatgrajai and others 1976a, 1976b; Sandberg and others 1977). The magnitude of response, in practical terms, is not known for northern and western pines. However, naval stores production in the United States is dominated by the South, where more than 90 percent of the oleoresin is produced. The reasons are both biological and technical; the major southern pines have a higher natural oleoresin content than northern and western species, and most southern pulpmills use the kraft process which allows byproduct recovery. Consequently, the opportunities for profitable lightwood reduction are in the South, and most of the pertaining research has been done there.

In July 1978, the EPA paraquat label was amended to allow paraquat to be used commercially for lightwood induction in all southern pines except sand pine (*Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.).

Oleoresin Production Potential

What is the magnitude of this potential silvachemicals source? Various paraquat treatments can at least double tree oleoresin content, producing about 80 lb of additional oleoresin in each cord of pulpwood (a cord contains about 80 ft^3 of solid wood). Within the 13 Southern States of USDA Forest Service Region 8, the southern pines, principally loblolly (*P. taeda* L.), slash, longleaf, and shortleaf (*P. echinata* Mill.) dominate on about 72.7 million of the 204.2 million acres of commercial forest land. On an additional 31.9 million acres, southern pines are present in admixture with hardwoods. These pines contain approximately 86.8 billion ft^3 of wood, about 1.085 billion cords, in growing stock 5 in. or larger in diameter (USDA Forest Service 1973, 1975a). Additional wood is accumulating at the rate of about 1.4 billion ft^3 annually. If all this merchantable growing stock were treated with paraquat, we might realize 43,400,000 tons of additional oleoresin in standing trees, an equivalent of about 290 million barrels of petroleum. These figures are interesting but have little bearing on what could be accomplished annually in the near future. During 1979, a recession year, the South harvested and processed about 26.1 million cords of pine pulpwood (Bellamy and Hutchins 1979). If our current paraquat technology had been used on these trees, the additional yield in oleoresins would have been about 2.1 billion lb.

The South has by no means reached its capacity for pine growth; on the existing forest-land base the growth and eventually the volume could be easily doubled (USDA Forest Service 1975b; Wahlenberg 1965). Indeed, the demand for southern pine pulpwood is expected to double by the year 2000 (USDA Forest Service 1975a). The opportunities for paraquat-induced oleoresin production from kraft pulpmills would increase in like manner.

Plainly, the chemically induced lightwood concept has strong potential for creating an important and expanding source of oleoresins. This forest resource is renewable. Natural stands and plantations could convert solar energy into oleoresins, under present constraints, ad infinitum. A tremendous resource base in standing timber already exists, and it is being steadily increased by wider application and greater intensity of forest management. This trend will likely continue, and cultural measures that favor pine volume growth will probably favor the oleoresin yield capabilities from paraquat treatment. These measures increase gum naval stores production (Clements 1974), and the origin of oleoresin is the same in both techniques.

Commercial Uses of Oleoresin, Present and Potential

The industrial uses of turpentine and rosin are many and varied. Much of the rosin is used for chemical intermediates and in synthetic rubber, paper size, coatings, and adhesives. Turpentine is often separated into its major components--alpha- and beta-pinene. Alpha-pinene goes mainly into synthetic pine oil and insecticides, beta-pinene into adhesives and essential oils of flavorings and fragrances (Zinkel 1975b). Many former markets for oleoresin products were lost because of unstable and frequently insufficient supplies. Uncertainty of adequate supply at a reasonable price has inhibited industrial development, investment, and research in uses of this resource. If induced lightwood stabilizes and increases supply, certain old markets may be recaptured and new uses will be developed.

Some promising new uses for oleoresin products, particularly rosin, are discussed by Collier (1976, 1977), who studied the feasibility of oleoresin substitution for petrochemicals. Possible uses for rosin include alkyd, polyester, and other resins, polyurethane foams and coatings, and synthetic lubricants. Suggested uses for turpentine include isoprene, additional adhesives, terephthalic acid, and possibly motor fuel. Oleoresin-enriched trees could also be the basis for a "complete utilization" chemical industry wherein the whole tree would be processed. Silvachemicals would be extracted and other wood products such as celluloses and lignin converted to methanol or other products (Brown 1976; Szego and others 1972).

In the past the oleoresin byproducts of kraft pulpmills were not recovered for marketing or further processing; instead, they were used directly as fuel. Turpentine-supplemented fuels were used in steam-generating boilers, and resin acids (rosin constituents) were left in the spent digesting liquor, aptly termed "black liquor." After evaporative condensing, this liquor went to the recovery furnace which regained chemicals for recycling. The resin acids, along with lignin and many other substances in the black liquor, furnished the necessary combustion energy (Grantham and Ellis 1974; Koch

1972). Consequently, even when a pulpmill does not recover oleoresin, it is not wasted; it reduces the amount of fuel oil required. If the price of fuel oil continues to rise, the trend toward attaining maximum oleoresin byproduct recovery may halt, with oleoresin partially recovered and partially used as fuel. Continental Group, Inc., first became interested in paraquat-induced lightwood because of the implications in reducing fossil fuel needs of their mills. However, with the present price of oleoresins relative to fuel oil, maximum oleoresin recovery is the goal.

Plant Production Capacity

What are the capabilities, and the prospects for expansion, of oleoresin production by the kraft pulpmills and wood naval stores extraction plants? For the pulpmills, additional turpentine recovery presents no serious difficulty. In some instances more condenser capacity will be required, but it has been jokingly stated that the greatest need will be simply more turpentine storage tanks.

The situation with rosin is more complex. Saponified resin acids and fatty acids are removed from black liquor by a mechanical skimmer installed in a settling tank (often called a "skim tank"). These soaps are then acidified to form crude tall oil, which contains both resin and fatty acids (Koch 1972; Zinkel 1975a). Most tall oil is now fractionated into tall oil fatty acids and resin acids (rosin). United States fractionating capacity is about 1 million tons per year, while production is about 800,000 tons (Zinkel 1975a). To take advantage of the additional resin acids in chemically induced lightwood, most pulpmills would have to increase skim tank and fractionating capacity, and also make other capital investments.

Wood naval stores plants would have to process a greater volume of paraquat-induced lightwood to achieve production comparable to that with natural lightwood, because paraquat-treated material is going to contain both lightwood and unenriched sapwood, and pound for pound less oleoresin. Other modifications would no doubt also be needed. In the South this industry will soon have to rely on chemically induced lightwood as a source of raw material or be forced out of production.

PHYSIOLOGY OF LIGHTWOOD PRODUCTION

Translocation of Paraquat

Paraquat solution is usually applied to the zylem of pine trees by spraying it on an exposed surface or placing it into open cuts or drill holes. Paraquat sprayed on the zylem surface must diffuse into the zylem and enter the tracheids before it can be transported upward in the transpiration stream. When cuts and drill holes are made in the zylem, some of the tracheids are severed, breaking the transpiration stream and allowing air to enter the tracheids. When the paraquat solution is added, the time required to re-establish the water column may delay effective movement in the transpiration stream. Most of the movement of paraquat is in the transpiration stream and therefore is upward.

Brown and Nix (1975) found that paraquat applied to the zylem surface of slash pine trees moved at 1/100 the velocity of water in the transpiration stream. They attributed this slow movement to the strong adsorption of the highly polar paraquat cation to the cellulose cell walls. With continued flow of water the paraquat cations slowly moved within the transpiration stream by repeated adsorption and desorption, similar to movement of compounds along a chromatographic column. Massive treatment with 45 ml of 8 percent paraquat per tree, applied by placing saturated cellulose fiber pads on exposed zylem surface, overloaded the adsorption sites causing large quantities of paraquat to move rapidly to the crown. All the trees were killed within 30 days. With normal rates (4 ml of 8 percent), paraquat moved 12 in. per day vertically and 0.2 in. per day radially. Davis and Carrodus (1978) suggested that some of the paraquat movement in Monterey pine (*Pinus radiata* D. Don) is associated with the trailing edge of water in the transpiration stream as water columns are broken when ray cells, whose energy is necessary for their integrity, are destroyed.

In 2-year-old loblolly pine seedlings, Schwarz and others (1977) found that most of the paraquat moves only a short distance. Even after 30 days, most of the paraquat applied to miniature bark streaks was from 0.4 in. below to 1.2 in. above the area of application. Low concentrations of paraquat moved to the needles and caused toxic effects in them.

It is fortuitous that paraquat is translocated primarily by the transpiration stream, at a slow rate that eventually becomes negligible; paraquat ion concentrations decrease geometrically above the application site. If paraquat, like many herbicides, moved rapidly to the crown and downward in the phloem to the roots, very little resinosis could occur before the tree was killed or badly injured. Consequently, lightwood formation and enhancement are possible only because of the translocation characteristics of paraquat.

Indirect evidence seems to indicate, however, that the rate and quantity of paraquat translocation vary greatly even in genetically identical material (Wolter and Zinkel 1976). Visual observations confirmed by analysis of wood samples show very high tree-to-tree variation in oleoresin enhancement as one progresses up the bole. Increased oleoresin accumulation extends only 4 to 6 ft above the wound site in some trees; others have oleoresin even bursting through the bark at heights of 30 ft or more. Such trees often can be found side by side and are comparable in size, vigor, crown class, age, and paraquat treatment. It seems virtually certain that this variation in resinosis is a function of variation between trees in paraquat translocation, but the causes are obscure. This phenomenon is more than interesting; it is of great practical significance. If all trees could be made to accumulate oleoresin in quantity equal to the average for the top 30 percent of trees, oleoresin production could be more than doubled.

Action of Paraquat

Treatment of pine trees with paraquat causes heavy resinosis in the sapwood zylem. Near the wound site, oleoresin content of this wood may be greater than 40 percent of the water-free weight of wood compared with the usual content of approximately 2 percent (Roberts and others 1973). Resinosis develops in a characteristic pattern following radial lines from the outer edges of the surface application to the pith. If heartwood or incipient heartwood has developed around the pith, it interrupts this pattern. New resin deposits do not form in the heartwood or the transition zone surrounding it. Resinosis is most intense at the level of application and diminishes upward and downward from this level and from the surface toward the zylem center. Resinosis usually extends upward 10 to 15 times farther than it extends downward from the area of application.

Working with 8-year-old slash pine trees, Birchem and Brown (1979) reported that oleoresin moved from parenchyma and epithelial cells centrifugally through half-bordered pits into the lumens of adjacent tracheids. When the tracheids were filled, the secondary cell walls also were impregnated with oleoresin. Miniutti (1977) also reported a pattern of oleoresin deposit in tracheids which indicated it entered from ray parenchyma cells through half-bordered pits. On the fringes of areas with resinosis, the summerwood tracheids were usually filled with oleoresin, but in the same area the lumens of the springwood tracheids appeared to be free of oleoresin.

In addition to resinosis, paraquat treatment causes many changes in the living parenchyma cells of the zylem including: (1) increased membrane permeability, (2) disruption of cellular organization, and (3) eventually destruction of cellular membranes and organelles including the nucleus (Birchem and Brown 1979; Brown 1975).

In 5-year-old slash pine trees, Brown and others (1976) found that starch disappeared from cells near the point of entrance of paraquat into the stem. This phenomenon was accompanied by increased synthesis of oleoresin and free fatty acids. Stored food reserves were mobilized, followed by a gradual lysis of the cytoplasm and enclosed organelles. They reported that the carbon from the mobilized food reserves was shunted into the terpenoid synthetic pathway before the death of the cells, thus contributing to the rapid production of oleoresin and its release into the tracheids.

In cell suspension cultures, similar destruction of membranes and disorganization of the cytoplasm and organelles takes place, but no oleoresin is produced (Birchem and Brown 1979; Brown 1975). Cell division stopped quickly in suspension cultures placed in 1 part per million paraquat and respiration increased initially, then dropped.

Finnerty and others (1976) found that soluble carbohydrates decreased and amino acids, keto acids, resin acids, and thiobarbituric acid-reacting substances increased in 5-year-old slash pines treated with 10 ml of 0.02 percent paraquat. Schwarz and others (1977) observed decreases in starch, tannins, and lipids accompanying heavy accumulation of oleoresin in paraquat-affected areas of loblolly pine seedlings.

Ryan and Schwarz (1979) and Wolter and Zinkel (1976) reported decreased photosynthesis in seedlings after paraquat treatment and indicated that the immediate carbon source for oleoresin synthesis must come from previously fixed carbon and not current photosynthate. Defoliation experiments by Brown and others (1979) show that some but not all oleoresin in paraquat-treated trees is produced from current photosynthate since defoliation reduced oleoresin production. By making saw cuts above and below the paraquat-treated area, they also showed that oleoresin precursors are normally transported in the tree stem. Saw cuts (10 in.) above and below significantly reduced resin soaking in the treated area.

The herbicidal effect of paraquat at the cellular level involves the reduction of the paraquat cation to a stable but very active free radical, which reacts with oxygen to form hydrogen peroxide or hydroxyl radicals with the paraquat free radicals being oxidized back to paraquat cations. The paraquat is not destroyed in the process but acts essentially as a catalyst for the formation of hydrogen peroxide or hydroxyl radicals by repeated recycling of the process (Calderbank 1968). Schwarz and Ryan (1980) indicated that a superoxide, which is very active in cell destruction, may be formed directly or through production of hydrogen peroxide. The hydrogen peroxide, hydroxyl radicals, or superoxides can peroxidize lipids in the membranes of cell and cellular organelles to produce lower molecular weight products, cause the characteristic changes in membrane permeability and integrity, and finally the complete disruption of cells.

In green plants the reduction potential for reducing paraquat comes from ferrodoxins in photosystem 1 of photosynthesis (Calderbank 1968). In nonphotosynthetic tissue, such as parenchyma cells of zylem in pine tree stems, the reduction potential probably comes from the electron transport system of mitochondrial respiration as suggested by Harris and Dodge (1972) for dark-germinated flax seed.

In lightwood formation, paraquat apparently acts as a catalyst to form oxidizing compounds that disrupt the cellular structure of the living zylem parenchyma cells. This action releases sugars, fatty acids, and amino acids that act as precursors for production of oleoresin constituents. Enzymes, which control synthesis of the oleoresin constituents, are apparently released in the same process or their production is stimulated by auxins produced in response to wounding by paraquat. Ethylene, whose production is normally stimulated by wounding plants, may be involved in stimulating enzyme activity.

OBJECTIVES OF STUDIES

The general objective of the studies on lightwood induction summarized in this paper has been to ascertain the feasibility of producing and processing chemically induced lightwood on a commercial scale. Data were gathered and evaluated for both woodlands operations and processing plants. Specific objectives were (1) Determine oleoresin yield as influenced by treatment factors and processing. (2) Assess insect pest hazards by treatment and tree species, and devise pest control measures. (3) Estimate wood growth loss due to paraquat treatment. (4) Appraise the quality of oleoresin from induced lightwood. (5) Uncover and solve technical problems in woodland and processing plants. (6) Estimate costs in dollars, and evaluate profit potential. (7) Determine environmental impact and safety, especially in reference to attaining EPA registration of paraquat for lightwood induction purposes.

To assist in meeting these objectives through cooperative studies, to reduce duplication in research efforts, and to disseminate results promptly, the Lightwood Research Coordinating Council was formed in 1974 and is now part of the Pulp Chemicals Association. Its original membership included private industry, universities, State and Federal forest services, and other public agencies. The majority of studies summarized herein were published in the proceedings of this group.

A WORD ABOUT METHODS

There has been a multitude of tests with paraquat for evaluating lightwood stimulation--several hundred of them--but not a great many well-designed studies that also had provision for adequate sampling. There are several reasons for this, the principal one being that factional studies in paraquat research (and forestry in general) that have more than a few variables soon get logistically out of hand. Compounding this for paraquat research, it was soon discovered that treated trees within a plot varied a great deal in their lightwood-forming response. In sampling for oleoresin production, Stubbs (1978) determined that about 30 trees in each treatment plot had to be sampled to achieve a 95 percent level of confidence for the mean--a confidence interval of 10 percent. Using another approach that did not employ population variance, Pombo and Propst (1979) concluded that 50-tree sampling was required. Their approach gave no information on the confidence limits to be expected but may have been suitable for their objectives. Few researchers or groups had the wherewithal, financial and otherwise, to do this sort of sampling or the consequent laboratory analyses for oleoresins, which could amount to thousands of determinations.

This disagreeable reality was often either ignored or not acted on because the resulting sampling load was impracticable, as in Marton and Marton (1976). Another approach was to limit sampling to only that necessary to determine relative differences between treatments, as in sampling only the basal 5 to 10 ft of trees. However, the consequence of both of these approaches is that accurate data on total oleoresin yields are quite scarce.

Confidence limits of 10 percent or more associated with useful oleoresin yield data may cause some concern. Furthermore, these confidence intervals only inform us about the precision of the sampling, not the true accuracy in estimating the actual population average (measurements with a yardstick that is not 3 ft long can give very satisfactory confidence limits). All experiments had some bias of this kind--in the sample collection methodology, in preparation, and in the actual laboratory analyses. Most workers used Shepard's (1975) method, or modifications of it, for resin acid determinations. Using titration, the quantity of all free acids in the sample solution is measured; most of these are resin acids but some are not, thus the method overestimates slightly. Turpentine analyses have usually slightly. Turpentine analyses have usually followed the Pulp Chemicals Association method as given by Drew and others (1971), which can present problems, especially with small samples from wood with a low level of turpentine. The modification developed by Munson (1979), used in many of the studies conducted by the authors, overcame many of these problems but yielded values 5 percent too high. This bias fortunately was consistent and could be easily corrected. For practical use in forest stands, estimation of oleoresin content from a sample of trees is not the only source of error. That estimate must then be applied to cruise data and volume tables, which also contain error. The best of volume tables are often off by 4 or 5 percent for a particular stand. Therefore--returning to whether 10 percent confidence limits of oleoresin yield are sufficiently exact--getting more precision through even more intensive sampling and supposing one has a more accurate and useful estimate is largely an illusion. Also, estimation only needs to be sufficiently accurate to meet the needs of decisionmaking. If a rational choice can be made with estimates of no better than 10 percent accuracy, and additional accuracy would cause no change in decision, it is a waste of money to invest in estimates with 5 percent accuracy.

As an example of tree sampling, the methods used by Stubbs and Outcalt (1982) are typical and may be instructive. Trees for oleoresin determination were randomly chosen. In virtually all studies, 30 trees were destructively sampled for each treatment at each sampling date. The diameters of selected trees were measured and then trees were felled. Once cut, the total height, distance to the live crown, and distance to a 4-in. top (diameter outside bark) were measured. Then 0.75-in-thick disks were cut at 1-ft intervals for the first 10 ft of bole and at 2-ft intervals thereafter to a 4-in. top (fig. 1). After the disks were debarked in the field, their diameters at 0 and 10 ft were measured. Disks 1 through 5 were put in a polyethylene bag, disks 6 through 10 in another, and the remainder in a third bag. Sample bags were packed in cardboard boxes and transported to a freezer for storage.

These samples were shipped frozen to our laboratory in Olustee, Fla., for analysis. There the sample disks were chipped, the chips were mixed, and subsamples were drawn. Part of the sample was analyzed to determine the quantity of resin acids by using Shepard's (1975) procedure. Another part of the sample was analyzed for the quantity and constituents of turpentine by methods developed at the Olustee laboratory (Munson 1979).

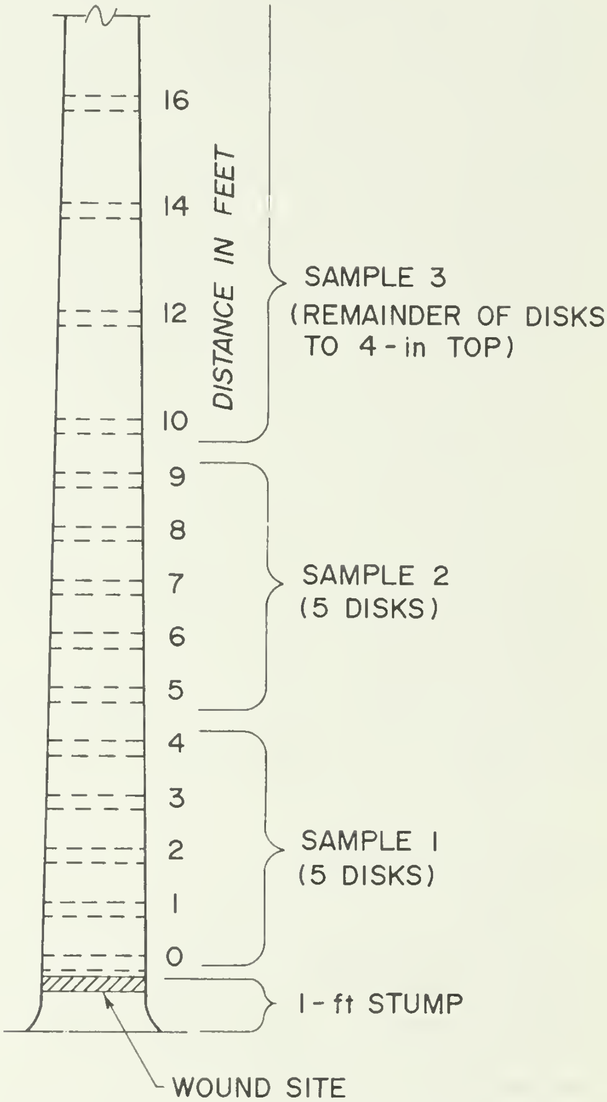

Figure 1.--Cutting diagram for collection of wood samples used in oleoresin analysis.

RESULTS AND DISCUSSION

Treatment Variables

Species of Pine

All southern pines have been shown to form lightwood after paraquat treatment (Peters and Roberts 1976). Loblolly and slash pines have the most potential for industrial use of lightwood technology because they occupy the most area and have the largest standing volumes. Of the two, there is 1.6 times more volume in loblolly pine than in slash and longleaf pines combined, and 4.4 times as much as in longleaf. Slash pine, however, has a generally higher normal oleoresin content than has loblolly pine, and shows more response to paraquat treatment. Consequently, of the southern pines, slash pine has received the most attention in paraquat research, followed by loblolly pine, with longleaf pine a distant third. The rest of the southern pines have been subjected to little more than an initial test or a few exploratory studies. To our knowledge, no studies have been designed specifically to compare response between species. However, when slash and loblolly pines were both injected with 2 percent paraquat during the summer (Stubbs and Outcalt 1982), the gain in oleoresin content after 12 months was 0.89 lb/ft^3 for slash pine and 0.45 lb/ft^3 for loblolly (see tables 11 and 14). This greater response by slash pine has been general throughout the South. The two species also differ in the effect of paraquat treatment on turpentine constituents.

For paraquat treatment, the slash pine belt and the more northerly zone, where loblolly generally dominates, form two quite distinct entities. For practical purposes, longleaf pine can be considered with slash pine. These two regions differ in oleoresin enhancement yields, probably in effects of season of treatment, and they assuredly differ in the degree of bark beetle hazard associated with paraquat treatment. In the future when more research results are available, it might be well to prepare separate information summaries for these two major species and general regions.

Age of treated pines

Pulpwood-size pines are the obvious choice for paraquat treatment, whether the wood is to go to pulpmills at the end of a normal pulpwood rotation, or to wood naval stores extraction plants. Trees of sawtimber size can be more profitably utilized for lumber and veneer. The age of pulpwood-size pines will range from 15 to 30 years or so, depending upon the site quality, stocking of the stand, and other factors.

Information is limited concerning the effect of tree age on response to paraquat treatment. In preliminary tests with loblolly pine, Stubbs and Outcalt (1982) show that trees as young as 9 years old will form lightwood when treated with paraquat. Mortality, however, can result from paraquat reaching the crowns of pines 9 to 12 years old. Death caused directly by paraquat is primarily a function of tree height; therefore, pines should be at least 30 ft tall before paraquat is applied. Because trees older than 12 years generally exceed 30 ft in height, mortality caused by paraquat toxicity is not a problem.

Although it is not economically sound to treat older trees of sawtimber size, it has been hypothesized that such trees are better able to withstand the stress caused by paraquat application. The reasoning is based on circumference being directly proportional to diameter, while basal area (cross section) and bole volume are proportional to diameter squared. In comparing 1/3-circumference treatments on a large pine and on a small pine, the larger tree has a greater volume of wood for transpiration stream flow per unit length of wound and paraquat absorption site. This assists the larger tree directly and also leads to greater dilution of the paraquat. In actual practice the above does not seem to be very important, although mortality from insects attracted to paraquat-treated trees is inversely correlated with diameter (Ericksen 1978; Outcalt and Stubbs 1979). Paraquat treatments severe enough to cause problems, as evidenced by heavy insect attack and subsequent tree mortality, are more than sufficient to overide any advantage of larger tree size and generally greater age.

Methods of Applying Paraquat

The chemical must reach live tissue within the tree to induce lightwood formation; therefore, trees must be wounded in some manner in order to apply the chemical. Of the many wounding methods tested, one of the oldest and most common is the "bark streak," a term from gum naval stores operations. Bark streaks are made by removing a 1-in-high section of bark, horizontally around the tree at stump height, generally for one-third of the tree's circumference. With slash pine, 1/3-circumference bark streaks were tested by Bailey (1976), Barker and Schmid (1976), Beers (1975), Conley and Bailey (1977), Conley and others (1976), Hertel and Williams (1975), Joyce and others (1977), Roberts (1976), Roberts (1978b), Roberts and Peters (1976), Roberts and Peters (1977), and Squillace (1975). The same wounding treatment was applied to loblolly pine by Beers (1975), Conley and others (1976), Marton (1975), Roberts (1978b), and Stubbs (1978). Enos and others (1978), Hertel and Williams (1975), and Nix (1976) tested 1/2-circumference bark streaks on slash pine; Enos and others, and Nix, also tested them on loblolly pine. Bark streaks 1 in. in height have been the rule, but Roberts and Peters (1977) compared streak heights of 1, 2, and 4 in. on slash pine, and Roberts (1979b) again compared 1- and 4-in. heights on that species.

Bark-streak wounds have been the most popular method used, featuring simplicity, rapidity and thus economy, amenability for mechanization, good results in oleoresin enhancement, and, if limited to 1/3-circumference, less hazard from bark beetles than most other treatments. Bark streaks in excess of 1/3-circumference do not produce enough additional oleoresin to offset the added stress they cause the tree, and thus the higher risk from bark beetles. And streaks 2 or 4 in. high have shown no advantage in oleoresin yield.

Therefore, we recommend 1-in-high bark streaks, not to exceed one-third of the tree's circumference. This is probably the most universally useful method of any tested, although, as discussed later, tree injectors have certain advantages and drill holes are highly useful for specialized purposes. These three general methods have proved to be the most useful. Bark streaks can be made by hand with a bark hack (a gum naval stores tool), or with a powered chipping saw (Clements and McReynolds 1977). More recently a cutting head mounted on a small-track vehicle has been devised for treating trees in this manner (Mappin and Propst 1979).

Ax frills, with or without herbicide application, were in early use as a means of killing trees. This wounding method has been used in paraquat studies by Enos and others (1978), Nix (1976, 1977), Roberts (1975), and Roberts and Peters (1976). The method is simple but little more can be said for it; it takes some skill and is extremely labor intensive.

Drill holes have received quite wide-spread testing. Holes with some downward slope are drilled tangentially into the bole of the tree, paraquat solution is placed in the holes, and then they are usually corked. Depending on the number and arrangement of holes, which in effect are a chord of some portion of the tree's circumference because they are drilled tangentially, treatment can be tailored to affect approximated 1/3-circumference, 1/2, or whatever. With slash pine, varied arrangements of holes have been tested by Enos and others (1978), Peters and Joyce (1975), Peters and Roberts (1977), Peters and others (1978, 1979), and Roberts (1979a). Enos and others (1978) also used drill holes with loblolly pine, as did Stubbs (1978). In terms of increased oleoresin, the drill holes have shown no advantage over simpler methods, such as the bark streak or tree injector, and they are at least twice as expensive (Stubbs 1978). Thus, they cannot be recommended for paraquat application except for stump treatment (described later).

A variant of the drill-hole method involves placing paraquat-impregnated wooden dowels into the hole or holes (Roberts and Peters 1977; Stubbs 1978). Or, cellulose plugs or other absorbent material can be put into holes and then saturated with paraquat solution (Enos and others 1978; Roberts 1979a; Roberts and Peters 1977). Neither version shows any particular advantage in slash or loblolly pines, and neither is recommended.

As the bark streak was borrowed from gum naval stores, so were most tree-injection methods taken directly or modified from tools and methods designed for applying herbicide to unwanted trees. One of these tools is the Punch-Hammer[1] (Crutchfield 1976a; Marton 1975), which wounds and meters chemical at the same time. According to Crutchfield (1976b), who used this tool on loblolly pine, wounds around the tree should not be spaced closer than 6 in. A second tool is the Hypo-Hatchet (Joyce 1978), which also wounds and applies in the same stroke. For paraquat treatment of large numbers of trees, neither of these tools is very suitable. They lack the paraquat solution storage capacity of tree injectors and are no easier to use.

Two devices not related to herbicide use that have been modified for use in paraquat treatments are the Med-E-Jet and grease gun. The former is used in the medical profession to inject precise dosages of innoculum through the skin by using compressed carbon dioxide as a propellant. Equipped with a needle, of which several designs have been tested, the Med-E-Jet is used in paraquat application by first forcing the needle through the bark, and then using the compressed carbon dioxide feature and metering mechanism to introduce set quantities of paraquat solution into the tree, by creating a cavity between the inner bark and zylem. Med-E-Jets so modified have been tested by Bailey (1976), Conley and Bailey (1977), Crutchfield (1976a), and Roberts (1979b); also by Drew (1976), Drew and Joyce (1975), and Joyce and others (1977) in reports pertaining to a single study. The device is fragile, ill-suited to large-scale treatment, and has produced highly variable results in oleoresin enhancement. Except as a basis for ideas in mechanization, it can be dismissed from further consideration. Roberts (1978a) utilized the high-pressure capability inherent in grease-gun design and modified one for use in paraquat injection. It will function as well as the Med-E-Jet, is easier to operate and much cheaper. In a test by Roberts (1979b) it did not appear to do as well in oleoresin enhancement as did a tree injector. With further development the tool might have some promise for small-scale operations.

Nowadays the most popular tools for deadening trees in timber stand improvement are tree injectors. Two of these, the Jim-Gem and Cran-Jector, have been used extensively in paraquat studies, including those on slash pine by Conley and Bailey (1977), Roberts (1979a, 1979b), and Stubbs (1978); on loblolly pine by Stubbs and Outcalt (1982) and Waite (1977, 1978); and on both slash and loblolly pines by Bailey (1976). Tree injectors have proved to be extremely useful tools for paraquat treatments, much the most satisfactory of all injection devices. Tree injectors and power-chipped bark streaks are presently the least expensive methods, and tree injection is somewhat less expensive than is chipping (Stubbs 1978, Stubbs and Outcalt 1982). Drew and Joyce (1979) came to the same conclusion, and gave a production rate of 2 acres of pines treated per person-day. In the class of timber they were dealing with, this amounted to something over 40 cords treated per person-day. A skilled, energetic, and strong person can maintain this rate in cooler weather if no problems are encountered. With ordinary laborers, breakdowns, and rainstorms, working all seasons day after day, Stubbs and Outcalt (1982) realized a production rate of about 26 cords per person-day (8-hour day). With careful selection of personnel, thorough training, and close supervision, a sustained production of about 35 cords per person-day could be achieved.

Use of tree injectors has the added attraction that, given nominally equivalent wounding and paraquat dosage, oleoresin enhancement is superior to the bark-streak method, the most satisfactory alternative (see Oleoresin Yields section below). However, injected trees are more prone to mortality from bark beetle attack than are trees given bark streaks (see the Insect Attack section below). Spacing of injector wounds around the base of the tree is impor-

[1]Throughout this paper, trade names are provided solely to identify chemicals and equipment used. Such mention does not constitute endorsement by the U.S. Department of Agriculture.

tant, especially in relation to beetle attack. Injector blades 1-1/2-in. wide are most commonly used, although other widths are available. With a 1-1/2-in. blade, spacing on 3-in. centers around the tree gives nominal treatment to 50 percent of the circumference. But paraquat has some lateral movement from the wound, about one-quarter of an inch on each side. Thus, this spacing treats roughly two-thirds of the tree circumference--which is too much. Trees with such severe wounding can be expected to be overwhelmed by bark beetles, regardless of paraquat concentration or insecticide spray. Wound spacing with a 1-1/2-in. blade should not be less than 5 in. on centers, which gives a nominal treatment of 30 percent of the tree's circumference. Spacing for other blade widths should be in proportion.

In conclusion, only two wounding methods are given general recommendation: (1) a single bark streak at stump height, 1 in. wide and extending one-third of the way around the tree circumference, and (2) use of a tree injector around the tree base, with spacing in proportion to blade width as given above. For bark streaks, paraquat solution is applied in a second operation, generally by spraying the surface of the wound until runoff. The tree injector wounds and meters paraquat solution into the wound in one operation. With slash pine, paraquat solution concentration (percent cation by weight in water) should not exceed 4 percent with the bark-streak method, and that concentration is risky. The bark beetle problem being what it is with paraquat-treated slash pine, one must be circumspect in using the tree injector with this species, and in no case should the paraquat solution concentration exceed 2 percent. North of central Georgia, the tree injector on slash pine has been satisfactory provided treatment duration did not exceed a year or so. In the main slash pine belt, the bark-streak method is preferred. For loblolly pine, paraquat concentration with the bark-streak method should not exceed 5 percent, and 2 percent is recommended with the tree injector. Paraquat concentrations will be discussed in detail in a later section.

Multiple wounding

In attempts to gain more oleoresin enhancement, additional wounds have been superimposed on trees at initial treatment time, or added sequentially later. In a southwide cooperative study sponsored by the Lightwood Research Coordinating Council, both slash and loblolly pines were given two treatments, one of which consisted of a 1/3-circumference bark streak at stump height and another one superimposed 3 ft higher, both sprayed with 4 percent paraquat solution. The result was unacceptable mortality from bark beetle attack, generally 25 percent or more, as reported for slash pine by Barker and Schmid (1976) and Beers (1975); for loblolly pine by Ericksen (1978) and Marton (1975); and for both slash and loblolly pines by Gill (1978). Nix (1977) treated both loblolly and slash pines with two 1/2-circumference bark-streak wounds, and reported no advantage in oleoresin yield over one bark streak. Using 1/4-circumference bark streaks, Enos and others (1978) put one on one side of the tree, another on the opposite side, and then two more above these but found little gain in oleoresin from these four 1/4-circumference bark streaks as compared with two of them. Therefore, multiple wounding can be summed up as usually hazardous and resulting in little if any additional oleoresin, certainly not enough to pay the cost of this additional treatment.

Mechanization

The opportunities for profitable mechanization of paraquat treatment appear to be excellent. The powered chipper (Clements and McReynolds 1977) for producing bark streaks has already been discussed. Some development was done on a cutting head for bark streaks mounted on a farm tractor (Schillings and Sanders 1975), but this work was not pursued to a satisfactory conclusion. Hercules, Inc., has two machines that employ a small front-end loader (Melroe Bobcat 722) modified with tracks for all-terrain use. For bark streaks, a custom cutting head is attached which also sprays paraquat solution to the newly cut wound. For stump treatment in their Pinex Program, Hercules, Inc., has developed a drilling head that also places paraquat solution in the holes (Fajans 1980).

Paraquat Concentration and Amount

Tests have included virtually the entire gamut of possible paraquat solution strengths, ranging from 0.22 percent (Enos and others 1978) to 24 percent (Roberts 1976), which is the undiluted concentration as sold by the manufacturer. Evaluation of paraquat solution concentrations must include hazard of bark-beetle-caused mortality as well as oleoresin yield.

From published information it is difficult to determine the effect of paraquat concentration on yield, because of variation between tests in wounding methods, treatment durations, and other factors. Concerning slash pine, Drew (1976) applied 2 and 8 percent paraquat to 1/3-circumference bark streaks. After 12 months, the 2 percent paraquat was nearly as affective in oleoresin enhancement as the 8 percent; however, after 24 months Joyce and others (1977) reported for the same study that 8 percent paraquat was more effective in oleoresin accumulation, but 33 percent of those trees were dead. Roberts (unpublished data) tested 0.5, 2.0, 4.0, 6.0, and 8.0 percent paraquat used with either a 1/3-circumference bark streak or a tree injector (1-1/4 in. blade, wounds spaced on 4-in. centers). After 12 months, for both wounding methods the 0.5 percent paraquat concentration resulted in significantly less oleoresin yield than the rest. With the injector, 2 percent was as effective as 8 percent paraquat; however, with the bark-streak method, oleoresin yield increased with paraquat concentration. Averaging together the oleoresin data from both wounding treatments, 8 percent paraquat induced about 12 percent more oleoresin than did 2 percent. But this study also indicated that in order to keep insect-caused mortality below 10 percent, the tree injector should not be used with a paraquat concentration higher than 2 percent, nor should the bark streak be used with a solution concentration higher than 4 percent.

Also with slash pine, Roberts and Peters (1977) found 2 percent paraquat to be as effective as 4 percent after 12 months, and mortality was negligible with both. Peters and others (1978) compared 0.5 and 2 percent paraquat, and after 19 months found oleoresin enhancement over controls to be about 76 percent for 0.5 percent paraquat and about 104 percent for 2 percent paraquat. To determine whether severe wounding would produce practicable increases in oleoresin in 3 months without need of an insecticide spray (one half the treatment cost; Stubbs 1978), Roberts (1979b) compared paraquat concentrations 1, 2, and 4 percent. The 2 percent solution produced somewhat higher yield, but the difference over the other two concentrations was not statistically significant.

When the above information as well as other published reports is considered, the efficacy of higher strength paraquat solutions in producing additional oleoresin appears to have been overrated. All the oleoresin yields discussed here are on a whole-tree basis, while many reports in the paraquat literature give oleoresin data for only the basal 5 or 10 ft. From these latter reports it often appears that higher concentrations give higher yields for the basal sections, and they may do so, but most such comparisons are confounded by increased wounding. We know of no published information that shows paraquat concentrations of less than 2 percent, when applied to the tree bole (root treatment is another matter), to be comparable in oleoresin enhancement to 2 percent or greater concentrations, if the treatment duration extends more than 6 months. Similarly, concentrations of 6 or 8 percent may be superior to lower concentrations if treatment durations exceed 1 year. But if paraquat solutions of 6 percent or more are to be profitable, 90 percent or more of the trees have to survive. Due to the bark beetle hazard, slash pine should not be injected with paraquat concentrations higher than 2 percent; for the bark streak we recommend not more than 4 percent, and 2 percent is certainly safer.

Working with loblolly pine, Nix (1977) tested 2 and 8 percent paraquat and found the 2 percent more effective in increasing oleoresin, and it suffered 1 less mortality. Roberts (unpublished data) applied 0.5, 2.0, 4.0, 6.0, and 8.0 percent paraquat to loblolly pine with a tree injector (1-1/4-in. blade, 4-in. centers) and on single, 1/3-circumference bark streaks. Combining results from both wounding methods, oleoresin yield data after 12 months showed a positive trend with increasing paraquat solution concentration. The 8 percent paraquat showed a 56 percent gain in yield over 0.5 percent paraquat, a 39 percent gain over 2 percent paraquat, 14 percent over 4 percent paraquat, and 9 percent over 6 percent paraquat. Tree losses to bark beetles were low at 1 or 2 percent in all the bark-streak treatments, and comparably low with the tree injector except for the 8 percent paraquat treatment. Stubbs and Outcalt (1982) also used the 1/3-circumference bark streak and a tree injector (1-1/2-in. blade and 5-in. centers) to compare 2 and 5 percent paraquat solutions on loblolly pine. Treatments were replicated in spring, summer, and fall. Overall, both concentrations performed equally well in lightwood induction (see table 10); although 5 percent paraquat showed a slight increase in oleoresin yield over 2 percent paraquat, the overall difference for all seasons combined was not statistically significant. However, in some summer treatments the 5 percent solution was superior. Bark-beetle-caused mortality was below 10 percent in all treatments except for spring application of 5 percent paraquat with a tree injector, and no insecticide spray protection (see table 9).

The preceding studies with loblolly pine, except for Nix (1977), were conducted in the Upper Coastal Plain of South Carolina. In this region loblolly pine can be paraquat treated with no protective insecticide spray whatever, and we expect the same would hold true from about the middle of Georgia northward. When treating without an insecticide spray, paraquat concentration should not exceed 5 percent on single, 1/3-circumference bark streaks and 2 percent using tree injectors (1-1/2-in. blade and 5-in. centers). If a protective insecticide spray is applied at time of paraquat treatment, higher concentrations can be used but the additional oleoresin gained, if any, will have a value very much less than the cost of the insecticide spray.

In treating loblolly pine from central Georgia southward, spray with insecticide and limit paraquat concentrations to 5 percent on single, 1/3-circumference bark streaks and 2 percent for tree injector.

Use of Ethrel

Efforts have been made to increase lightwood induction by mixing paraquat with other chemicals. In early tests, Ethrel (2-chloroethyl phosphonic acid) showed the most promise. Working with slash pine, Peters and Roberts (1977) added a 5 percent Ethrel solution to paraquat solutions of 0.5, 1.0, and 2.0 percent. The addition of Ethrel to paraquat increased oleoresin enhancement in what appeared to be a synergistic manner; i.e., the combination was more than additive. Wolter (1977) also reported that Ethrel alone would produce some lightering in red pine (*P. resinosa* Ait.). Continuing research on slash pine, Peters and others (1978) tested a 5 percent Ethrel solution with 0.5 percent and 2 percent paraquat, plus other treatments. Again the Ethrel appeared to interact with paraquat, and in the best treatment in terms of oleoresin yield (2 percent paraquat plus 5 percent Ethrel), the admixture of Ethrel accounted for a 30 percent increase in oleoresin accumulation. A third experiment with slash pine gave quite different results. Peters and others (1979) compared mixtures of 5, 10, and 15 percent Ethrel with 2 percent paraquat and found no significant increase in oleoresin yield attributable to Ethrel.

From the foregoing, we must conclude that the case for Ethrel-paraquat synergism with slash pine is not proven, but the addition of Ethrel will usually increase oleoresin production. More information is needed before treatments involving Ethrel can be recommended for slash pine; in all the above-mentioned research with this species the wounding treatment involved combinations of drill holes, often sequential over time. Such treatments would not be economical.

With loblolly pine, Stubbs and Outcalt (1982) tested 10 percent Ethrel solution added to 2 and 5 percent paraquat solutions. Chemicals were applied to 1/3-circumference bark streaks or injected into trees. The injector had a 1-1/2-in. blade and wounds were spaced 5 in. apart on centers. Matching treatments without Ethrel were also applied. Ethrel increased oleoresin production, with the greatest increase occurring in summer-applied treatments (see table 10). Ethrel improved yields by increasing the level of oleoresin accumulation over a greater portion of the tree, especially the second 5 ft of the bole. When the tree injector was used, Ethrel was beneficial in combination with 2 percent paraquat but not with 5 percent. With the bark streak the results were reversed, being generally better with 5 percent paraquat (see table 13).

For loblolly pine, given one 1/3-circumference bark streak, we recommend the addition of 10 percent Ethrel solution to 5 percent paraquat solution. A 5 percent paraquat concentration is too high for use with the tree injector unless an insecticide spray is given; even if Ethrel is added, this operation is not as profitable as using 2 percent paraquat, a treatment that requires no insecticide spray cost. And because Ethrel showed no benefit when added to 2 percent paraquat concentration, we do not recommend the use of Ethrel with tree injectors on loblolly pine.

Use of other chemicals

Joyce and Drew (1979) tested more than 200 chemicals or combinations of chemicals, and found that none of them would induce as much oleoresin enhancement as did paraquat. They also experimented with chemicals in mixture with paraquat, of which triethylamine (TEA) was the most promising. An 8 percent solution of TEA was added to 2 percent paraquat and applied with a tree injector to slash pine. After 12 months, the yield increases over paraquat only were 36 percent more turpentine and 32 percent more resin acids. A similar experiment with loblolly pine gave increases of 35 percent more turpentine and 26 percent more resin acids. These increases exceed anything reported for Ethrel, and triethylamine should be tested further.

Season of Treatment

Drew (1976) found that in north Florida there was little difference between summer and winter treatment of slash pine for oleoresin production. Our research in Florida and that of nearby cooperators in this region tend to substantiate this finding, but for a short-duration treatment of 3 months, Roberts (1979b) found that March (early spring) treatment produces more gain in oleoresin than does December (winter) treatment.

Farther north, however, season of treatment does appreciably affect ultimate oleoresin yield. In the Piedmont of South Carolina, oleoresin production from paraquat treatment in August (Nix 1976) was less than that from April treatment (Nix 1977). Studies by Stubbs and Outcalt (1982) on loblolly pine also show that season of treatment significantly affects oleoresin enhancement in the Upper Coastal Plain of South Carolina. Spring applications produced the best average oleoresin yields, with no difference between average yields of summer and fall treatments (table 1). Oleoresin production within the first 5 ft of the bole was equal for all seasons of treatment, but spring treatments caused a greater response in the upper portions of the stem. A significant interaction was found between season of treatment and wounding method. Superiority of the tree injector over the bark streak decreased from spring to summer to fall (see table 10).

Spring is also the time of greatest hazard from bark beetle attacks, both in the slash pine belt and in the loblolly pine dominated regions farther north. We have taken this into consideration, however, in the treatment recommendations we have given in previous sections of this paper, and thus prescriptions by season as related to bark beetle hazard will not be given.

Table 1.--Average oleoresin content of loblolly pine 1 year after treatment with 2 or 5 percent paraquat, by season of treatment

Tree section	Spring	Summer	Fall
	Percent of dry weight		
0-5 ft	8.72a	8.38a	8.61a
5-10 ft	4.60a	4.01ab	3.70b
10 ft to 4-in. top	2.40a	2.28ab	2.14b
Total stem	4.36a	3.65b	3.83b

Values followed by the same letter within rows are not significantly different at *P* = 0.05.

Treatment Duration

Preliminary evidence for slash pine indicated that about 80 percent of all the oleoresin to be expected from a single paraquat application accumulates within 11 months after treatment. More recent data for slash pine, however, show a linear increase for up to 17 or 18 months (Drew 1976; Hurley and others 1977; Joyce and others 1977) and then an actual decrease in oleoresin content at 24 months. The latter may well be an artifact of sampling. Enos and others (1978) for slash pine show a fairly steady increase in oleoresin through 20 months. A study of slash pine by Stubbs and Outcalt (1982) showed an overall linear increase in oleoresin accumulation throughout the study duration of 22 months (fig. 2).

For loblolly pine, Stubbs and Outcalt (1982) found that oleoresin content increased over time, but that the change was not linear. All of the loblolly data show a decrease in the rate of lightwood formation at some time during the study (figs. 3 and 8). It is unlikely that the oleoresin content actually decreased as some of these data indicate. It is more probable that the accumulation leveled off, with the apparent decrease due to random variation in samples.

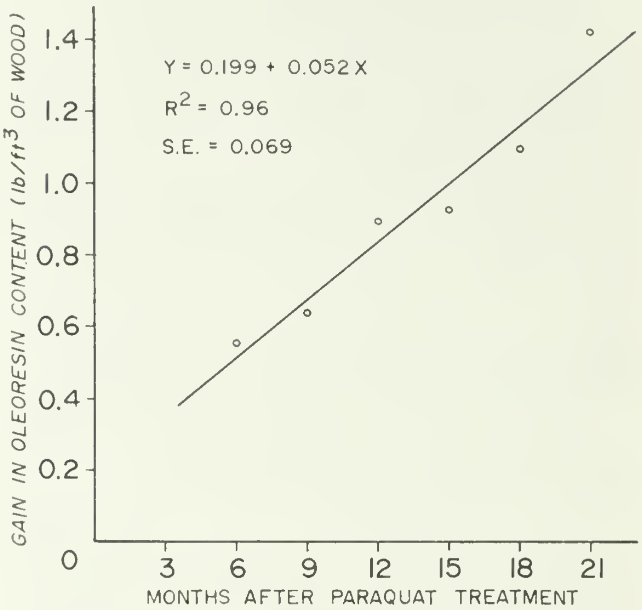

Figure 2.--Additional oleoresin resulting from tree-injector applied, 2 percent paraquat treatment of slash pine.

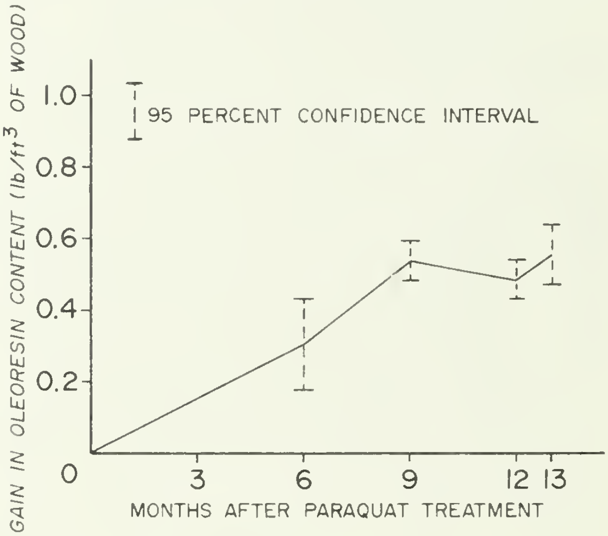

Figure 3.--Additional yields of oleoresin from loblolly pine after a 1/3-circumference bark streak, 5 percent paraquat treatment.

These loblolly pine data show an initial increase in oleoresin formation, then a leveling off with little change at approximately 12 through 18 months after treatment, followed by a second surge in accumulation. Slash pine shows a similar pattern, but less pronounced (see fig. 2). This period of reduced lightwood formation does not appear to be a seasonal effect, because it occurred during the summer in the slash pine study and in the fall or dormant period in the loblolly studies.

Severity of treatment can affect the pattern of oleoresin production over time. Trees treated by Stubbs and Outcalt (1982) with two dowels had reached virtually maximum oleoresin content after 8 months, and this level was maintained with little variation through 21 months (fig. 4). All the other treatments showed some increase in oleoresin accumulation, 12 months compared to 21 months after treatment (figs. 2 and 8), although the rate of increase varied. This extreme treatment using two dowels per tree is not recommended in any case, because of high tree-mortality rates.

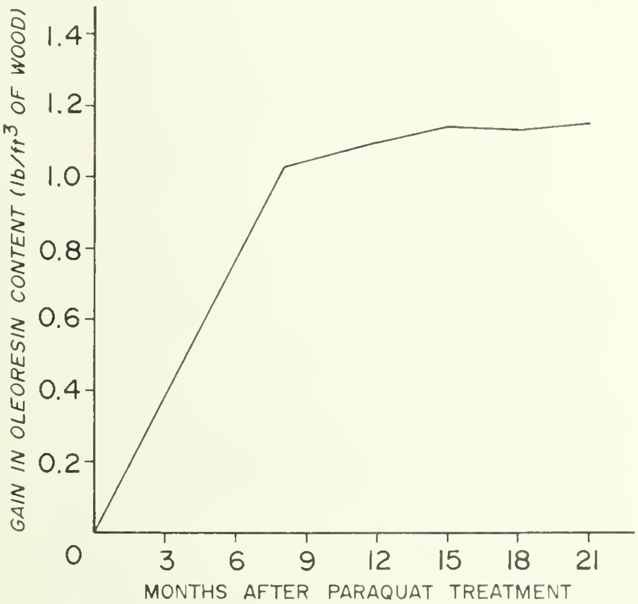

Figure 4.--Additional oleoresin content of loblolly pine resulting from a double-dowel paraquat treatment.

It appears that treatment duration for slash pine can extend for 18 months or more, if the bark beetles allow, with a steady increase in oleoresin yield over time. For loblolly pine, these data show little reason for extending treatment beyond 1 year.

Treatments to Produce Lightwood in Stumps

Hercules, Inc., scientists have applied a variety of solution concentration by several methods (Enos and others 1978). Their success with low concentrations of paraquat and interest in utilizing the stumps that are left after tree harvest led them to the development of the "Hercules Pinex" treatment. This treatment involves drilling two parallel downward-sloping holes from the root collar into the taproot of pine trees and filling the holes with a dilute solution of paraquat (Fajans 1980).

Two years after treatment, Brown and Pienaar (1981) found that 0.25 percent paraquat solution applied in two 1/2-in-diameter holes did not significantly affect tree growth, but 0.5 percent paraquat applied to one 1/2-in-diameter hole reduced volume growth by 13 percent. The 0.25 percent paraquat treatment increased oleoresin content of the stump and taproot by 4.3 times and that in the first 4-ft bolt of the stem by 1.4 times. Observed insect attacks were considered to be comparable to what would be expected in trees worked for gum naval stores.

Preliminary studies now in progress by USDA Forest Service scientists (unpublished information) in cooperation with Reichhold Chemicals, Inc., and Owens-Illinois Corp. showed that resin acids content of the stump and taproot of slash pines was increased by drilling two parallel downward-sloping holes in the taproot and filling them with paraquat concentrations ranging from 0.05 to 0.5 percent. One year after treatment (fig. 5), the lowest paraquat concentration tested, 0.05 percent, increased resin acids in the stump and taproot by 4.8 times. Further increase in paraquat concentration caused a moderate increase in resin acids, and then a decline. In the lowest 5-ft bolt of the stem, resin acids showed a continuous but diminishing increase as paraquat concentration increased. Black turpentine beetle attacks and tree mortality increased as paraquat concentration increased (fig. 6). Paraquat concentrations should be kept below 0.1 percent to minimize tree mortality and the invasion of lightwood streaks into the merchantable tree stem.

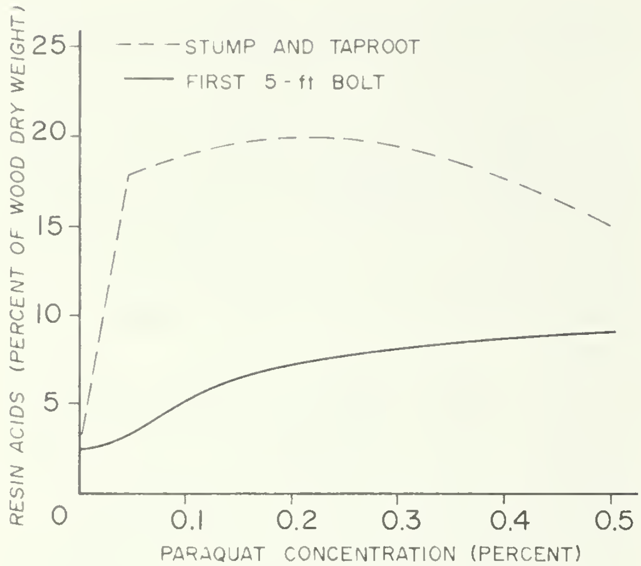

Figure 5.--Effect of paraquat concentration on resin-acids increase after treatment of slash pine taproots and lower bole.

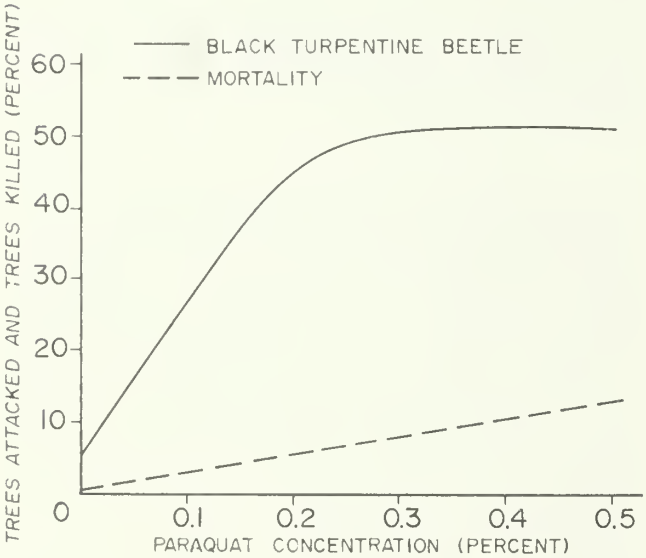

Figure 6.--Tree mortality and black turpentine beetle attack as related to paraquat concentration used in drill holes in slash pine taproots.

Insect Attack and Tree Mortality in Paraquat-Treated Stands

Since the discovery that paraquat would induce lightwood formation in southern pines, one of the major concerns has been bark beetle attacks on treated trees. An increased level of bark beetle attack has been noted in most of the paraquat research studies conducted in the South. In order of importance, mortality losses have been caused by engraver (*Ips* spp.), southern pine (*Dendroctonus frontalis* Zimm.), and black turpentine beetles (*D. terebrans* Olivier). Secondary insects, principally ambrosia beetles (*Platypus* spp.), have attacked dying trees but have seldom caused mortality.

Slash pine has proved to be more susceptible to bark-beetle-caused mortality than has loblolly pine. Studies involving slash pine will be discussed first, beginning with those that report heavy losses. After treating with 8 percent paraquat on a 1/3-circumference bark streak, Joyce and others (1977) reported that mortality reached 33 percent after 24 months. The trees were sprayed four times with a BHC solution. Gill (1978) used the same treatment and had 26 percent loss after 18 months among trees sprayed with 1 percent lindane. Use of 1/2-circumference frills resulted in heavy mortality even though the paraquat concentrations used were 1.66 percent and less (Enos and others 1978). These trees had received a 1 percent spray of BHC. In a 19-year-old overstocked plantation, Roberts (1979a) applied 2 percent paraquat by two methods and observed heavy mortality after 12 months. The tree injector method with wounds spaced on 4-in. centers resulted in 58 percent of the trees dying, but even the 1/3-circumference bark-streak method caused 25 percent mortality. The trees had received a 1 percent BHC spray.

Among studies reporting moderate losses is Draper's (1978), in which, after 18 months, 8 percent paraquat applied to a 1/3-circumference bark streak resulted in mortality of 13 percent in a 15-year-old stand and 3 percent in a 24-year-old stand. Both stands were sprayed repeatedly with lindane. Outcalt and Stubbs (1979) used 2 percent paraquat with a tree injector at 5-in. centers, and a 1 percent BHC spray. Mortality was about 4 percent after 10 months and rose to 13 percent at 15 months.

In addition, there have been some studies where negligible or no losses occurred, as in the Second LRCC Southwide Study. Two percent paraquat was applied to a 1/3-circumference bark streak, trees were sprayed to a height of 3 ft with 1 percent BHC or lindane, and the treatment duration was 9 months. Five months after treatment, Overgaard and others (1977) found 38 percent of the trees had been attacked by *Ips* spp., but no mortality. After 9 months, Roberts (1978a) confirmed that mortality had been negligible. In a study employing the tree injector and a good many other experimental wounding methods, all with 2 or 4 percent paraquat, Roberts and Peters (1977) found that the tree injector invited the most insect attack, but after 12 months only 2 of the 430 trees in the study had died. Finally, Peters and others (1978) reported low mortality after 19 months in a study using 0.5 or 2 percent paraquat placed in drill holes.

Loblolly pine in general is less susceptible than slash pine to beetle-caused mortality after paraquat treatment. However, all the authors have had loblolly pine studies where the limits of wounding severity were overstepped, and the resulting mortality from bark beetles was heavy. Others have had similar experiences. In southern Alabama, Waite (1977) applied 8 percent paraquat in summer with a tree injector on 3-in. centers, and sprayed with BHC. In a brief time, attack by *Ips* beetles was heavy, and the trees had to be cut after 2 months. In a second study Waite (1978) reduced the paraquat concentration to 4 percent and treated the trees in winter. This study was to have extended for 9 months, but the trees had to be cut at 6 months. *Ips* beetles again. Nix (1977) reported heavy losses after applying 8 percent paraquat to either a 1/2-circumference bark streak or an ax frill, first in April with a second treatment in July. Gill (1978) treated loblolly pine with 8 percent paraquat on a 1/3-circumference bark streak and reported 19 percent tree mortality after 18 months. After the same treatment, Ericksen (1978) encountered 19 percent mortality in a 24-year-old stand but no mortality in a stand 13 years old.

Treatments causing very low losses are also frequently reported, as in Enos and others (1978), who treated loblolly pine with 1.66 percent paraquat applied to a 1/2-circumference ax frill. Also, Moore (1977) and Outcalt and Stubbs (1979) experienced negligible losses after spraying 2 or 5 percent paraquat onto single, 1/3-circumference bark streaks. In another study, 2 or 5 percent paraquat with and without Ethrel was applied with either a 1/3-circumference bark streak or a tree injector on 5-in. centers. Tests were made in the spring, summer, and fall; also, one-half of the trees were sprayed with insecticide and the rest were not sprayed. Most treatments had very light mortality after 6 months (Moore and others 1979) and 12 months (Stubbs and Outcalt 1982).

From questionnaires sent out on two occasions to those conducting studies of lightwood induction with paraquat, Drew (1977, 1978) prepared two summary papers giving overviews of the insect pest situation. In his 1977 paper, Drew reported that *Ips* beetles were the most important pests, especially on slash pine. No insecticide, concentration of insecticide, or spray method was totally effective. Paraquat concentration, not the dosage or amount per tree, is correlated with insect attack; concentrations higher than 4 percent are too much for use with slash pine, and 5 percent should not be exceeded with loblolly pine. Of application methods, tree injectors invited more attack than bark streaks, and the more severe the wound the greater the attacks. Spring treatments are likely to have the highest rates of insect attack, and fall treatments the lowest. There appeared to be a positive correlation between oleoresin enhancement and severity of beetle attack; however, virtually all these oleoresin data were for basal sections and were not on a whole-tree basis. Drew's survey of 1978 strengthened what were essentially the same conclusions.

To keep mortality at a low level, the common thread that runs through the previous discussions is evident: (1) With slash pine, do not use paraquat concentrations that are higher than 4 percent with a bark streak or 2 percent with a tree injector. (2) With loblolly pine, the limits are 5 percent paraquat for bark streaks and 2 percent for tree injectors. (3) Any wounding that affects more than one-third of the tree's circumference is too much. (4) In general, longer treatment durations mean more risk of mortality from bark beetles. (5) Neither an initial insecticide spray nor repeated spraying is to much avail if the paraquat treatment is too severe, either in paraquat concentration or wounding. (It should be mentioned that only the basal 10 ft or less is sprayed, usually 3 or 6 ft. (6) Do not treat stands with low tree vigor.

There has been some concern that beetle populations might build up in treated trees and then attack surrounding trees, causing severe losses. No such attacks have occurred in any study reported, and there is no evidence whatever that this will happen. Furthermore, even when heavily attacked trees given severe treatments were adjacent to less severely treated trees, there has been no evidence of a significant spread of beetles from the heavily attacked trees. Thus, it appears there is little threat of beetles causing any significant mortality in adjoining stands (Clark 1979; Drew 1977, 1978; Hertel and others 1977).

Degree of Hazard and Control of Insect Pests

The insect problems associated with paraquat-induced resinosis soon attracted the help and interest of entomologists, who began to assess the problem and then attempted to devise adequate control measures. In a series of experiments, Hertel and others (1977) treated slash pine in north Florida in the winter (January), spring (April), summer (July), and fall (November) with 8 percent paraquat applied to single, 1/3-circumference bark streaks. All trees were sprayed with 1 percent BHC to a height of 3 ft. Only the winter treatment had an acceptable level of survival--about 93 percent--and they were lucky as we now know. In a study of wounding intensity installed in summer, they tested 1/3-, 1/2-, and 2/3-circumference bark streaks plus two superimposed 1/3-circumference bark streaks, all with 4 percent or 2 percent paraquat. Half the trees received a 1 percent lindane spray to a height of 3 ft and the other half did not. With 4 percent paraquat, the 1/3-circumference wound plus lindane spray had the lowest mortality, 10 percent. With 2 percent paraquat plus lindane spray, mortality was 10 percent or zero with 1/3-, 1/2-, and even 2/3-circumference treatments (there were but 10 trees per treatment, and one dead tree gave 10 percent mortality). Mortality was severe in all treatments without lindane spray; they concluded that this spray was a necessity, and subsequent experience has verified this conclusion for slash pine. To further test paraquat concentration effect, 2 percent was compared with 8 percent on trees wounded in the summer with single, 1/3-circumference bark streaks. On trees given a 1 percent lindane spray, mortality was 50 percent for the 8 percent paraquat after 18 months, but zero for the 2 percent paraquat. Their general conclusions were: (1) Trees must be sprayed with insecticide. (2) Spring is the worst time to treat with paraquat, winter the least hazardous. (3) Wounds should not exceed 1/3-circumference with 4 percent paraquat. (4) Paraquat concentration should not be higher than 4 percent.

Merkel and Clark (1981) tested a number of insecticides, including lindane, at concentrations of 1 and 2 percent sprayed to heights of 3 or 10 ft. Slash pines in north Florida were treated in spring, summer, fall, and winter with 4 percent paraquat using 1/3-circumference wounding. Half the trees were sprayed; the others were left unsprayed. After 12 months, lindane proved to be much the best insecticide and spraying proved to be necessary. However, in the spring treatment, mortality was 40 percent or more no matter which spray was used. In general, 1 percent lindane gave as good protection as 2 percent, and spraying to a 3 ft height was as effective as spraying to 10 ft.

Tests of other insecticides compared with BHC or lindane have also been made by Merkel (1979), Moore (1977), and Williams (1979). In all instances, BHC or lindane was the most effective in reducing bark beetle attack.

The entomological studies we have discussed in some detail all concerned slash pine in north Florida. In what follows, quite different results were obtained in the Upper Coastal Plain of South Carolina, primarily with loblolly pine. In a series of studies there, the southern pine beetle population was low, and black turpentine beetle attacks on paraquat-treated trees caused negligible mortality. *Ips* beetles were the primary insect pests and accounted for virtually all of the insect-caused tree mortality.

Effect of paraquat treatment, season, and insecticide

On plots of 20 trees each, Moore (1977) applied one of four paraquat treatments: (1) 1/3-circumference bark streak (wound only), (2) 1/3-circumference bark streak with 5 percent paraquat, (3) 1/3-circumference bark streak with 2 percent paraquat and insecticide, and (4) 1/3-circumference bark streak with 5 percent paraquat and insecticide. These treatments were replicated with three different insecticide sprays--BHC, Reldan (chlorpyrifos-methyl), and Dursban (chlorpyrifos) at two levels each, sprayed on the tree boles to a height of 12 ft. All treatment combinations were applied in spring, summer, and fall to loblolly pine plantations at each of three locations on the Savannah River Plant (DOE), near Aiken, S. C.

Reporting results of this study, Outcalt and Stubbs (1979) noted that even though season and length of treatment are confounded, season of treatment did not significantly influence tree mortality (table 2). Also, because these data show additional mortality with longer treatment duration, we would expect average mortality by season to be even more equivalent if all seasonal replications reached 28 months. Only the 5 percent paraquat treatment without insecticide had significantly higher mortality (3.8 percent) than the control, but mortality was not significantly reduced when this paraquat treatment was used with an insecticide. Thus, prophylactic spraying of insecticide immediately after paraquat treatment, which accounts for approximately half of the total treatment cost (Stubbs 1978), certainly would not pay in this case. Because use of insecticide did not affect mortality, it is not surprising that there was no difference in tree mortality by insecticide type.

Table 2.--Mortality of paraquat-treated loblolly pine by season of treatment, treatment method, and insecticide

Treatment variable	Tree mortality
	Percent
Season and duration of treatment (1,800 trees)	
Spring (18 months)	2.2
Summer (28 months)	4.4a
Fall (22 months)	3.8a
Treatment method (1,080 trees)	
Control	2.0a
1/3 bark streak (wound only)	2.2a
1/3 bark streak, 2% paraquat, insecticide	3.1ab
1/3 bark streak, 5% paraquat, insecticide	4.0ab
1/3 bark streak, 5% paraquat, no insecticide	5.8b
Insecticide (720 trees)	
BHC	2.8a
Dursban (chlorpyrifos)	3.3a
Reldan (chlorpyrifos-methyl)	4.6a

Within a variable, means followed by the same letter are not significantly different at $P = 0.05$.

Effect of wound type, paraquat concentration, and paraquat dosage

Because the objectives and the treatments imposed differ among the following studies, each study is presented separately.

In the first study, a 140-acre block of loblolly pine plantation ranging in site index from 90 to 95 was selected. Between September and January, five different treatments were imposed: control, 1/3-circumfer-ence bark streak and 5 percent paraquat, drill hole and 5 percent paraquat, one dowel, and two dowels (2.04 lb of paraquat/ft^3 of dowel). All trees treated with paraquat were sprayed with 0.1 percent BHC in water to a height of 6 ft (Outcalt and Stubbs 1979).

After 18 months, the 1/3-circumference bark streak with 5 percent paraquat caused the least mortality among the treatments tested (table 3). Mortality after this treatment was not significantly greater than on untreated control plots. The drill-hole treatment caused higher mortality than the bark-streak treatment. This result was rather unexpected, because others have reported that, given equal paraquat concentrations, larger wounds result in a greater incidence of beetle attack. Both one- and two-dowel treatments caused unacceptable tree mortality--31 and 90 percent, respectively.

In a second study, 5 percent paraquat was again applied to single, 1/3-circumference bark streaks on loblolly pine, also sprayed with 0.1 percent BHC in water. Insect-caused mortality in this study was negligible; as in the first study, this treatment did not significantly increase mortality. Several treated plots had less mortality than controls, and the mortality rate throughout the study, 2 percent, was less than is normally present in stands of this age and stocking (Stubbs and Outcalt 1982).

A factorial design was employed in a third study (Stubbs and Outcalt 1982). Wound types were a 1/3-circumference bark streak or tree-injector incisions with a 1-1/4 in. blade and 4-in. spacing on centers. A paraquat concentration of 0.5, 2, 4, 6, and 8 percent was applied at a rate of 0.15, 0.40, or 0.65 ml/in. of wound. An untreated control was also included, giving a total of 31 different treatment combinations. Each of these was applied to two five-tree plots in loblolly plantations, age 22, at three locations. After treatment, all tree boles were sprayed to a height of 6 ft with 0.5 percent lindane in water. Past tests by others had indicated that bark beetle attack increased with increasing paraquat concentration. This study was particularly well suited to investigation of this relationship. Three months after treatment, beetle attacks were positively correlated with paraquat concentration for both the 1/3-circumference bark streak and the injector wounding methods (fig. 7). Although

Table 3.--Bark beetle attack and associated mortality of loblolly pine after four paraquat treatments

Treatment[a] [b]	Beetle incidence before treatment	Beetle incidence at 18 months[c]	Mortality at 18 months
	- - - - - - - - - - Percent	- - - - - - - - - -	
Control	4.1	4.1a	0.4a
Bark streak, 5% paraquat	4.2	6.0ab	1.5a
Drill hole, 5% paraquat	5.7	12.4b	6.9b
One dowel[d]	2.8	19.0c	31.0c
Two dowels	6.7	--	90.0d

Means followed by the same letter within columns, are not significantly different at *P* = 0.05.

[a] 3,000 trees per treatment, except two dowels which had 10,000 trees.
[b] All but control trees were sprayed with 0.1 percent BHC in water.
[c] Live trees under attack.
[d] 2.04 pounts of paraquat per cubic foot of dowel.

attacks appear to be higher with the bark streak than with the injector at 4 and 6 percent concentrations, the difference is not statistically significant. When data from both wound types are combined, the result is a smooth curve with attacks increasing at an exponential rate

where: $Y = 0.81\ (1.61^{X}),\ R^2 = 0.99$

Y = Percent of trees attacked

X = Percent paraquat

The tree mortality shown in figure 7 also has a positive relationship with concentration, but it rises at a much slower rate. For this combination of wound methods, species and location, after 3 months it appeared that paraquat concentrations even moderately greater than 4 percent substantially increased insect problems (Outcalt and Stubbs 1979).

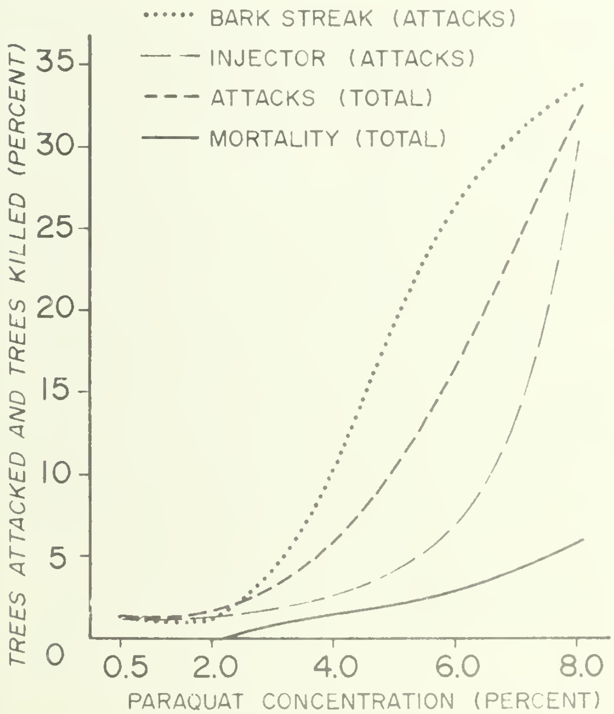

Figure 7.--Bark beetle attack and associated mortality of loblolly pine 3 months after treatment, as affected by application method and paraquat concentration.

However, after 12 months a somewhat different picture emerged (table 4). Tree mortality is of paramount importance, not rate of beetle attack, and mortality was negligible with paraquat concentrations less than 8 percent. The amount of paraquat solution that trees received had a very weak correlation with bark beetle attack and no correlation with tree mortality. On the average, the total amount of paraquat ion a tree received increased with increasing dosage. Thus it appears paraquat concentration, not quantity, is the key factor involved in bark beetle attack (Stubbs and Outcalt 1982).

Slash pine plantations were treated during May and June with 2 percent paraquat applied with a tree injector using a 1-in. blade and 5-in. spacing on centers. Following paraquat treatment, the tree boles were sprayed to a height of 5 ft with 1 percent BHC in diesel oil (Outcalt and Stubbs 1979). Tree mortality was low for the first 10 months after treatment (table 5). However, during the next 5 months, which corresponded to the second growing season, mortality increased to 13 percent. Because mortality decreased as tree size increased, stand volume loss was less--about 10 percent. Even though this loss is fairly high, about 2 cords/acre, our data indicate it will be more than offset by the value of the additional oleoresin. The break-even point of profit versus costs and losses is not reached until volume loss amounts to about 20 percent.

Minimizing insecticide requirements in lightwood induction

Use of insecticide in preventive sprays immediately after paraquat treatment has become virtually standard practice. This insecticide application, however, accounts for 50 percent or more of the total cost of treating trees (Stubbs 1978), and it may be neither necessary nor effective, depending on the paraquat treatment used and evidently, geographic area. Results from earlier studies, wherein 2 or 5 percent paraquat was applied to bark streaks with very light or no application of insecticide, indicated that minimal tree mortality, 2 percent or less, was possible for at least 18 months thereafter (Moore 1978; Outcalt and Stubbs 1979).

Table 4.--Bark beetle attack and mortality of paraquat-treated loblolly pine 1 year after treatment by concentration, dosage (ml/in. of wound), and wounding method

Paraquat concentration and solution dosage	Tree injector		Bark streak	
	Beetle attack[a]	Mortality	Beetle attack[a]	Mortality
	Percent			
0.5 percent				
0.15	7	0	7	0
0.40	13	3	7	3
0.65	0	0	7	0
Average	7	1	7	1
2.0 percent				
0.15	0	0	3	0
0.40	3	0	7	0
0.65	20	3	13	3
Average	8	1	8	1
4.0 percent				
0.15	3	0	3	0
0.40	3	0	27	7
0.65	10	3	23	3
Average	5	1	18	3
6.0 percent				
0.15	0	0	27	3
0.40	7	0	10	0
0.65	10	7	30	3
Average	6	2	22	2
8.0 percent				
0.15	13	0	33	3
0.40	43	13	27	0
0.65	53	47	33	0
Average	36	20	31	1

[a]Each attack entry is based on 30 trees; its corresponding mortality entry is for the same 30 trees.

Table 5.--Bark beetle attack and associated mortality of 14,200 slash pines after injection with 2 percent paraquat [a]

Treatment duration	Bark beetle incidence[b]	Cumulative tree mortality
	- - - - - *Percent* - - - - -	
Pretreatment	1.5	--
5 months	4.0	2.2
10 months	3.1	3.7
15 months	3.2	13.2
22 months	--	18.9

[a]After treatment, all trees were sprayed with 1 percent BHC in diesel fuel to a height of 5 feet.

[b]Live trees under attack at the end of each period.

That evidence and the discovery that mixing Ethrel with paraquat would increase oleoresin yield (Peters and others 1978) suggested that, in the geographic area around the Savannah River Plant, certain paraquat treatments applied with minimal or no insecticide resin soaking with minor losses from insects. To test this theory, a factorial experiment incorporating Ethrel and other variables was installed. Study objectives were to identify the combination of season, wounding, and chemical treatment that would minimize insecticide requirements while inducing adequate resinosis in loblolly pine (Moore and others 1979).

The following factors were involved:

- Three blocks or locations
- Three seasonal treatment times (March, June, and November) within each block
- Two concentrations of lindane (0 and 0.25 percent)
- Three concentrations of paraquat (0, 2, and 5 percent)
- Two concentrations of Ethrel (0 and 10 percent)
- Two methods of paraquat application (1/3-circumference bark streak and tree injector).

The design was a split split plot (in season and insecticide), with a complete factorial of paraquat and Ethrel levels with wounding methods, resulting in 12 factorial treatment combinations. The control (untreated trees) may be considered as an addition to these. Each of the three locations had three plots of 520 trees; each plot was randomly assigned to one of the three seasonal treatment dates. Within each of these 520-tree seasonal plots, the 0.25 percent lindane treatment was randomly assigned to one of two split plots. The 12 factorial treatment combinations plus the control were applied to subplots of 20 trees within both of the split plots of a given seasonal replication.

Wounding was done about 12 in. above the ground, either with a tree injector on 5-in. centers around the tree, or with a modified chain-saw chipper as a 1-in. high, 1/3-circumference bark streak. Paraquat was applied at 1 ml per incision with the injector;[2] with the bark streak, the solution was sprayed on by a calibrated applicator as follows: trees in 6- through 8-in. d.b.h. classes received 3 ml; 9- through 11-in. trees received 6 ml; trees 11 in. and greater received 9 ml. After paraquat was applied, the basal 12 ft of trees in designated split plots were sprayed with a water emulsion of 0.25 percent lindane.

With no insecticide protection, use of 5 instead of 2 percent paraquat increased tree mortality when applied in spring, but not in summer or fall (table 6). When treatments were applied during

[2]Throughout this paper, tree injector dosages are given in milliliters (ml) because the metering devices on the injectors are normally scaled in these units. For those wishing to convert, 1 ml = 0.0338 fluid oz.

the spring or summer, use of the tree injector increased mortality over that of bark-streak treatments. Addition of Ethrel increased tree mortality only when used during the summer. Overall, fall treatments had significantly lower tree mortality than either spring or summer treatments.

This study demonstrates that season of treatment, wounding method, concentration of paraquat, addition of Ethrel, and use of insecticide can all affect tree mortality following paraquat treatment. Because of interactions, there was no one best treatment but rather a number of treatments that performed satisfactorily on the basis of tree mortality. Nearly all paraquat treatments applied in the fall had very low mortality even without insecticide protection (table 7). For treating during the summer, paraquat plus Ethrel applied with a tree injector is not recommended unless a protective spray is used (table 8). Even with insecticide spray, tree mortality can be relatively high if the tree injector treatment is used during the spring (table 9). As in other studies, the 5 percent paraquat solution applied to a 1/3-circumference bark streak had consistently low tree mortality for all seasons, even with no insecticide spray. Therefore, all our data indicate that this is a safe treatment method for all seasons in this region, and it does not require the added expense of an insecticide spray.

Table 6.--Mortality of 2,895 loblolly pines without insecticide protection 1 year after paraquat treatment, by treatment season

Treatment variable	Tree mortality		
	Spring	Summer	Fall
	- - - - - - *Percent* - - - - - -		
Paraquat concentration			
0 percent	0.5a	2.0a	2.0a
2 percent	4.8d	7.0b	2.4a
5 percent	20.3c	9.2b	3.4a
Wounding method			
Chipper saw	3.0a	3.9a	2.0a
Tree injector	14.1c	8.1b	3.2a
Ethrel concentration			
0 percent	8.6b	2.4a	1.8a
10 percent	8.7b	9.7b	3.4a
Average (890) trees, each group)	8.6a	6.0a	2.6b
Control (75 trees, each group)	1.4	2.5	3.0

Within each treatment variable, means of a row or column followed by the same letter are not significantly different at $P = 0.05$.

Table 7.--Mortality of loblolly pine 1 year after fall paraquat treatment

Treatment	Tree mortality			
	Insecticide		No insecticide	
	Number of trees	*Percent*	*Number of trees*	*Percent*
5% paraquat				
Chipper, Ethrel	0	0	1	1.6
Chipper, no Ethrel	0	0	0	0
Injector, Ethrel	0	0	5	7.0
Injector, no Ethrel	0	0	3	4.9
2% paraquat				
Chipper, Ethrel	1	1.7	2	2.8
Chipper, no Ethrel	1	1.6	2	2.4
Injector, Ethrel	1	1.6	3	4.6
Injector, no Ethrel	2	3.0	0	0
0% paraquat				
Chipper, Ethrel	1	1.8	2	2.5
Chipper, no Ethrel	0	0	2	2.8
Injector, Ethrel	1	1.5	1	1.6
Injector, no Ethrel	0	0	1	1.3
Average (890 trees, each group)	0.6	0.9[a]	1.8	2.6[a]
Control (75 trees, each group)	2	3.1	2	3.0

[a]Mortality of trees sprayed with insecticide was significantly less than that of unsprayed trees at $P = 0.05$.

Table 8.--Mortality of loblolly pine 1 year after a summer paraquat treatment

Treatment	Tree mortality			
	Insecticide		No insecticide	
	Number of trees	*Percent*	*Number of trees*	*Percent*
5% paraquat				
Chipper, Ethrel	2	2.6	6	8.1
Chipper, no Ethrel	2	2.9	3	4.2
Injector, Ethrel	1	1.3	16	23.5
Injector, no Ethrel	0	0	2	2.5
2% paraquat				
Chipper, Ethrel	0	0	4	5.6
Chipper, no Ethrel	0	0	2	2.8
Injector, Ethrel	2	2.6	12	16.0
Injector, no Ethrel	0	0	2	2.9
0% paraquat				
Chipper, Ethrel	0	0	1	1.5
Chipper, no Ethrel	0	0	1	1.2
Injector, Ethrel	2	2.9	3	3.8
Injector, no Ethrel	0	0	1	1.3
Average (890 trees, each group)	0.8	1.0[a]	4.4	6.0b[a]
Control (75 trees, each group)	1	1.1	2	2.5

[a]Mean for sprayed trees significantly less than for unsprayed trees at $P = 0.05$.

Table 9.--Mortality of loblolly pine 1 year after a spring paraquat treatment

Treatment	Tree mortality			
	Insecticide		No insecticide	
	Number of trees	*Percent*	*Number of trees*	*Percent*
5% paraquat				
Chipper, Ethrel	7	9.6	8	11.8
Chipper, no Ethrel	1	1.4	0	0
Injector, Ethrel	13	16.3	20	27.0
Injector, no Ethrel	5	7.4	31	41.9
2% paraquat				
Chipper, Ethrel	1	1.3	2	2.6
Chipper, no Ethrel	2	2.7	3	4.2
Injector, Ethrel	4	5.8	5	7.2
Injector, no Ethrel	3	4.2	4	5.3
0% paraquat				
Chipper, Ethrel	2	2.6	0	0
Chipper, no Ethrel	4	5.0	0	0
Injector, Ethrel	4	5.3	2	2.7
Injector, no Ethrel	1	1.4	0	0
Average (890 trees, each group)	3.9	5.3a[a]	6.3	8.6[a]
Control (75 trees, each group)	0	0	1	1.4

[a]Mean for sprayed trees is significantly less than that for unsprayed trees at $P = 0.05$.

It must be emphasized that these findings are not applicable throughout the South. The extent of the geographic region to which they apply is somewhat conjectural, but it is likely that they are reasonably pertinent from middle Georgia northward, provided that activity by the southern pine beetle is low. The need for different prescriptions, probably by regions, to control bark beetles after paraquat application is evident in the data presented by Drew (1978). For instance, lightwood treatments that can be applied with impunity in South Carolina may be disasterous in north Florida.

Loss of Wood-Volume Growth

Paraquat treatment causes tissue damage and necrosis, especially of the inner bark and cambium layer above the wound site. The bole area with dead tissue will produce no additional wood, and growth is probably reduced in areas with tissue damage. However, trees often produce compensatory growth as a response to wounding.

Thus, the question soon arose as to whether there was appreciable wood-growth loss due to paraquat treatment. Squillace and Moyer (1976) treated slash pine with 8 percent paraquat applied to a 1/3-circumference bark streak. After 20 months' treatment, they concluded that treated trees produced 29 percent less wood volume than the control trees during that interval. Drew (1980) computed growth loss on slash pine treated with 2 or 8 percent paraquat applied on a 1/3-circumference bark streak. The growth loss for a 2-year duration was 22 percent for the 8 percent paraquat treatment, but negligible for 2 percent paraquat. Testing the effects of 0.25 or 0.5 percent paraquat solutions placed in holes bored into the stumps of slash pines, Brown and Pienaar (1981) reported that the lower concentration produced no significant reduction in growth over a 2-year period, but the 0.5 percent concentration caused growth loss of about 13 percent.

Working with loblolly pine, Nix (1979) reported a 24 percent growth loss over a 2-year period from trees treated with 4 percent paraquat sprayed on a 1/2-circumference bark streak. Two of the authors (Outcalt and Stubbs) attempted to determine growth loss in their several studies. They measured d.b.h. and height of thousands of trees before treatment and then prior to harvest, but this method was not sensitive enough to detect growth loss.

Most of these reported growth losses involve treatments more severe than we now recommend. For recommended treatments, we doubt that growth loss exceeds 10 or 15 percent for either slash or loblolly pines.

Oleoresin Yields

In this section we present only those oleoresin yields for paraquat treatments currently recommended, and which have been reported on a whole-tree basis, or can be computed to this basis. From these data we have often computed yields per cord, using these values: (1) 80 ft^3/cord of wood for both slash and loblolly pines; (2) an ovendry weight of 33 lb/ft^3 for slash pine, 31 lb for loblolly pine.

In slash pines (Joyce and others 1977), the increase in oleoresin yield attributable to paraquat treatment 2 years before appears to be from 100 to 125 lb/cord, 19 percent of which is turpentine and the rest resin acids. The data of Peters and others (1978) for slash pine give a per cord amount of about 90 lb of additional oleoresin after a 19-month treatment period. Data for a 9-month treatment period (Roberts 1978b) give per cord oleoresin enhancement values of about 80 lb (20 percent turpentine) for slash pine, and about 43 lb (20 percent turpentine) for loblolly pine.

This gleaning is pitifully small, considering all the tests of paraquat induction of lightwood that have been made. This situation was one of the reasons the senior author, who was in a fortunate position to do so, determined to carry out large-scale tree sampling and oleoresin analyses. Results from studies by Stubbs and Outcalt (1982) are now presented.

In tests on loblolly pine, increases in oleoresin/ft^3 were determined on a whole-tree basis (bole to a 4 in. top). The 1/3-circumference bark streak and the drill hole, with paraquat solution applied to the streak or into the hole, have given comparable increases in oleoresin content (fig. 8, table 10) but the drill-hole treatment had higher tree mortality from beetles (table 3). Higher yields were obtained by using a single paraquat-impregnated dowell in a drill hole, or by using two dowels, but tree mortality was prohibitive (table 3). In a variety of treatments using the bark streak and the tree injector on loblolly pine, the tree injector showed an overall superiority in oleoresin yield (table 11). Where degree of wounding, paraquat solution concentration, and season of treatment were equivalent, oleoresin content 12 months after treatment was about 25 percent greater for the tree-injector method. Taking insect problems into consideration with data from the same study, the tree injector used in the spring or fall with 2 percent paraquat plus 10 percent Ethrel, gave the best average yields (table 12) without undue losses to tree mortality (tables 7 and 9). This amounts to raising oleoresin content from about 65 lb/100 ft^3 to about 145 lb/100 ft^3.

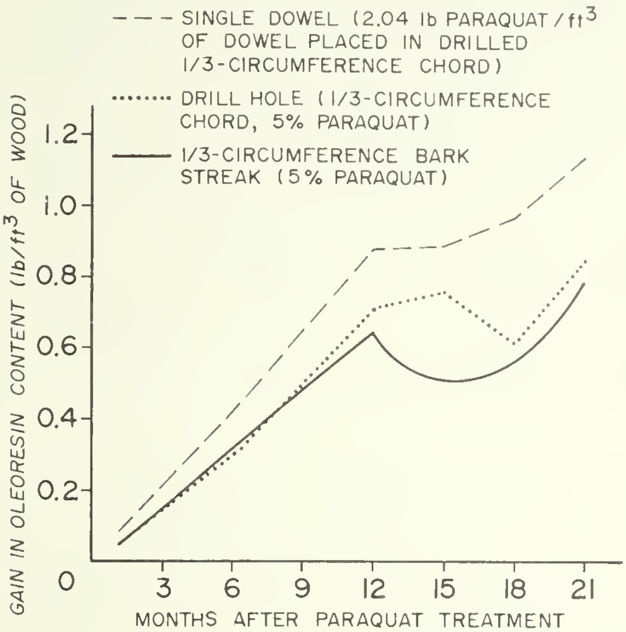

Figure 8.--Effects of three different methods of paraquat application on increases in oleoresin yield from loblolly pine.

Table 10.--Additional oleoresin content of loblolly pines at various times after paraquat treatment

Treatment	Gain in oleoresin content after-- 6 months	9 months	12 months	15 months	18 months	21 months
	- - - - - - - - - - - -	- - - -	*lb/ft^3*	- - - -	- - - -	- - - -
1/3 bark streak, 5% paraquat	0.31 $\pm$.13	0.54 $\pm$.09	0.64 $\pm$.10	0.50 $\pm$.10	0.57 $\pm$.10	0.78 $\pm$.11
Drill hole, 5% paraquat	.29 $\pm$.13	--	.69 $\pm$.10	.74 $\pm$.10	.61 $\pm$.10	.84 $\pm$.11
Drill hole, one dowel	.42 $\pm$.13	--	.87 $\pm$.10	.88 $\pm$.10	.96 $\pm$.10	1.13 $\pm$.11
Drill hole, two dowels	--	1.04 $\pm$.18	1.09 $\pm$.17	1.14 $\pm$.17	1.13 $\pm$.17	1.15 $\pm$.19

Means are above; 95 percent confidence intervals are below.

Table 11.--Effect of treatment variables on total oleoresin content of loblolly pine 1 year after paraquat application, by season of treatment

Treatment variable	Oleoresin content in-- Spring	Summer	Fall	Mean
	- - -*Percent of dry weight*- - -			
Paraquat concentration				
2 percent	4.23a	3.43a	3.91a	3.86a
5 percent	4.48a	3.86b	3.74a	4.03a
Wounding method				
Bark streak	3.66a	3.20a	3.54a	3.47a
Tree injector	5.06b	4.10b	4.11b	4.42b
Ethrel concentration				
0 percent	4.23a	3.49a	3.71a	3.81a
10 percent	4.48a	3.81b	3.94a	4.08b
Control	2.15	1.94	2.11	2.08

Values followed by the same letter within columns are not significantly different at $P = 0.05$.

Table 12.--Additional oleoresin content of loblolly pine 1 year after various paraquat treatments, by season of treatment

Treatment	Gain in oleoresin Spring	Summer	Fall
	- - - - - - - - lb/ft^3 - - - - - -		
0% paraquat			
Bark streak, Ethrel	-0.02a	0.09a	0.04a
Injector, Ethrel	-.10a	.11a	.03a
2% paraquat			
Bark streak	.39a	.38b	.40b
Bark streak, Ethrel	.50a	.29b	.42b
Injector	.82bc	.45bc	.59b
Injector, Ethrel	.89c	.73d	.84b
5% paraquat			
Bark streak	.39a	.33b	.43b
Bark streak, Ethrel	.61ab	.55c	.53b
Injector	1.01c	.75d	.58b
Injector, Ethrel	.91c	.75d	.49b

Ethrel in all treatments was applied in a 10 percent solution of active ion by weight.

Within columns, values followed by the same letter are not significantly different at $P = 0.05$.

Slash pines injected with 2 percent paraquat in the summer doubled their oleoresin content after only 9 months (table 13). Oleoresin content continued to increase throughout the study, reaching over three times the normal level at 22 months. Unfortunately, tree mortality also increased throughout the study (see table 5), but this treatment was satisfactory over a 12-month period. Based on this study and others, treatments that have acceptable risk in tree mortality will raise oleoresin content from about 90 lb/100 ft^3 of wood to 190 lb or more. Athough the untreated slash pine oleoresin content as given in table 13 is about 65 lb/100 ft^3, 85 to 95 lb is more representative, especially for slash pine in the main slash pine belt.

Table 13.--Oleoresin content of slash pines at various times after paraquat treatment

Treatment	Oleoresin content after--					
	6 months	9 months	12 months	15 months	18 months	22 months
	lb/ft³					
Tree injector, 2% paraquat	1.19 ±.05	1.29 ±.16	1.54 ±.08	1.56 ±.10	1.73 ±.10	2.06 ±.17
Control	.65 ±.07	.65 ±.07	.65 ±.07	.65 ±.07	.65 ±.07	.65 ±.07
Gain	.54 ±.12	.64 ±.17	.89 ±.13	.91 ±.17	1.08 ±.16	1.41 ±.19

Means are above; 95 percent confidence intervals are below.

In addition to yields on a whole-tree basis, it can be important to know how oleoresin is distributed in the merchantable bole. Tables 14 and 15 give oleoresin content of the first bolt, second bolt, etc. Because paraquat is applied at the base of the tree, and due to the nature of the resinosis process, the highest oleoresin concentrations are in the lower bole. For several years our industrial cooperators and others have examined the idea of combining an oleoresin extraction plant, using a hydrocarbon solvent process, with a pulpmill. Oleoresin-rich basal sections of a tree would be directed to the solvent extraction plant and the rest sent to the pulpmill. After extraction, chips from the solvent plant would also go to the pulpmill. In planning an operation like this, oleoresin yield data by tree section are obviously necessary. The advantages of solvent extraction are the production of higher quality oleoresin products than those from kraft pulpmill processes, and greater recovery of oleoresins.

Oleoresin Quality

Oleoresin produced as a result of paraquat treatment is of comparable quality to that from untreated trees (Conley and others 1976; Enos and others 1978; Landry 1977; McBride 1977, 1978; Zinkel and McKibben 1978). Specific aspects of oleoresin composition are discussed next.

Ratio of turpentine to resin acids

Analyses of oleoresin from paraquat-treated trees have virtually always shown a relative increase in the turpentine component as compared with control trees. In loblolly pine this amounts to a few percent gain, from 17 or 18 per-

Table 14.--Resin acids, turpentine, and oleoresin content of loblolly pine 21 months after paraquat treatment, by application method

Bole section and component	Treatment			
	1/3 bark streak	Drill hole	Dowel	Control
	- - - - - -	- - - lb/ft^3	- - -	- - - - - -
1st 5 ft				
Resin acids	2.19a	1.96b	1.97b	0.62c
Turpentine	.73a	.59b	.57b	.12c
Oleoresin	2.92a	2.56b	2.54b	.74c
2nd 5 ft				
Resin acids	1.20a	1.26a	1.55b	.54c
Turpentine	.35a	.35a	.45b	.09c
Oleoresin	1.55a	1.61a	2.00b	.63c
10 ft to 4-in. top				
Resin acids	.59a	.74b	1.06c	.49d
Turpentine	.12a	.17b	.29c	.08d
Oleoresin	.71a	.91b	1.35c	.57d
Whole tree				
Resin acids	1.10a	1.16a	1.38b	.54c
Turpentine	.31a	.31a	.39b	.09c
Oleoresin	1.41a	1.47a	1.76b	.63c

Means followed by the same letter within a row are not significantly different at $P = 0.05$.

Table 15.--Resin acids, turpentine, and total oleoresin content of slash pine 22 months after a tree-injector, 2 percent paraquat treatment

Component	First 5 ft	Second 5 ft	10 ft to 4 in. top	Whole tree
	- - - - - -	- - - lb/ft^3	- - -	- - - - - -
Resin acids	2.82 $\pm$.23	1.76 $\pm$.17	1.01 $\pm$.11	1.55 $\pm$.13
Turpentine	1.02 $\pm$.12	.61 $\pm$.08	.30 $\pm$.05	.51 $\pm$.06
Oleoresin	3.84 $\pm$.33	2.37 $\pm$.23	1.31 $\pm$.14	2.06 $\pm$.17

Means are above; 95 percent confidence intervals are below.

cent of the total oleoresin to 19 to 21 percent (Stubbs and Outcalt 1982). The rest is, of course, resin acids. Slash pine normally has 20 to 21 percent turpentine and increases to about 25 percent after paraquat treatment.

Turpentine composition

Changes in turpentine composition differ in slash and loblolly pine following paraquat treatment. In slash pine there is an appreciable increase in the proportion of beta-pinene and some decrease in alpha-pinene compared with untreated trees (table 16). For loblolly pine there is a minor decrease in the proportion of beta-pinene after treatment but no change in the alpha-pinene percentage (table 17). Drew (1976) reported that beta-pinene from paraquat-treated slash pine in north Florida rose from 21 percent to 34 percent; a final report for the same study by Joyce and others (1977) gave values of 22 percent for controls, rising to 33 percent 24 months after treatment. Roberts (1978b) reported data for slash pine that show the beta-pinene component of turpentine increased from 22 to 28 percent. His data for loblolly pine show no significant decrease in the beta-pinene fraction but an increase in alpha-pinene from 61 to 64 percent. From the foregoing it is plain that except for beta-pinene in slash pine, paraquat treatment has little effect on turpentine composition.

Table 16.--Change in monoterpene composition of slash pine, by number of months after paraquat treatment

Terpene	Injector	Control
	- - - *Percent* - - -	
6 months		
Alpha-pinene	62.8a	67.0b
Beta-pinene	24.6a	19.1b
12 months		
Alpha-pinene	60.3a	67.0b
Beta-pinene	28.3a	19.1b
18 months		
Alpha-pinene	59.3a	67.0b
Beta-pinene	28.4a	19.1b

Within rows, values followed by the same letter are not significantly different at $P = 0.05$.

Resin acids composition

From the discussion of Zinkel and McKibben (1978) and the data of Enos and others (1978), there appear to be no significant changes in resin acids as a result of paraquat treatment.

Tall oil composition

Paraquat treatment increases the resin acids content of the wood by 100 percent or more; therefore, the resin acids fraction of tall oil increases considerably. There has been no evidence that paraquat treatment increases fatty acids. In fact, there has been

Table 17.--Change in monoterpene composition of loblolly pine, by number of months after paraquat treatment

Terpene	Bark streak	Drill hole	Dowel	Control
	- - - - - - - - - - - - *Percent*	- - - - - - - - - - -		
12 months				
Alpha-pinene	67.6a	66.6a	68.0a	67.9a
Beta-pinene	19.3ab	19.6ab	16.7a	21.1b
21 months				
Alpha-pinene	67.3b	63.9a	62.9a	64.9ab
Beta-pinene	19.1a	19.8ab	18.4a	21.9b

Within rows, values followed by the same letter are not significantly different at $P = 0.05$.

concern that paraquat treatment reduces the yield of fatty acids, which at present are more valuable than resin acids. McBride (1977, 1978) reported that there appeared to be a decrease in fatty acids, as did Gill (1978). Conley and others (1976), however, found no significant change in fatty acids, nor did Enos and others (1978). Zinkel and McKibben (1978) give evidence for little or no change, and suggest that reported decreases were likely due to oxidation of samples, sampling problems, or both. We conclude that if there is a decrease in fatty acids, it is likely to be inconsequential.

Paraquat residue

Paraquat cannot be detected in the paper, turpentine, or tall oil produced by kraft pulp and paper mills (Earle 1975). Neither is paraquat to be found in the oleoresin products produced by wood naval stores extraction plants (Enos and others 1978).

Economics

Treatment Costs

The costs given in table 18 (Stubbs and Outcalt 1982) are presented on the basis of cubic feet of wood, because this sort of wood-volume measurement is least subject to variation. A cord may vary in actual solid wood content from 70 to nearly 100 ft^3. Data are also given on a per tree basis, because tree size enters into costs based on volume. It is emphasized that these costs are in no sense absolute, due to inflation, availability and cost of labor, and many other factors, but are nonetheless useful and valid for treatment comparisons.

The chipper or bark-streak method, in which horizontal 1/3-circumference wounds are made with a power tool and then sprayed with paraquat solution, would appear to be the least expensive method. However, the per tree data show that use of the tree-injector method could be somewhat less expensive; this

Table 18.--Costs per 100 cubic feet of wood and per tree for five paraquat treatment methods

Treatment method	Treatment				
	Paraquat	Paraquat application	Insecticide	Insecticide application	Total
	- - - - - - - - - - - - - - - - *Dollars* - - - - - - - - - - - - - - -				
Chipper (5% paraquat)	0.12 (0.018)	1.32 (0.21)	0.15 (0.02)	1.38 (0.21)	2.97 (0.46)
Drill hole (5% paraquat)	0.12 (0.018)	2.88 (0.41)	0.16 (0.02)	1.40 (0.21)	4.56 (0.66)
Tree injector (2% paraquat)	0.11 (0.011)	1.62 (0.16)	5.76[a] (0.56)	1.88 (0.18)	9.37 (0.91)
Single dowel	1.45 (0.210)	2.55 (0.37)	0.16 (0.02)	1.40 (0.21)	5.56 (0.81)
Double dowel	2.16 (0.340)	4.59 (0.73)	0.15 (0.02)	1.31 (0.21)	8.21 (1.30)

Values per 100 cubic feet are above; those per tree are below.

[a] Includes cost of diesel oil carrier; water used in all other spray applications.

treatment as applied was quite costly, because we used diesel oil for the insecticide carrier. If water were used as in the other treatments, and if trees were of comparable size to those treated with a chipper (injected slash pines were smaller than the loblolly pines in chipper experiments), then the cost of treating 100 ft^3 would be about $2.65 as compared with $2.97 for the chipper method. Labor, paid at a rate of $4.15 per hour, accounts for about 85 percent of these costs. The drill-hole method is considerably more expensive than either the tree-injector or chipper methods, and it shows no advantage in oleoresin production. Aside from the high treatment costs, neither dowel method is viable because of high mortality from bark beetle attack.

In previous sections of this paper we have shown that both bark-streak wounding with 5 percent paraquat, and tree-injector application with 2 or 5 percent paraquat, can be used on loblolly pine in South Carolina with no insecticide application whatever, with nominal losses to beetle attack. Costs for such treatments were about $1.40 instead of $3/100 ft^3 of wood.

Cost-Benefit Comparisons

In these comparisons we set the value of oleoresin at $0.07/lb and the value of wood at $16/100 ft^3. With the data presented in tables 10, 12, and 13, other values that the reader may consider more suitable can be readily substituted. We used a total treatment cost of $3/100 ft^3 for both the bark-streak and injector methods, of which $1.60 is for insecticide spraying. Use of Ethrel added $0.06/100 ft^3. Paraquat-treatment expenses can be regarded as either costs or investments; we considered them as costs and did not deduct from profit any interest on investment. The reader can do so, using any interest figure that is appropriate to the situation. In determining the value of additional oleoresin in tables 19, 20, and 21, we deducted the value of oleoresin lost in trees that died. Finally, we assumed that all the additional oleoresin gained by paraquat treatment would be recovered by the extraction plant. Actual recovery efficiency can vary from 50 to 90 percent, and readers should apply whatever percentages are reasonable for their operations.

For loblolly pine, the 1/3-circumference bark-streak or chipper method took a little over 6 months to reach the break-even point (table 19). Maximum profit is shown for a treatment duration of 21 months, but the 12-month duration would give a comparable return if interest on investment capital were deducted. Since tree mortality was very low for this treatment, returns over time were primarily a function of increase in oleoresin content.

Regarding slash pine, if water had been used instead of diesel oil as the carrier for the insecticide spray, the paraquat treatment would have been profitable (table 20), assuming that this substitution would cause no appreciable increase in tree mortality. Tree mortality had more influence on profit in this slash pine study than that with loblolly pine, because mortality was higher and continued to increase throughout the test. But oleoresin also continued to accumulate at a fair rate, except for months 12 through 15. Thus, the maximum test time, 22 months, is financially the best harvest time even after deductions for mortality loss both in wood and oleoresin. The dip in expected profits at 15 and 18 months is caused by the previously mentioned temporary leveling in oleoresin accumulation, but a continuing tree mortality.

As shown by information presented in table 21, an insecticide spray on loblolly pine in the study region usually does not pay. Treatment costs can be halved by not spraying; an insecticide spray does not afford a sufficiently high level of protection, and some treatments simply do not require insecticide protection. The difference in tree mortality between sprayed and unsprayed treatments must be about 10 percent before spraying is worthwhile, if wood is valued at $16/100 ft^3.

Overall, summer treatments were poorest (table 21). In comparison with fall treatments, insect-caused tree mortality was greater but oleoresin yields were not, and spring treatments had much higher oleoresin yields. However, the

Table 19.--Cost-benefit analysis, per 100 cubic feet of wood, for 5 percent paraquat application to 1/3-circumference bark streak, on loblolly pine

Treatment duration (months)	Value additional oleoresin[a]	Treatment cost	Value of wood lost[b]	Profit
	- - - - - - - - - - - - - Dollars	- - - - - - - - - - - - -		
6	2.17	3.00	0	-0.83
9	3.78	3.00	0	.78
12	4.48	3.00	0	1.48
15	3.50	3.00	0	.50
18	3.99	3.00	0	.99
21	5.38	3.00	.22	2.16

[a]Based on an oleoresin value of $0.07 per pound.
[b]Losses due to tree mortality; wood valued at $16 per 100 cubic feet.

Table 20.--Cost-benefit analysis, per 100 cubic feet of wood, for 2 percent paraquat application to slash pine, by a tree injector

Treatment duration (months)	Value of additional oleoresin[a]	Treatment cost	Value of wood lost[b]	Profit
	- - - - - - - - - - - - - Dollars	- - - - - - - - - -		
6	3.77	3.00	0.13	0.64
9	4.40	3.00	.42	.98
12	5.83	3.00	.91	1.92
15	5.72	3.00	1.54	1.18
18	6.65	3.00	1.89	1.76
22	8.53	3.00	2.21	3.32

[a]Based on an oleoresin value of $0.07 per pound.
[b]Losses due to mortality; wood valued at $16 per 100 cubic feet.

Table 21.--Profit or loss per 100 cubic feet of wood for several paraquat treatments of loblolly pine, by insecticide protection and season of treatment, 12 months after treatment

Treatment	Insecticide			No insecticide		
	Spring	Summer	Fall	Spring	Summer	Fall
	Dollars[a]					
2% paraquat						
Bark streak	-0.77	-0.34	-0.50	0.55	0.74	0.95
Bark streak, Ethrel	.18	-1.03	-.44	1.53	-.44	.95
Average	-.29	-.68	-.47	1.04	.15	.95
Injector	1.83	.15	.53	3.19	1.20	2.73
Injector, Ethrel	1.88	1.50	2.47	3.17	.27	3.41
Average	1.85	.82	1.50	3.18	.73	3.07
Average, 2% paraquat	.78	.07	.51	2.11	.44	2.01
5% paraquat						
Bark streak	-.53	-1.22	.01	1.33	.14	1.61
Bark streak, Ethrel	-.74	.27	.65	.42	.78	1.93
Average	-.63	-.47	.33	.87	.46	1.77
Injector	2.37	2.04	1.06	-3.99	3.30	1.68
Injector, Ethrel	-.34	2.12	.37	-1.13	-1.20	.61
Average	1.01	2.08	.71	-2.56	1.05	1.14
Average, 5% paraquat	.19	.80	.52	-.84	.75	1.46
Average, 2 and 5 percent paraquat	.48	.44	.52	.63	.60	1.73

[a] Based on an oleoresin value of $0.07 per pound, wood valued at $16 per 100 cubic feet, and treatment costs at $3 per cubic foot with insecticide, $1.40 without insecticide.

best treatment for the summer season, 5 percent paraquat applied with a tree injector, did show one of the highest profits of any tested, regardless of season of application. Although tree mortality was highest after spring treatments, so was oleoresin yield. Therefore, profitability is attractive in spring treatments if paraquat concentration is limited to 2 percent. On the basis of yields, tree mortality, and profit potential, 2 percent paraquat with or without Ethrel applied with a tree injector during spring or fall had the best overall performance for loblolly pine. As noted previously, these data may not apply to the entire range of loblolly pine.

Ethrel increased oleoresin yield by an average of 15 percent (from data in table 12), which amounted to additional oleoresin of about 8 lb/100 ft^3 of wood treated. On this basis, the cost of Ethrel use was $0.06, the return $0.56 with oleoresin at $0.07/lb. However, averaging all treatments the use of Ethrel increased mortality from 1.8 to 3.4 percent, an average loss of $0.26/100 ft^3, so the average additional profit from the use of Ethrel was $0.56, -0.06, -0.26, or -0.24/100 ft^3 of wood treated.

Because of fluctuation in prices, the primary utility of tables 19, 20, and 21 is for comparing treatments and treatment durations, not profit projection. With the yield and mortality data presented in other sections of this report, it is possible to calculate profits based on whatever assumptions the reader believes are appropriate. A factor to consider in such calculations is growth, because changes in oleoresin yield on a per acre basis are dependent on oleoresin production, tree mortality, and tree growth. Profit on a ft^3 basis will always be less than profit on a per acre basis if there is any additional growth; i.e., at a given yield in lb of oleoresin/ft^3 of wood, added growth will produce more lb/acre of oleoresin.

Effect of Paraquat-Treated Pulpwood on Mill Operations

Mill Trials With Loblolly Pine

Waite (1977) reported a mill trial using wholly paraquat-treated trees, in volume about 480 cords. No difficulties were encountered, and the only operational differences noted were that the digesters gassed off harder due to the additional turpentine in the wood, and somewhat poorer pulp washing caused a saltcake loss of about 20 lb/ton of ovendry pulp. No loss in product quality occurred. Per ton of bleached pulp, an additional 0.8 gal of turpentine and 35.9 lb of tall oil were obtained. Two additional trials at the same mill involved 320 cords of treated wood as 40 percent of mill furnish, and 480 cords as 60 percent of furnish. Waite (1978) again reported that no significant problems arose and product quality was unaffected. Turpentine yields increased by 0.36 and 0.46 gal/ton of bleached pulp, with tall oil increases of 9.5 and 22.4 lb.

In a cooperative study with the U.S. Department of Energy and USDA Forest Service, Jonakin and Millard (1979) found that there were no detrimental effects to the pulpmill operations or to paper and chemical products. Approximately 4,500 cords of paraquat-treated wood were processed, supplying 25 percent of the mill furnish for 25 days. The treated wood produced about 40 percent more tall oil than did untreated wood, and the potential for increased turpentine production was at least as great, but the recovery system could not cope with the increased amount.

Mill Trials With Slash Pine

Landry (1977) gives details of a trial that used 4,000 cords of treated wood, making up 5, 15, and 25 percent of the mill furnish for 4 days each. No operational difficulties were noted, but the short time period for each subtrial produced sampling and byproduct inventory problems, making it difficult to determine the additional turpentine and tall oil gained. Similar difficulties plagued a second cooperative mill trial involving the U.S. Department of Energy, USDA Forest Service, and Continental Forest Industries (Stubbs and Outcalt 1982). About 1,100 cords of paraquat-treated slash pine supplied 12 percent of the pulpmill furnish over a 9-day period. No detrimental effects were observed during any phase of wood handling or pulping operations, and no lowering of product quality was detected. However, no significant increase in turpentine or tall oil could be determined due to problems similar to those of Landry (1977). The calibration period proved too short, and the differences were too small with only 12 percent of the total wood used having oleoresin enrichment.

Mill Trial Results

All of the mill trials must be considered successful. They demonstrate that paraquat-treated wood can be processed in quantity without disrupting papermill operations or reducing quality of products. Furthermore, the trials show that improvements will be needed in some mills in order to take full advantage of the increased oleoresin content of paraquat-treated wood.

ENVIRONMENTAL IMPACT AND SAFETY

Paraquat has been used for agricultural purposes for more than 20 years. In his summary article, Calderbank (1968) discusses paraquat use as a herbicide and preharvest desiccant; its mode of action; fate in plants, soil, and water; and its toxicology. Because of the molecular structure and ionic charge of paraquat, it adheres strongly to organic materials and soil colloids. Paraquat applied to wood cannot simply be washed off. And soil colloids, which aside from organic matter are primarily clay minerals, hold paraquat so strongly that the only effective way of displacing it is to reflux with a strong acid. Normal soils have a tremendous capacity to absorb and inactivate paraquat. Even loamy sand, with 4 percent clay content, about as light a textured soil as can be found except in some sand dunes, is capable of absorbing about 56 lb of paraquat/acre in the surface 1 in. As an example of the quantity of paraquat entering an ecosystem with a typical paraquat treatment, use of 5 percent aqueous solution in stands with pulpwood-size trees amounts to distributing about 1.6 lb of paraquat/acre, and virtually all of that is taken up by the tree and remains there.

Because of this strong retention by soil colloids, ground water can contain no paraquat. If paraquat is placed in open water, it soon disappears due to uptake by weeds and algae, and eventual photochemical and biological degradation. Similar degradation occurs in terrestial ecosystems with the result that paraquat in soils and herbaceous plants is soon gone (Calderbank 1968). Paraquat in the wood of treated pines also degrades, but a residual is left at harvest time. Conley and others (1976) analyzed a freshly harvested pine for paraquat content 12 months after 8 percent paraquat had been applied to a 1/3-circumference bark streak, and found a paraquat residue of 4 parts per million. Paraquat in the wood of treated trees has a covering of bark, and even if it were on a bare wood surface it is not easily displaced. Thus, the hazard that paraquat-treated wood presents to either woods workers or wildlife is nil. There is no evidence that wildlife has ever suffered from the broadcast-type paraquat applications used in agriculture, and the manner in which it is used for lightwood stimulation must present even risk. Paraquat absorption in the gut is poor; the small amounts that might be ingested orally after a forestry operation would be rapidly and completely secreted. Paraquat properly used presents no threat to the environment (Calderbank 1968; Fletcher 1974).

After wood is taken to a pulpmill, the contained paraquat which is acidic meets the highly alkaline digester liquor and is promptly and totally destroyed; no paraquat can be found in the paper or byproducts (Earle 1975). The extraction processes used in the wood naval stores industry also result in oleoresin products free of paraquat (Enos and others 1978), because the paraquat residue remains in the wood chips.

There is no doubt that paraquat is poisonous and hazardous if not treated with due caution. Droplets can be absorbed through the skin or through the lungs, but known deaths have been caused primarily by oral ingestion. The oral lethal dose (LD_{50}) for humans is not well known, but seems to be about 30 mg/kg body weight (Fletcher 1974). For a man weighing 180 lb, this is equivalent to swallowing about 50 ml, 1.7 fluid oz, of 5 percent paraquat solution. The probability of accidentally swallowing this much is slight. Not only is paraquat ill-tasting, but it also burns the mouth. For a 10-year period, Fletcher (1974) reported three accidental deaths in the United States, a major user of paraquat. Treatment of paraquat poisoning has greatly improved, and with prompt medical attention, recovery is now 100 percent.

Benzene hexachloride (BHC) was the insecticide used in most of the studies discussed in this paper. It was only mildly hazardous as a pesticide, demanding only routine precautions. However, BHC has been banned from use and lindane, the gamma isomer of BHC, is now the standard insecticide for control of pine bark beetles.

CONCLUSION AND RECOMMENDATIONS

Paraquat treatment for producing resin-soaked wood in loblolly and slash pines is on an operational basis, and has been for some time. The effects of recommended treatments can be predicted with more than adequate accuracy for loblolly pine. This information is based on scores of tests and experiments. The most useful paraquat experiments are of necessity both large scale and expensive, as typified by those of Stubbs and Outcalt (1982), made possible through the cooperation of the U.S. Department of Energy. These studies were conducted over a 4-year period, involved about 500 acres and 84,800 pines with volume totaling 1,221,000 ft^3, and required thousands of analyses for oleoresin content of cut sample trees. This sort of effort removed results of paraquat treatment, a highly variable phenomenon influenced by the many factors discussed in this paper, from what might be a random occurrence to virtual certainty. Using the recommended treatments for loblolly pine, oleoresin content will be more than doubled and tree mortality will be negligible, often not significantly different than in untreated stands.

Paraquat treatment effects for slash pine in the main slash pine belt may not be on as firm a basis, primarily because experimentation and subsequent sampling for oleoresin yield could not be made on as large a scale, and the balance of treatment intensity versus bark beetle hazard was more difficult to achieve. On the other hand, experimentation has continued for a much longer period in this region, and we have certainly learned what to avoid. The totality of research results, especially recent experiments, shows beyond reasonable doubt that if slash pine in this region is given the paraquat treatments we recommend in this section, oleoresin content will be doubled. Tree mortality will be acceptable--less than 10 percent after 1 year, usually 1 to 5 percent.

Whether paraquat treatment will be profitable for any one group depends on oleoresin enhancement, losses of oleoresin following tree harvest to the time the wood is processed, recovery efficiency of the mill or plant, the prices of oleoresin products, and the costs of treatment. Untreated slash pine containing about 90 lb oleoresin/100 ft^3 of wood will gain approximately 100 lb more oleoresin after recommended paraquat treatment; the gain in loblolly pine will be 65 lb or more/100 ft^3 from wood originally containing about 60 lb/100 ft^3. Losses of oleoresin after trees are cut and oleoresin recovery efficiency can both vary widely, depending on the procedures and processing of any one mill. Therefore, potential users of paraquat-induced lightwood technology will need to obtain estimates of these losses specific to their operation. Some capital investment in the mill, as in added settling tank capacity, may also be required. Unfortunately, oleoresin prices have historically been subject to much fluctuation. In this regard, pulp and paper companies with secondary processing, as in crude tall oil fractionation, are probably in the most favorable position. Because labor accounts for most of the treatment cost at present, mechanization could greatly reduce this cost. A satisfactory estimate of profitability can be made if reasonably accurate data on the above factors are obtained.

We believe that a major factor in slowing industrial use of lightwood technology is concern over possible bark beetle attacks on treated trees, subsequent mortality, and the creation of a large bark beetle population that will expand in all directions. The studies discussed here, which extended over a period of 10 years, show this apprehension to be unfounded. In the many lightwood induction studies we have conducted or been closely associated with, southern pine beetle populations were generally low but endemic populations of *Ips* spp. beetles were both active and opportunistic. *Ips* beetles are the ubiquitous enemy of paraquat-treated trees (Drew 1977, 1978). We had no difficulty in bringing about severe *Ips* beetle attacks and subsequent mortality if trees were given severe paraquat treatment. However, in no case did these heavily attacked stands become centers of spread to other stands. Adjoining stands showed no observable increase in either attack or mortality, and these included stands that had also been given paraquat but with a milder treatment.- We know of no instance in the South where heavily attacked, paraquat-treated stands have caused further beetle infestations. The reason seems to be that brood success, the development of larvae to adult beetles, is generally low in paraquat-treated trees.

We and others have found that beetle-attack hazard is directly correlated with the concentration of the paraquat solution used, rather than the absolute amount of cation applied. For slash pine, paraquat concentrations of more than 4 percent by cation weight are to be avoided, with 5 percent the limit for loblolly pine. If a tree injector is used with either pine species, paraquat concentration should not exceed 2 percent. Of secondary importance is the season when treatments are applied; in general the spring is worst, followed by summer. With loblolly pine, there is little insect problem after either fall or winter treatments. In the main slash pine belt, only winter treatments show less beetle attacks, but beetles are by no means inactive then. Avoid treating overstocked stands of poor vigor, especially slash pine, on mediocre or poor sites. Stands ripe for self-thinning, with or without the help of bark beetles, are poor investments for paraquat treatment even if beetle-caused losses are small.

In treating slash pine, for good oleoresin yields and acceptable losses from insects, we conclude that:

- Two percent paraquat concentration applied to a bark streak (chipper) wound, sprayed to the point of runoff, can be used throughout the year. The wound should be an in. in height and not exceed one-third of the tree's circumference. A protective spray of insecticide must be given to each tree at the time of paraquat treatment; use 1 percent lindane in a water emulsion sprayed to a height of 3 ft.

- Four percent paraquat can be applied to a 1/3-circumference bark streak in all seasons except spring. An insecticide spray as described in the preceding paragraph, is necessary.

- Tree-injector application must be used with caution, and not at all in the spring. Two percent paraquat concentration and no higher is recommended, with 0.4 to 0.5 ml per injector incision. If a 1-1/2-inch blade is used, incisions should be spaced on 5-in. centers. The same proportion of wounding should be maintained with other widths of blades by varying the distance between centers. An insecticide spray, as given earlier, is necessary. Tree-injector treatment will generally produce more oleoresin accumulation than will bark-streak wounding, but it also increases risks from bark beetle attacks.

- Treatment duration with slash pine is dependent on bark beetle activity. If activity is low, an 18-month period is recommended. As a rule, attack is prompt after treatment and its intensity can be assessed early. This is not always the case, however, and if mortality exceeds 4 or 5 percent in 8 months, the treatment duration should be limited to 12 months or less.

- We emphasize again that an insecticide spray is essential. If heavy bark beetle attack and subsequent tree mortality occur as the result of poor initial tree vigor, drought, or beetle epidemic, additional sprays are of little use and certainly not economic. The trees should be salvaged as soon as possible.

For treatment of loblolly pine north of middle Georgia, to produce the maximum oleoresin yield compatible with negligible losses from insects, our conclusions are:

- Five percent paraquat concentration applied to a 1/3-circumference bark streak can be used with impunity throughout the year. Insecticide sprays for this treatment are neither necessary nor useful. Adding a 10 percent Ethrel solution to this paraquat concentration will increase oleoresin yields, but do not add Ethrel to spring or summer treatments, or mortality may exceed 10 percent.

• Five percent paraquat should not be used in any season with the tree-injector wounding method.

• Use a 2 percent paraquat concentration with the tree injector. Space incisions as with slash pine. Injection usually results in a greater oleoresin yield than the bark-streak method, but injected trees are also more prone to insect-caused mortality. Spring treatment is marginal, but this method can be used the rest of the year without need of an insecticide spray. If 10 percent Ethrel is used with this treatment, summer applications should be avoided unless the trees are given an insecticide spray.

• Treatment duration for loblolly pine should be about 1 year. Yields will usually continue to increase beyond this period, but at a rate too low to be economically attractive.

• Insecticide sprays are not needed except in the preceding single instance with Ethrel. Treatments that demand insecticide spray protection may produce somewhat more oleoresin, but not enough to cover the spray costs.

• Loblolly pine south of middle Georgia should be given the same treatments with this important addition: An insecticide spray, as described under slash pine recommendations, is definitely required.

The best paraquat treatment for loblolly pine in terms of greatest profit potential, taking into consideration oleoresin yield, mortality loss, and treatment costs, is 2 percent paraquat, with or without 10 percent Ethrel, applied with a tree injector either in the spring or fall, without use of an insecticide spray if used north of middle Georgia. Data are insufficient to make as specific a recommendation for slash pine. The recommended treatments will increase oleoresin content by 100 to 150 percent, from about 65 lb/100 ft^3 to 125 lb or more in loblolly pine, and from about 90 lb/100 ft^3 to 190 lb or more in slash pine.

The operation of pulpmills demands much skill and high technology. To use them to determine changes in oleoresin yields is both cumbersome and complicated. Too many subtle things can happen to obscure oleoresin recovery results. This occurred in both of our cooperative pulpmill trials, particularly the one with slash pine, and it has occurred to some degree in every mill trial of paraquat-treated wood of which we are aware. However, the value of these trials is to demonstrate that there are few or no processing problems, to determine where improvements in the byproduct recovery system should be made, and to produce evidence that no decline in the quality of mill products occurs.

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The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

United States
Department of
Agriculture

Forest Service

Southeastern Forest
Experiment Station

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THEORY OF GAMES AND APPLICATIONS IN FORESTRY

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Southeastern Forest Experiment Station
Asheville, North Carolina

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Theory of Games and Applications in Forestry

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I. Introduction and Theoretical Aspects

I.0. Game Theory in Forestry

The theory of games of strategy derives from von Neumann and Morgenstern (1944). Their book was greeted with considerable enthusiasm by military strategists, economists, and others. The elegance of their development of the theory is much admired. Still, substantive applications within forestry and other natural resources fields have been rare. The root cause of this paucity of applications is not clear. Surely the theory is little known to forest managers and decisionmakers. All this suggests that an exposition of game theory for natural resources managers could encourage application of the techniques in solving real problems. Hence this paper. Aside from that, the theory has an intrinsic beauty and study of such abstractions, as of mathematics generally, inculcates lofty habits of mind.

There are very obvious limitations to the applicability of game theory. Thus, two-person, constant-sum games assume two knowledgeable and selfish adversaries with opposed interests. Clearly, the adversaries can be two people, but need not be. They can as well be two agencies, two companies, two coalitions, two armies. All that is required is that individuals in each group share, so far as the game being played is concerned, a common interest.

The interests must be strictly opposed. One player's gain is the other's loss. Each is assumed knowledgeable of all options and their consequences. Each is expected to try to maximize his own gain, implying he seeks to maximize his opponent's loss. Such situations must be rare within a single organization with a united purpose. Thus, within a company or agency managing land for profit or public good, it appears that opportunities for strict applicability of this theory as a guide to rational behavior are indeed rare. Even between companies within an industry or between departments within an agency, compelling examples of complete antagonism do not readily come to mind in profuse abundance.

Still, there are instances of conflicting situations that can be described fundamentally as a game of strategy between two or more adversaries. The insight provided by the game theoretic formulation and solution can be a helpful guide to choosing, predicting, or understanding rational behavior in such circumstances. A few examples that may be suggestive of many are given in §II. Those are necessarily much simplified in order to treat them in the space allotted and so that the techniques of problem solving may not be lost in the complexities of more realistic situations.

In order that the theory may not seem trival, we now attempt to show that the logic of game theoretic abstractions has profound implications for large problems (as well as delightful implications for small ones). To do so we extract freely from Garrett Hardin (1968). Hardin's thesis was that the world population problem has no technical solution but requires rather a fundamental extension of morality. Some of his analyses are used out of that context--since they apply equally to the one we consider.

With regard to some of its attributes, the forests of a nation are often conceived as a commons. Their beauty and protective influence over water and wildlife resources are thought of as a natural resource. Concerned citizens frequently express an interest in the conservation of these resources and sometimes object to management measures implemented to achieve the immediate objectives of the landowner.

In Hardin's words:

"The tragedy of the commons develops in this way. Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.

"As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, 'What is the utility to me of adding one more animal to my herd?' This utility has one negative and one positive component.

(1) The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1.

(2) The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility of any particular decision-making herdsman is only a fraction of -1.

"Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another.... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit--in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all."

Do these concepts of a constant-sum game, and the tragic implications of dominated strategies so graphically described, have any analogous implications in the complex problems of formulation of forest resources management policy? Hardin himself gives both a specific and general illustration that establishes the affirmative.

"The National Parks present another instance of the working out of the tragedy of the commons. At present, they are open to all, without limit. The parks themselves are limited in extent--there is only one Yosemite Valley--whereas population seems to grow without limit. The values that visitors seek in the parks are steadily eroded. Plainly, we must soon cease to treat the parks as commons or they will be of no value to anyone.

"What shall we do? We have several options. We might sell them off as private property. We might keep them as public property, but allocate the right to enter them. The allocation might be on the basis of wealth, by the use of an auction system. It might be on the basis of merit, as defined by some agreed-upon standards. It might be by lottery. Or it might be on a first-come, first-served basis, administered to long queues. These, I think, are all the reasonable possibilities. They are all objectionable. But we must choose--or acquiesce in the destruction of the commons that we call our National Parks... In a reverse way, the tragedy of the commons reappears in problems of pollution. Here it is not a question of taking something out of the commons, but of putting something in--sewage, or chemical, radioactive, and heat wastes into water; noxious and dangerous fumes into the air; and distracting and unpleasant advertising signs into the line of sight. The calculations of utility are much the same as before. The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for everyone, we are locked into a system of 'fouling our own nest,' so long as we behave only as independent, rational, free-enterprisers."

Hardin concludes that the solution to producing temperance in the use of a commons resides in mutual coercion mutually agreed upon. Importantly, he remarks:

"It is worth noting that the mortality of an act cannot be determined from a photograph. One does not know whether a man killing an elephant or setting fire to the grassland is harming others until one knows the total system in which his act appears. 'One picture is worth a thousand words,' said an ancient Chinese; but it may take 10,000 words to validate it. It is as tempting to ecologists as it is to reformers in general to try to persuade others by way of the photographic shortcut. But the essence of an argument cannot be photographed: it must be presented rationally--in words."

The compelling logic of the foregoing analysis leads to the conclusion that policies to protect forest resources will best rely on mutual coercion mutually conceived from reliable evidence concerning the functioning of the total forest ecosystem. Again quoting Hardin,

"reaching an acceptable and stable solution will surely require more than one generation of hard analytical work--and much persuasion."

Persuasion and agreement depend on understanding the analytical work--including the tools of the analysis. Occasionally the appropriate analytical tool is the theory of games of strategy.

I.1. Zero-Sum, Two-Person Games

The following abstraction taken as a definition of a game of strategy will be sufficiently general for most purposes. One of two players is required to choose one among the finite set of strategies

$$A = \{ a_1, a_2, \ldots, a_i, \ldots, a_m \}.$$

The second player is required to choose one strategy from the finite set

$$B = \{ b_1, b_2, \ldots, b_j, \ldots, b_n \}.$$

Each player is aware of all of his own and all of his opponent's alternatives, but must choose his own strategy without benefit of knowing his opponent's choice. Subsequent to a choice of strategy, say a_i, by Player I, and a choice of strategy, say b_j, by Player II, Player II is required to pay Player I an amount ℓ_{ij} (possibly negative). Such games are called two-person games for obvious reasons and zero-sum games since the sum of the winnings of the two players is zero; there is no "house." Clearly, zero-sum, two-person games are characterized by their payoff matrix which is known to both players.

	Player II Strategies						
	b_1	b_2	...	b_j	...	b_n	
a_1	ℓ_{11}	ℓ_{12}	...	ℓ_{1j}	...	ℓ_{1n}	
a_2	ℓ_{21}	ℓ_{22}	...	ℓ_{2j}	...	ℓ_{2n}	
...	...	...	...	...	...	...	
a_i	ℓ_{i1}	ℓ_{i2}	...	ℓ_{ij}	...	ℓ_{in}	
...	...	...	...	...	...	...	
a_m	ℓ_{m1}	ℓ_{m2}	...	ℓ_{mj}	...	ℓ_{mn}	

It is obvious that Player II would like to choose a strategy so that the payoff (which is his loss) is as small as possible. But, the payoff depends on the strategy chosen by Player I. So, the question arises as to whether Player II has an optimum strategy. And conversely for Player I, who wishes to make the payoff (which is his gain) as large as possible.

I.2. Strictly Determined Games

In the payoff matrix for certain games there is a payoff, ℓ_{ij} say, simultaneously not larger than any payoff in the same row, and not smaller than any payoff in the same column. Such payoffs are said to be a saddlepoint, the game is said to be strictly determined, and ℓ_{ij} is called the value of the game.

Consider the implications to the two players should the payoff matrix in **§I.1** contain a saddlepoint at ℓ_{ij}. If Player I then chooses the strategy a_i, he guarantees himself a payoff (gain) of at least ℓ_{ij}--no matter what strategy Player II chooses. Conversely, if Player II chooses the strategy b_j, he guarantees himself a payoff (loss) of no more than ℓ_{ij}. In this situation, it is clear that neither player may, by any alternate choice of strategy, hope to obtain more favorable results. Player I cannot do better than choose a_i, which is called a maximim pure strategy and is optimum for him. Player II cannot do better than choose b_j, which is called a minimax pure strategy and is optimum for him. The payoff is then $\ell_{ij} = v$, say the value of the game.

I.3. Inadmissible Strategies

In some payoff matrices, a systematic search for optimum strategies is facilitated by deleting certain rows and/or columns. In the payoff matrix of §I.1, suppose the first two columns possess the property:

$$\ell_{i1} \geqslant \ell_{i2}, \text{ all } i = 1, 2, \ldots, m, \text{ and}$$

$$\ell_{i1} > \ell_{i2}, \text{ some } i = 1, 2, \ldots, m,$$

i.e., in each row the payoff in column 1 is always as large as the payoff in column 2--and sometimes larger. In that case, choosing b_2 is always as good as choosing b_1 for Player II, and sometimes (for countering some choices of his opponent) it is better. Player II can have no reason ever to prefer strategy b_1 to b_2, and b_1 is said to be dominated by b_2. Any strategy of either player so dominated by an alternative strategy is said to be inadmissible and may be deleted from further consideration.

I.4. Computations for Strictly Determined Games

The payoff matrix of §I.1 may be systematically examined to determine whether it has a saddlepoint or not by appending a column (composed of the row minima) and a row (composed of the column maxima) as follows.

Player I Strategies	Player II Strategies: b_1	b_2	$\ldots$	b_n	
a_1	ℓ_{11}	ℓ_{12}	$\ldots$	ℓ_{1n}	$\min\limits_j \ell_{1j}$
a_2	ℓ_{21}	ℓ_{22}	$\ldots$	ℓ_{2n}	$\min\limits_j \ell_{2j}$
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$
a_m	ℓ_{m1}	ℓ_{m2}	$\ldots$	ℓ_{mn}	$\min\limits_j \ell_{mj}$
	$\max\limits_i \ell_{i1}$	$\max\limits_i \ell_{i2}$	$\ldots$	$\max\limits_i \ell_{in}$	

If the maximum of the elements in the appended column (i.e., the maximum of the row minima) is equal to the minimum of the appended row (i.e., the minimum of the column maxima), then the game is strictly determined (i.e., the payoff matrix has a saddlepoint). Moreover, any strategy of Player I that maximizes the row minima is a maximin strategy and an optimum strategy for him. Conversely, any strategy of Player II that minimizes the column maxima is a minimax strategy and an optimum strategy for him. Finally, the value of the game is

$$v = \max_i \min_j \ell_{ij} = \min_j \max_i \ell_{ij} .$$

It may be noted that a payoff matrix may have more than one saddlepoint. The payoff is always v at each of them. And, when either player has more than one optimum strategy, he will be indifferent between them since each guarantees a payoff of v.

I.5. Mixed Strategies

We have completed our theoretical description of strictly determined games of strategy. Henceforth we are particularly interested in games with payoff matrices where

$$\max_i \min_j \ell_{ij} < \min_j \max_i \ell_{ij}$$

(the opposite inequality is arithmetically impossible). From §1.4 it is obvious that Player II always has a pure strategy that ensures his loss will be no greater than the right-hand side of the last inequality. Analogously, Player I has a pure strategy that ensures his gain will be no less than the left-hand side. In §1.4 these two quantities were equal, and discovery of such strategies constituted a solution of the game.

Now the disparity between the two sides of the last inequality may be viewed opportunistically by both players--for it suggests the possibility of increased gain (reduced loss) over that guaranteed by the maximim (minimax) pure strategy. The fundamental theorem of games addresses this possibility and provides a definitive solution for each player. It employs the concepts of mixed strategies for the players and expected payoff in the repetitive play of the same game.

Consider then that Player I can elect to choose among his pure strategies, a_1, with the aid of a random device. Thus, with such a device, he might choose strategy a_1 with probability p_1; a_2 with probability p_2, ..., and strategy a_m with probability p_m where:

$$0 \leqslant p_i, \; i = 1, 2, \cdots, m; \text{ and } 1 = \sum_{i=1}^{m} p_i .$$

(For example, if in each play of a certain game, Player I has only two pure strategies, a_1 and a_2, and he chooses a_1 if the flipping of a (fair) coin shows heads, and he chooses a_2 if the coin shows tails, then $m = 2$ and $p_1 = p_2 = 1/2$.) Choice of a particular set of probabilities

$$\underline{p} = [\; p_1 \;\; p_2 \;\; \cdots \;\; p_m \;]$$

constitues choice of a mixed strategy by Player I. The set of all mixed strategies available to Player I is the set of all 1xm vectors, such as $\underline{p}$ above, where the elements of $\underline{p}$ are nonnegative and sum to one.

Analogously, Player II could choose among his pure strategies, b_1, b_2, $\cdots$, b_n, with probabilities

$$\underline{q} = [\; q_1 \; q_2 \; \cdots \; q_n \;] ,$$

i.e., he could choose a mixed strategy by electing one among all 1xn vectors whose elements are nonnegative and sum to one.

I.6. Expected Payoff

Given a particular choice of a mixed strategy, $\underline{p}$, by Player I, and a particular choice of a mixed strategy, $\underline{q}$, by Player II, it is a simple computation to find the expected payoff in a long series of repetitions of a zero-sum, two-person game. For the expected payoff is the sum over all prospective payoffs of the product of the payoff and its probability of occurrence. Clearly the probability of any payoff in the payoff matrix, say ℓ_{ij}, is

$$\Pr(\ell_{ij}) = p_i \; q_j$$

since ℓ_{ij} is realized if and only if Player I chooses his strategy a_i (which he does with probability p_i), and Player II chooses his strategy b_j (which he does with probability q_j), and since (§I.1) choice by each player is made in the absence of knowledge, and therefore independently, of his opponent's choice. Thus, given $\underline{p}$ and $\underline{q}$, the expected payoff is

$$\sum_i \sum_j \ell_{ij} \Pr(\ell_{ij}) = \sum_i \sum_j \ell_{ij} \; p_i q_j = \underline{p} \;\; L \; \underline{q}'$$

where $\underline{q}'_{nx1}$ is the matrix transpose of $\underline{q}_{1xn}$, $L = L_{mxn}$ is the payoff matrix, and $\underline{p}$ L $\underline{q}$, is simply the matrix product

$$\underline{p} \, L \, \underline{q}' = [\; p_1 \; p_2 \; \cdots \; p_m \;] \begin{bmatrix} \ell_{11} & \ell_{12} & \cdots & \ell_{1n} \\ \ell_{21} & \ell_{22} & \cdots & \ell_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \ell_{m1} & \ell_{m2} & \cdots & \ell_{mn} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ \cdots \\ q_n \end{bmatrix}$$

which is a scalar, i.e., one number.

I.7. The Fundamental Theorem

The fundamental theorem of games of strategy given by John von Neumann established that for every payoff matrix L

$$\max_{\underline{p}} \min_{\underline{q}} \underline{p} \; L \; \underline{q}'$$

and

$$\min_{\underline{q}} \max_{\underline{p}} \underline{p} \; L \; \underline{q}'$$

both exist and they are equal. Their common value, say V, is called the value of the game. Stated another way, the theorem establishes that in any zero-sum, two-person game Player I has a strategy, $\underline{p}^*$, among his strategies $\underline{p}$, and Player II has a strategy, $\underline{q}^*$, among his strategies $\underline{q}$, such that

$$\underline{p} \; L \; \underline{q}^{*\prime} \leqslant V = \underline{p}^* \; L \; \underline{q}^{*\prime} \leqslant \underline{p}^* \, L \, \underline{q}'.$$

Thus, from the left inequality, Player II has a strategy, $\underline{q}^*$, that guarantees that his expected loss will not exceed V no matter what strategy Player I chooses. And, from the right inequality, Player I has a strategy, $\underline{p}^*$, that guarantees that his expected gain will be at least V no matter what strategy Player II chooses. Since neither player, by alternative choice of strategy, can improve his prospects, each may as well choose $\underline{p}^*$ and $\underline{q}^*$, respectively, so as to achieve V in the long run: $\underline{p}^*$ is a maximin mixed strategy and optimum for Player I; $\underline{q}^*$ is a minimax mixed strategy and optimum for Player II.

It should be observed that the choice of a pure strategy, a_i, by Player I, i.e., the certain choice of a_i can be described as the choice of the mixed strategy with $p_i = 1$ and $p_k = 0$, where $k \neq i$. And, similarly, the choice of the pure strategy, b_j, by Player II can be described as the choice of the mixed strategy where all elements are zero except for one in the j^{th} position.

When the payoff matrix has a saddle-point, the maximin pure strategy satisfies the defining property of $\underline{p}^*$, the optimum mixed strategy for Player I, and the minimax pure strategy satisfies the defining property of $\underline{q}^*$, the optimum mixed strategy for Player II.

I.8. Mention of Other Games

Extensions in several directions of the theory of the preceding sections have been attempted. Some of them will now be briefly reviewed.

Games involving three persons, four persons, and in general many persons have been formally considered. Here we will confine ourselves to quoting a single paragraph from Dorfman and others (1958):

"The theory of many-person games in the hands of von Neumann and Morgenstern is essentially a theory of coalitions, their formation and revision. The underlying idea is that two persons in such a situation cannot do worse by acting jointly than by acting severally, and may do better. Thus a many-person game tends to be reduced to a two-'person' game in which each 'person' is a coalition. The problems then become: which coalitions will form and how will the winnings be divided among the members of the coalition? To pursue the answers proposed for these questions would lead us into a specialized discussion, and since these answers are not very satisfactory we refrain."

Extending the results of zero-sum games to constant-sum games is easy. Indeed, in some elementary expositions the basic theory is presented on the basis of the assumption that the sum of the winnings of the two players is always a constant, say ℓ. We have taken ℓ to be zero for convenience.

Further extension to non-constant-sum games is much more difficult. When one player's gain is not necessarily the other's loss, there is the possibility of increased gain by both players through collusion and cooperation. Unfortunately, as McKinsey (1952) observes:

"Despite the great importance of general games for the social sciences, there is not available so far any treatment of such games which can be regarded as even reasonably satisfactory."

I.9. Decision Theory

One application of the theory of zero-sum, two-person games envisions a game of strategy between a decisionmaker and "nature." Some modification of the preceding arguments is required, and there is considerble controversy. Moreover, even a cursory review of the subject would require a treatment comparable in size to that given here to games of conflict between selfish opponents. Still, this important subject must be mentioned.

So, we now consider briefly that the abstraction of §I.1 is sometimes used to describe the situation of a decisionmaker (Player II) "in the real world" confronted with choosing among decisions or actions, $b_1, b_2, \cdots, b_n$. In the natural resources field, the sets of actions confronting various decisionmakers are as diverse as one can imagine. They may deal with business, forest management, personnel, silviculture, engineering, and selection, its maintenance or deployment of equipment. The list goes on. Typically, choice of a particular decision commits one for the future. Even if it doesn't, the optimum choice of action is typically not evident due to uncertainties about markets, economic conditions, natural events such as weather to be encountered, action or state of biological agents, etc. In any event, it is possible to envision the applicability of the materials of §I.1 to some of these situations by taking Player I to be, for lack of a better descriptor, "nature" and the strategies of "nature" to be the various events or conditions that the decisionmaker may confront. The payoff, ℓ_{ij}, becomes the cost (possibly negative, indicating a net benefit) of taking action, b_j, should condition a_i materalize. Clearly, Player II wishes to choose an action, b_j, to minimize his costs (maximize his benefits). But, in the formulation of §I.1, as in real life, uncertainty about the condition, a_i, that may prevail creates uncertainty about the desirable action.

Now, a disparity. Previously, Player I was considered to be an intelligent, deliberative opponent, informed of the payoff matrix, and expected to choose a strategy, a_i, to maximize Player II's loss. "Nature," whether denoting next month's weather, the biological agents at work in a forest, or general economic conditions expected for the next quarter, can hardly be construed as so perverse. Still, on occasion, the minimax solution given by game theory is recommended for decisionmakers who simply wish to guard against the worst contingency.

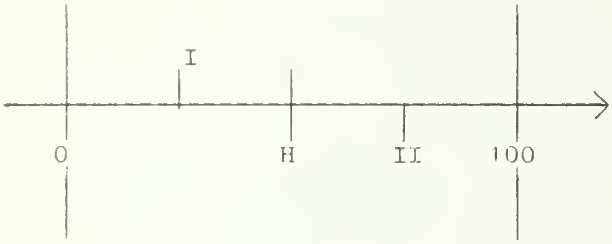
More often, an alternative base on prognosis is recommended. For example, if weather is the adversary, and potential conditions are enumerated, then something of the probability of their occurrence must be known--perhaps from climatic records. If the period of time of concern to the decisionmaker is near and short, perhaps the historical frequency of conditions may be modified by a weather forecast. Analogously, enough of the health of a forest may be known to specify the likelihood of various biological conditions, and there are forecasts of future economic conditions. What is usually recommended to the decisionmaker equipped with information on the likelihood of various conditions is that he determine his expected loss under each of his alternatives and choose that one minimizing his expected loss given his information. That is, a Bayesian strategy, is usually recommended in such formulations as better justified than a minimax one.

For the reader interested in decision theory, several references in §IV are selected from a voluminous literature.

II. Procedural Aspects and Illustrative Applications

II.1. Locations for Two Companies in a Forest

Suppose a single railroad traverses a homogeneously forested region. Within the forest, distances along the railway from one boundary to the other are scaled from zero to 100. Suppose two forest products companies intend to enter this market by constructing a single rail siding each where wood may be scaled, purchased, and loaded for transport to their respective mills. They must locate at two points, such as I and II, in the following figure.



If we construct a point, H, halfway between I and II and assume each company will get all of the wood marketed from its side of point H, where should the two companies locate their siding?

This problem fits very neatly into the format of a zero-sum, two-person game (§I.1) if it's assumed for simplicity that the companies can locate only at a finite number of points along the railway, say at 0, 20, 40, 50, 60, 80, and 100. Suppose further that the companies will split the market 50-50 if they choose the same location. The payoff matrix is shown in the table below. The losses shown in the table are the proportions of the market yielded by Company II to Company I, depending on the two locations chosen. Clearly, Company II wishes to choose a location (strategy) to minimize such a payoff. Company I wishes to maximize it.

To ascertain whether this payoff matrix has a saddlepoint (§I.1), the minimum loss in each row is appended on the right of the payoff matrix (§I.4). Analogously, the maximum loss in each column is appended to the bottom. Finally, it is observed that the maximum of the row minima is .50, as is the minimum of the column maxima, i.e., the two are equal and this payoff matrix has a saddlepoint. Moreover, the optimum location (maximum strategy) for Company I is in the center of the forest (at location 50). The optimum location (minimax strategy) for Company II is also in the center (at location 50).

		Location of Company II							
		0	20	40	50	60	80	100	Row minima
Location of Company I	0	.50	.10	.20	.25	.30	.40	.50	.10
	20	.90	.50	.30	.35	.40	.50	.60	.30
	40	.80	.70	.50	.45	.50	.60	.70	.45
	50	.75	.65	.55	.50	.55	.65	.75	.50 ← maximum
	60	.70	.60	.50	.45	.50	.70	.80	.45
	80	.60	.50	.40	.35	.30	.50	.90	.30
	100	.50	.40	.30	.25	.20	.10	.50	.10
Column maxima		.90	.70	.55	.50 ↑ minimum	.55	.70	.90	

When both companies locate in the center, they share the market 50-50 (.50 is the value of the game). The payoff corresponding to the two optimum strategies exhibits the characteristic property of a saddlepoint--it is smallest in the row and largest in the column containing it (§I.2).

Notice that locating one company at any point other than the center yields more than half of the market to the competitor who locates in the center.

II.2. When to Patrol

Consider next a problem that confronts, in more or less complex form, many forest managers whose jobs include an element of law enforcement, i.e., whether to patrol an area susceptible to unlawful entry. Problems of this type arise in many forms due to the susceptibility of forest land to timber trespass, poaching, arson, etc.

Suppose a company forester is alerted that his lands are the intended target of an arsonist. During any particular susceptible period (e.g., overnight) the arsonist may either attempt to set fire or he may not (i.e., he may stay home). The forester's alternative strategies may be to patrol or refrain. Suppose the payoff matrix is

Action of Arsonist	Action of Forester: Patrol	Don't patrol	Row minima
Burn	-100	10	-100
Don't burn	1	0	0
Column maxima	1	10	

The numerical values of these payoffs are debatable--as is the assumption of zero-sum payoffs. But, the rationale could be something like this. If neither protagonist acts, the (mutual) result is the status quo--indicted by zero payoff. If the patrol is employed in the absence of the arsonist, the company incurs a cost of 1 man-day of unnecessary labor. Alternatively, if the arsonist strikes in the absence of a patrol, the company incurs 10 man-days' labor in suppressing the fire. Both of these labor costs are assumed to accrue in satisfaction to the arsonist as payment for a real or imagined injustice by the company. Finally, if both protagonists act, the arsonist is caught and fined and/or imprisoned at considerable personal loss. The company correspondingly gains from the relief from future patrols and suppression from the arsonist apprehended and perhaps from others who might entertain like ambitions for revenge or mischief in the absence of an example of the potential consequences.

This simple game does not possess a saddlepoint since

$$\max_i \min_j \ell_{ij} = 0 < 1 = \min_j \max_i \ell_{ij},$$

i.e., the maximum of the row minima is less than the minimum of the column maxima. Hence, the optimum strategy for at least one of the players involves a mixture of his pure strategies, and the value of this game has not been determined.

A general algebraic solution for 2x2 games with payoff matrices

$$\begin{bmatrix} \ell_{11} & \ell_{12} \\ \ell_{21} & \ell_{22} \end{bmatrix}$$

without saddlepoints is available. In such games, Player I's optimum mixed strategy is to choose his first pure strategy with probability p and his second with probability 1-p where

$$p = \frac{\ell_{22} - \ell_{21}}{\ell_{11} - \ell_{12} - \ell_{21} + \ell_{22}} .$$

Analogously, Player II's optimum mixed strategy is to choose his first and second pure strategies with probabilities q and 1-q, respectively, where

$$q = \frac{\ell_{22} - \ell_{12}}{\ell_{11} - \ell_{12} - \ell_{21} + \ell_{22}}.$$

Finally, the value of the game is

$$V = \frac{\ell_{11} \cdot \ell_{22} - \ell_{12} \cdot \ell_{21}}{\ell_{11} - \ell_{12} - \ell_{21} + \ell_{22}}.$$

Using the numerical payoffs given at the beginning of this section and the relevant formulas, it is easy to find that

(i) the optimum strategy for the arsonist is to burn the woods with probability $p \approx 1/111 \approx .009$ and to stay home with probability $1-p = 110/111 \approx .991$,

(ii) the optimum strategy for the forester is to patrol with probability $q = 10/111 \approx .09$ and to refrain with probability $1-q = 101/111 \approx .91$, and

(iii) the value of the game is $V = 10/111$.

II.3. A Graphical Method for Finding an Optimal Strategy for Any Player With Two Strategies

Without attempting to motivate the specific game, we next illustrate a graphical technique for finding (approximately) an optimum mixed strategy for any player who has only two pure strategies from which to choose. His opponent may have any (finite) number of pure strategies. Careful study of this material will facilitate understanding of §III. The example here is from Singleton and Tyndall (1974).

Consider the game with payoff matrix

	Player II Strategies				
	b_1	b_2	b_3	b_4	Row minima
a_1	1	2	4	0	0
a_2	0	-2	-3	4	-3
Column maxima	1	2	4	4	

Since the payoff matrix has no saddle-point, the problem for Player I is to find a mixture of his two pure strategies, a_1 and a_2, that maximizes his minimum expected gain (against any pure or mixed strategy of Player II). Thus, Player I seeks a probability, p, with which he will choose his strategy a_1 (and consequently a probability, 1-p, with which he will choose his strategy a_2) to maximize his minimum expected gain.

Consider that, given p, Player I's expected gain against b_1 (cf. column one of the payoff matrix) is

$$\xi_1\ (p) = 1p + 0\ (1 - p).$$

This function is plotted and labeled in the following graph. It shows, for example, that if Player I chooses p = 0, so that he chooses with certainty his strategy a_2, then he gains against b_1 exactly zero (cf. payoff matrix). If Player I chooses p = 1 so that he chooses with certainty his strategy a_1, then he gains against b_1 one. If Player I chooses an intermediate p so that he chooses a mixture of a_1 and a_2, then his expected gain against b_1 is given by the graph of ξ_1 (p). Thus, if Player I flips a fair coin to choose between a_1 and a_2, his expected gain against b_1 is one-half.

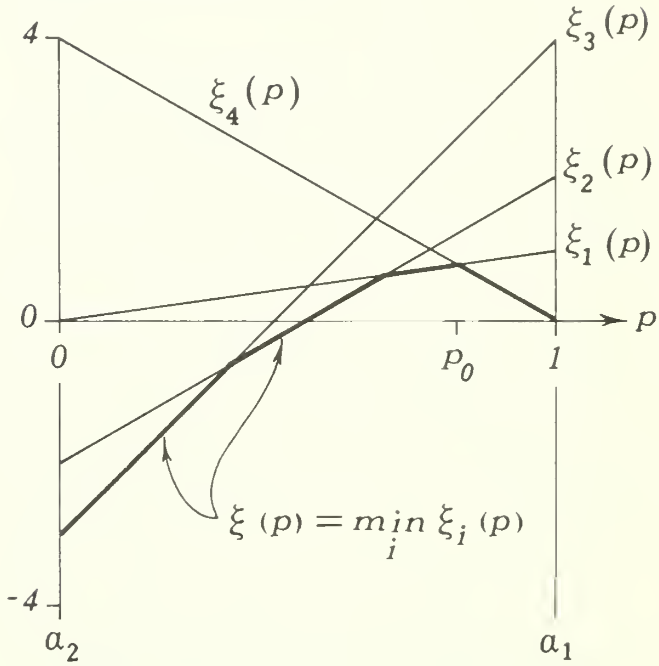
Similarly, given p, Player I's expected gain against b_2, b_3, and b_4 (cf. columns 2, 3, and 4 of the payoff matrix) are, respectively,

$$\xi_2\ (p) = 2p - 2\ (1 - p),$$

$$\xi_3\ (p) = 4p - 3\ (1 - p), \text{ and}$$

$$\xi_4\ (p) = 0p + 4\ (1 - p).$$

All of these functions are depicted in the following graph.



Points on these straight lines depict the expected gain of Player I against each of the pure strategies of Player II for any p in the interval zero to one, inclusive, i.e., for any mixed strategy for Player I.

But, the graph instantly shows more than that. For every p, it shows Player I's minimum expected gain, whatever Player II's strategy. Player I's minimum expected gain is

$$\xi (p) = \min_i \ \xi_i (p),$$

the bold, segmented linear function in the graph. Clearly, Player I maximizes his minimun expected gain by choosing p to maximize ξ (p), i.e., by choosing the point, p_0, ticked on the graph's axis at p = 0.8. Thus, Player I's optimum strategy is to choose

a_1 with probability 0.8, and

a_2 with probability 0.2.

Any alternative choice of p clearly lowers Player I's minimum expected gain (cf. graph).

III. Programing for Computer Execution

Following the strategy implicit in §II.3, we can outline a linear programing method for the solution of general mxn games.

Consider the game with payoffs

$$\ell_{ij};\ i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n$$

where m and n are (in principle) any finite positive integers. Consider first the problem of finding an optimum strategy for Player I, i.e., an optimum vector, $\underline{p}$, of probabilities for choosing among his m pure strategies $a_1, a_2, \cdots, a_m$. Should Player I choose the particular mixed strategy (cf. §I.5)

$$\underline{p} = [p_1, p_2, \cdots, p_m] ,$$

then his expected gain against each of Player II's strategies may be written down. These expectations are:

(against b_1)

$$\xi_1 (\underline{p}) = p_1 \ell_{11} + p_2 \ell_{21} + \cdots + p_m \ell_{m1} ;$$

(against b_2)

$$\xi_2 (\underline{p}) = p_1 \ell_{12} + p_2 \ell_{22} + \cdots + p_m \ell_{m2} ;$$

$$\cdots$$

and

(against b_n)

$$\xi_n (\underline{p}) = p_1 \ell_{1n} + p_2 \ell_{2n} + \cdots + p_m \ell_{mn}.$$

Now, for the moment, simply define a quantity V as the minimum of these expectations, i.e., define

$$V = \min_i \{ \xi_1 (\underline{p}), \xi_2 (\underline{p}), \cdots, \xi_n (\underline{p}) \} .$$

Then (cf. §II.3) Player I's problem is to choose $\underline{p}$ to maximize V.

In analogy with problems of linear programing, think of Player I as having

(i) choice variables $p_1, p_2, \cdots, p_m$, and V, and

(ii) the objective of maximizing V.

Remembering the constraints on the p_i and the definition (immediately above) of V, Player I's problem is to choose $p_1, p_2, \cdots, p_m$ to:

maximize V such that

$$\begin{aligned}
p_1 \ell_{11} + p_2 \ell_{21} + \cdots + p_m \ell_{m1} &\geq V \\
p_1 \ell_{12} + p_2 \ell_{22} + \cdots + p_m \ell_{m2} &\geq V \\
&\cdots \\
p_1 \ell_{1n} + p_2 \ell_{2n} + \cdots + p_m \ell_{mn} &\geq V \\
p_1 + p_2 + \cdots + p_m &= 1 \\
p_1 &\geq 0
\end{aligned}$$

$$p_2 \geq 0$$

$$\cdots$$

$$p_m \geq 0$$

Now, adding a constant to all elements of the payoff matrix changes nothing as far as strategies for playing a game are concerned. In particular, the constant to be added may be chosen to be $-\max_i \min_j \ell_{ij}$. This clearly assures that the value of the game is nonnegative. Consequently, we may assume that $V \geq 0$. Then Player I's problem of finding an optimum strategy is the following linear programing program in more conventional notation:

Choose $p_1, p_2, \cdots, p_m, V$ to maximize V subject to

$$\begin{aligned}
V &\geq 0 \\
p_1 &\geq 0 \\
p_2 &\geq 0 \\
&\cdots \\
p_m &\geq 0 \\
p_1 + p_2 + \cdots + p_m &\geq 1 \\
\ell_{11} p_1 + \ell_{21} p_2 + \cdots + \ell_{m1} p_m - V &\geq 0 \\
\ell_{12} p_1 + \ell_{22} p_2 + \cdots + \ell_{m2} p_m - V &\geq 0 \\
&\cdots \\
\ell_{1n} p_1 + \ell_{2n} p_2 + \cdots + \ell_{mn} p_m - V &\geq 0
\end{aligned}$$

Player II's problem of finding an optimum strategy is the famous duality problem of linear programing.

IV. Suggested Reading

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Thompson, E. F. The theory of decision under uncertainty and possible applications in forest management. Forest Science 14: 156-163; 1968.

Swindel, Benee F.

Theory of games and applications in forestry. Gen. Tech. Rep. SE-26. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 13 p.

Theory has been developed covering two-person, constant-sum games of strategy. This theory is summarized and some possible applications in forestry are suggested.

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ABSTRACT

Equations and tables are presented for estimating total and merchantable volumes and weights of loblolly pine planted on prepared sites in the Lower Atlantic Coastal Plain. The equation system can be used to predict current and projected yields in cubic feet and green and dry weights.

Keywords: *Pinus taeda*, taper equations, volume equations, forest management in Southeastern States.

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1. Introduction

During the past few decades, plantations have assumed an increasingly important role in the forests of the Southeastern United States. Initially, most plantations in this region were established on old-field sites, but in recent years, the vast majority of new plantations have been established on cutover land following mechanical site preparation. The use of mechanical site preparation is a fairly new development in southeastern forest management, and reliable information on the yields that can be expected from site-prepared plantations has not been generally available. The studies reported here were initiated to obtain such information for unthinned loblolly pine plantations in the Lower Atlantic Coastal Plain of the Carolinas, Georgia, and Florida.

A description of the data collection activities and characteristics of the data bases obtained is provided in section 2. Taper equations, volume equations, and tables showing predicted individual tree volumes and weights by diameter and height classes are presented in section 3. Site index curves for the plantation population studied are contained in section 4. Section 5 provides tables of expected stand structure and per acre volume and weight yields for selected combinations of soil group, plantation age, site index, and number of trees per acre. Methods for predicting mortality are included in section 6, together with yield tables that describe stand development through time for selected combinations of soil group, site index, age, and initial number of trees per acre. Equations used in generating the various tables and curves are presented in each section. For those wishing to express results in metric units, a table of conversion factors is given in Appendix I. A set of FORTRAN computer subroutines is contained in Appendix II. These subroutines were used to generate the tables and graphs presented in this report, and they can be easily used to compute values for situations not included in the published tables and graphs.

2. Data Collection

Basic data for the studies reported here were collected during the summers of 1975, 1976, 1977, 1979, and 1981. Data acquisition involved the collection of yield plot data and felled sample tree data.

Yield plot measurement began in 1975 with the establishment of 44 temporary plots in the Lower Coastal Plain of South Carolina, Georgia, and Florida. During 1977, an additional 182 monumented plots were installed in the North and South Carolina Lower Coastal Plain. Table 1 and figure 1 show the geographic distribution of these sample plots by County and State. Plantations included in the sample satisfied the following criteria:

- at least 10 years of age
- planted following mechanical site preparation
- unthinned
- unfertilized
- unpruned
- show no evidence of excessive insect or disease damage
- show no evidence of interplanting or excessive numbers of wildlings

Plots were generally laid out in a rectangular configuration designed to include approximately 64 original plant-

Table 1.--Distribution of 226 yield plots by County, State, and year of measurement

State and County	Number of plots 1975	1977	State and County	Number of plots 1975	1977
Florida			Craven	--	11
Marion	2	--	Duplin	--	1
Nassau	4	--	Jones	--	20
			Onslow	--	8
	6	--			
				--	83
Georgia					
Bryan	2	--	**South Carolina**		
Camden	3	--	Allendale	2	--
Charlton	6	--	Beaufort	1	--
Chatham	3	--	Berkeley	--	10
Effingham	3	--	Charleston	--	5
Glynn	1	--	Colleton	--	1
Liberty	5	--	Dillon	--	4
Long	6	--	Dorchester	--	34
McIntosh	2	--	Georgetown	--	27
Wayne	1	--	Hampton	1	1
			Jasper	2	6
	32	--	Marion	--	2
			Marlboro	--	1
North Carolina			Orangeburg	--	1
Beaufort	--	8	Williamsburg	--	7
Bladen	--	1			
Brunswick	--	3		6	99
Carteret	--	3			
Columbus	--	28			
			Total	44	182

ing spaces. In plantations where rows were irregular or indistinguishable, square 0.1-acre plots were used. Plots were purposively located within the plantations to achieve uniform stocking within the plot. The location procedure was not an attempt to find areas with maximum stocking, in any sense, and essentially simply involved shifting the plot location to avoid obvious "holes" in the stand.

Data collected for each plot included the following:

- method of site preparation (obtained from company records)
- plantation age (from planting date)
- length and width of plot
- total number of trees in each 1-inch d.b.h. class
- number of wildlings and Cronartium-infected trees in each 1-inch d.b.h. class
- d.b.h., crown class, and total height of at least two trees in each d.b.h. class
- a complete soil profile description

The site-preparation methods identified included many combinations of such treatments as burning, chopping, harrowing, rootraking, bedding, etc.

The distribution of the yield plots by age, site index, and number of trees per acre at the time of measurement is

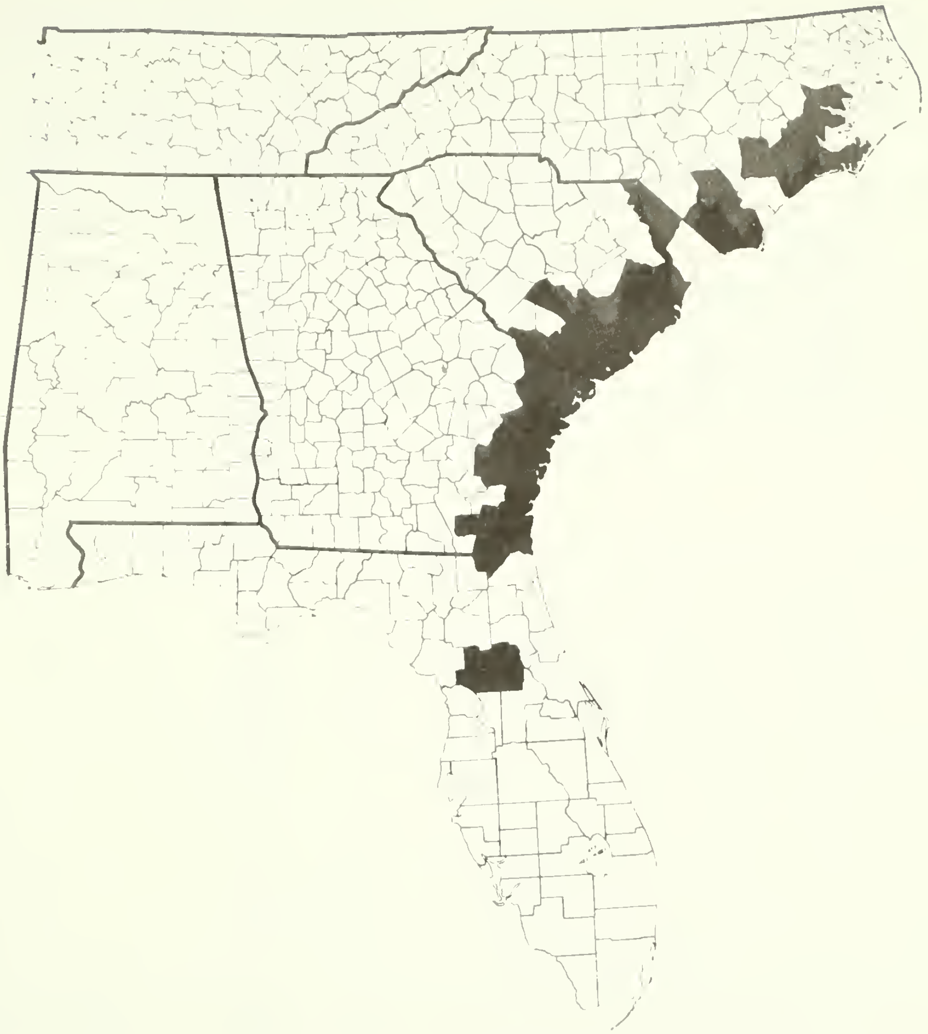

Figure 1.--Geographic distribution of sample plots, by County and State.

shown in table 2. Additional information on collection of the yield plot data is available in Smith (1978).

Felled sample tree data were collected during 1977 in the 182 established plots in North and South Carolina plantations. In addition, 12 of the Georgia-Florida plantations sampled for yield information during 1975 were revisited during 1976 for felled sample tree data. Generally, four trees were felled in each plantation sampled. Two were selected from the larger diameter classes, one from the classes close to average d.b.h., and one from the lower end of the d.b.h. range. No trees were cut in or immediately adjacent to the yield plots. A total of 762 trees was included in this sample. Distribution of the sample trees by diameter and height classes is shown in table 3.

After felling, disks were removed from the trees at 5-foot intervals and sufficient field and laboratory measurements were made to determine the following quantities:

- total stem outside bark (o.b.) volume
- total stem inside bark (i.b.) volume
- merchantable stem (o.b.) volumes to merchantable diameter limits (o.b.) of 2, 3, 4, and 6 inches
- merchantable stem (i.b.) volumes to merchantable diameter limits (o.b.) of 2, 3, 4, and 6 inches

Table 2.--Distribution of yield plots by age, site index, and number of trees per acre

Age class	Site class	Trees per acre							Total
		300	400	500	600	700	800	900	
	40			3		1			4
	50		2	5	7	2			16
10	60		3	2	3	4	2		14
	70			3	4	3			10
	80		3	4			1		8
	40		3	2	3	3	1		12
	50	1	2	8	7	6	2	1	27
15	60		7	10	8	6	1	4	36
	70	1	4	9	7	1	1	1	24
	80	2	7	4		1	1		15
	40		2	2					4
	50		1	2	4		2		9
20	60	1	2	4	6				13
	70	2	5	3	4	3			17
	80	2	3	1	1	1			8
	40			1					1
25	60	2	1	3					6
	70				1				1
30	50				1				1
Total		11	45	66	56	31	11	6	226

Site index for individual plots was calculated using the equations described in section 4. Equations and site index values tabulated here are based on an index age of 25 years.

Table 3.--Number of felled sample trees by height and diameter classes

Diameter class (inches)	Height class (feet)													Total
	15	20	25	30	35	40	45	50	55	60	65	70	75	
2		3	1											4
3	1	8	16	12	9	1								47
4		4	10	20	21	20	8	3						86
5		1	8	26	30	22	16	9	4					116
6				17	25	25	19	9	10	3				108
7			1	6	23	37	29	21	12	8	3			140
8					2	9	22	26	16	9	3			87
9			1			2	10	12	24	20	10	2	1	82
10						1	1	7	11	16	10	6		52
11							1	3	3	5	7	7		26
12										2	2	3		7
13											1	3	2	6
14													1	1
Total	1	16	37	81	110	117	106	90	80	63	36	21	4	762

Table 4.--Distribution of the 1981 remeasured yield plots by State and County

Location	Number of plots
North Carolina	
Beaufort	6
Bladen	1
Brunswick	1
Carteret	2
Columbus	10
Craven	8
Duplin	1
Jones	19
Onslow	5
	53
South Carolina	
Berkeley	8
Charleston	4
Dillon	2
Dorchester	28
Georgetown	20
Hampton	1
Jasper	6
Marlboro	1
Orangeburg	1
Williamsburg	6
	77
Total	130

- total stem green weight (wood and bark)
- merchantable stem green weight (wood and bark) to merchantable diameter limits (o.b.) of 2, 3, 4, and 6 inches
- total stem dry weight (wood only)
- merchantable stem dry weight (wood only) to merchantable diameter limits (o.b.) of 2, 3, 4, and 6 inches

Details of the procedures used to obtain these values are found in Flowers (1978).

The plots established in 1977 were remeasured during the summer of 1981 to obtain growth and survival data. Of the original 182 plots, 130 were reidentified and measured for (a) plantation age, (b) number of trees in each 1-inch d.b.h. class, (c) number of wildlings and Cronartium-infected trees in each 1-inch d.b.h. class, and (d) d.b.h., crown class, and total height of at least two trees in each d.b.h. class. Plots that were not remeasured had been clearcut, thinned, or otherwise disturbed during the 4 years since establishment. Distribution of the remeasured plots by State and County is shown in table 4.

3. Individual Tree Volume and Weight

This section presents the system of tree volume, weight, and taper equations used to develop the yield tables. Although there are a number of loblolly pine volume and weight equations in existence, they were developed for old-field plantations in the Piedmont and Coastal Plain (Bailey and Clutter 1970; Burkhart and Clutter 1971; Burkhart and others 1972; Romancier 1961; Shipman 1961). The following equations were developed specifically for site-prepared plantations of the flatwoods by Flowers (1978) from the felled sample tree data. They incorporate current mensurational techniques that provide great flexibility in calculation of volumes and weights.

Volume Prediction

Total stem volume, o.b.

$$TV_o = 0.00395569\, D^{1.8945}\, H^{0.9288} \tag{1}$$

Total stem volume, i.b.

$$TV_i = 0.00148209\, D^{1.9229}\, H^{1.1105} \tag{2}$$

Merchantable stem volume, o.b.

$$MV_o = TV_o[1 - 0.4724\, D_m^{3.3559}\, D^{-3.1135}] \tag{3}$$

Merchantable stem volume, i.b.

$$MV_i = TV_i[1 - 0.5694\, D_m^{3.4304}\, D^{-3.2395}] \tag{4}$$

where:

TV_o = total stem volume (cubic feet), o.b.
TV_i = total stem volume (cubic feet), i.b.
MV_o = merchantable stem volume (cubic feet), o.b.
MV_i = merchantable stem volume (cubic feet), i.b.
D = d.b.h. (inches)

D_m = merchantable diameter (inches), o.b.
H = total height (feet)

Weight Prediction

Total stem green weight (wood plus bark)

$$TGW = 0.133280\ D^{1.9159}\ H^{1.0481} \quad (5)$$

Total stem dry weight (wood only)

$$TDW = 0.028932\ D^{1.8721}\ H^{1.2273} \quad (6)$$

Merchantable stem green weight (wood plus bark)

$$MGW = TGW[1 - 0.4819\ D_m^{3.3208}\ D^{-3.0622}] \quad (7)$$

Merchantable stem dry weight (wood only)

$$MDW = TDW[1 - 0.4868\ D_m^{3.5503}\ D^{-3.3322}] \quad (8)$$

where:

TGW = total stem green weight, wood plus bark (pounds)
TDW = total stem dry weight, wood only (pounds)
MGW = merchantable stem green weight, wood plus bark (pounds)
MDW = merchantable stem dry weight, wood only (pounds)
D = d.b.h. (inches)
D_m = merchantable diameter (inches), o.b.
H = total height (feet)

Tabulations of predicted volumes and weights, by height and diameter classes for these equations, are given for selected merchantability limits in tables 5 to 20.

Taper Equations

Variable top merchantable volume and weight relationships of the type shown in equations (3), (4), (7), and (8) are very useful because a single equation expresses weight or volume of a tree to any desired top diameter limit. However, in practice, the user often needs to know the outside- or inside-bark diameter at a given height up the stem or, conversely, the height at which a given outside- or inside-bark diameter occurs. It has recently been shown that total and merchantable volume equations of the type given by (1), (2), (3), and (4) implicitly define taper functions that relate upper-stem diameter to a given height up the stem (Clutter 1980). Taper functions derived from these equations can therefore be used to estimate upper-stem dimensions. The taper functions for the present volume equations are:

Prediction of diameter o.b. from height aboveground

$$d_o = 1.129318\ D^{0.899034}\ H^{-0.685006} \times (H-h)^{0.737518} \quad (9)$$

Prediction of height aboveground from diameter o.b.

$$h = H - [0.84798\ D^{-1.2190}\ H^{0.9288}\ d_o^{1.3559}] \quad (10)$$

Prediction of diameter i.b. from height aboveground

$$d_i = 0.770783\ D^{0.883723}\ H^{-0.619672} \times (H-h)^{0.764991} \quad (11)$$

Prediction of height aboveground from diameter i.b.

$$h = H - [1.405410\ D^{-1.155207}\ H^{0.810039}\ d_i^{1.307206}] \quad (12)$$

where:

d_o = diameter (inches) o.b. at a point h feet up the stem
d_i = diameter (inches) i.b. at a point h feet up the stem
h = distance aboveground (feet) to a point on the stem where d_o and d_i occur
D = d.b.h. (inches)
H = total height (feet)

Example Applications

Consider a loblolly pine tree with a d.b.h. of 10.5 inches and a height of 65 feet. Total cubic-foot volumes, o.b. and i.b., are estimated from equations (1) and (2) as follows:

$$TV_o = 0.00395569\ (10.5)^{1.8945}\ (65)^{0.9288} = 16.43 \text{ cubic feet}$$

$$TV_i = 0.00148209\ (10.5)^{1.9229}\ (65)^{1.1105} = 14.05 \text{ cubic feet}$$

Merchantable volumes o.b. to a 6- and 4-inch top are calculated from equation (3):

$$MV_o(6) = (16.43)[1 - 0.4724\ (6)^{3.3559}\ (10.5)^{-3.1135}] = 14.33 \text{ cubic feet}$$

$$MV_o(4) = (16.43)[1 - 0.4724\ (4)^{3.3559}\ (10.5)^{-3.1135}] = 15.89 \text{ cubic feet}$$

and merchantable volumes i.b. are calculated from equation (4):

$$MV_i(6) = (14.05)[1 - 0.5694\ (6)^{3.4304}\ (10.5)^{-3.2395}] = 12.21 \text{ cubic feet}$$

$$MV_i(4) = (14.05)[1 - 0.5694\ (4)^{3.4304}\ (10.5)^{-3.2395}] = 13.59 \text{ cubic feet}$$

Table 5.--Total volume outside bark

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
2	0.18	0.24	0.29											
3	0.39	0.51	0.63	0.75	0.86	0.98	1.09							
4	0.68	0.88	1.09	1.29	1.49	1.68	1.88	2.07	2.26					
5	1.03	1.35	1.66	1.97	2.27	2.57	2.86	3.16	3.45	3.74				
6			2.34	2.78	3.20	3.63	4.05	4.46	4.87	5.28	5.69			
7			3.14	3.72	4.29	4.86	5.42	5.97	6.53	7.08	7.62	8.17		
8			4.04	4.79	5.52	6.25	6.98	7.69	8.41	9.11	9.82	10.52		
9			5.05	5.98	6.91	7.82	8.72	9.62	10.51	11.39	12.27	13.15	14.01	14.88
10					8.43	9.54	10.65	11.74	12.83	13.91	14.98	16.05	17.11	18.17
11						11.43	12.75	14.07	15.37	16.66	17.95	19.23	20.50	21.76
12									18.12	19.65	21.16	22.67	24.17	25.66
13										22.86	24.63	26.38	28.13	29.87
14												30.36	32.37	34.37

Volume includes entire stem with bark above a 6-inch stump height. Block indicates extent of data.

Table 6.--Total volume inside bark

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
2	0.11	0.16	0.20											
3	0.25	0.34	0.44	0.54	0.64	0.74	0.84							
4	0.43	0.59	0.76	0.93	1.10	1.28	1.46	1.64	1.82					
5	0.66	0.91	1.17	1.43	1.70	1.97	2.24	2.52	2.80	3.09				
6			1.66	2.03	2.41	2.79	3.18	3.58	3.98	4.38	4.79			
7			2.23	2.73	3.24	3.76	4.28	4.82	5.35	5.90	6.44	7.00		
8			2.88	3.53	4.19	4.86	5.54	6.22	6.92	7.62	8.33	9.04		
9			3.62	4.43	5.25	6.09	6.95	7.81	8.68	9.56	10.45	11.34	12.25	13.16
10					6.43	7.46	8.50	9.56	10.63	11.71	12.79	13.89	15.00	16.11
11						8.96	10.22	11.48	12.77	14.06	15.37	16.69	18.01	19.35
12									15.09	16.62	18.17	19.72	21.30	22.80
13										19.39	21.19	23.01	24.84	26.68
14												26.53	28.64	30.77

Volume includes entire stem without bark above a 6-inch stump height. Block indicates extent of data.

Table 7.--Merchantable volume outside bark to a 2.0-inch top diameter

D.b.h. (inches)	Height (feet)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
5	1.00	1.30	1.61	1.90	2.19	2.48	2.77	3.06	3.34	3.62				
6			2.30	2.73	3.14	3.56	3.97	4.38	4.78	5.19	5.59			
7			3.10	3.68	4.24	4.80	5.36	5.91	6.45	7.00	7.54	8.07		
8			4.01	4.75	5.48	6.21	6.92	7.64	8.34	9.05	9.74	10.44		
9			5.03	5.95	6.87	7.78	8.68	9.57	10.45	11.33	12.21	13.08	13.94	14.80
10					8.40	9.51	10.61	11.70	12.78	13.86	14.93	15.99	17.05	18.10
11						11.40	12.72	14.03	15.32	16.61	17.90	19.17	20.44	21.70
12									18.08	19.60	21.12	22.62	24.12	25.61
13										22.83	24.59	26.34	28.08	29.82
14												30.32	32.33	34.32

Volume includes merchantable stem with bark above a 6-inch stump height to a 2.0-inch top diameter outside bark. Block indicates extent of data.

Table 8.--Merchantable volume inside bark to a 2.0-inch top diameter

D.b.h. (inches)	Height (feet)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
5	0.64	0.88	1.13	1.38	1.64	1.90	2.17	2.44	2.71	2.98				
6			1.63	1.99	2.36	2.74	3.13	3.51	3.91	4.30	4.70			
7			2.21	2.70	3.20	3.72	4.24	4.76	5.29	5.83	6.37	6.92		
8			2.86	3.50	4.16	4.82	5.50	6.18	6.87	7.57	8.27	8.98		
9			3.60	4.41	5.23	6.06	6.91	7.77	8.64	9.51	10.40	11.29	12.19	13.09
10					6.41	7.44	8.47	9.53	10.59	11.66	12.75	13.84	14.94	16.06
11						8.94	10.19	11.45	12.73	14.02	15.33	16.64	17.97	19.30
12									15.06	16.59	18.13	19.69	21.25	22.83
13										19.36	21.16	22.97	24.80	26.64
14												26.50	28.61	30.73

Volume includes merchantable stem without bark above a 6-inch stump height to a 2.0-inch top diameter outside bark. Block indicates extent of data.

Table 9.--Merchantable volume outside bark to a 4.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	- - -	- - -	- - -	- - -	- - -	- - -	- - -	Cubic feet	- - -	- - -	- - -	- - -	- - -	- - -
5	0.69	0.90	1.11	1.32	1.52	1.72	1.92	2.12	2.31	2.51				
6			1.90	2.26	2.60	2.95	3.29	3.63	3.96	4.30	4.63			
7			2.77	3.29	3.79	4.29	4.79	5.28	5.77	6.26	6.74	7.22		
8			3.73	4.42	5.10	5.78	6.44	7.11	7.76	8.42	9.07	9.71		
9			4.78	5.67	6.54	7.40	8.26	9.11	9.95	10.79	11.62	12.45	13.27	14.09
10					8.11	9.18	10.24	11.29	12.34	13.38	14.41	15.44	16.46	17.48
11						11.11	12.39	13.67	14.93	16.19	17.44	18.68	19.92	21.15
12									17.73	19.22	20.70	22.18	23.65	25.11
13										22.48	24.21	25.94	27.65	29.36
14												29.95	31.94	33.91

Volume includes merchantable stem with bark above a 6-inch stump height to a 4.0-inch top diameter outside bark. Block indicates extent of data.

Table 10.--Merchantable volume inside bark to a 4.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
5	0.42	0.58	0.75	0.91	1.09	1.26	1.44	1.61	1.79	1.98				
6			1.33	1.63	1.93	2.24	2.55	2.87	3.19	3.51	3.84			
7			1.96	2.40	2.85	3.30	3.76	4.23	4.70	5.18	5.66	6.15		
8			2.66	3.25	3.86	4.48	5.10	5.73	6.38	7.02	7.68	8.33		
9			3.42	4.19	4.97	5.77	6.57	7.39	8.21	9.05	9.89	10.74	11.59	12.45
10					6.19	7.18	8.18	9.20	10.22	11.26	12.31	13.36	14.43	15.50
11						8.71	9.93	11.16	12.41	13.67	14.94	16.22	17.51	18.81
12									14.77	16.27	17.78	19.31	20.85	22.39
13										19.07	20.84	22.63	24.43	26.25
14												26.19	28.28	30.38

Volume includes merchantable stem without bark above a 6-inch stump height to a 4.0-inch top diameter outside bark.
Block indicates extent of data.

Table 11.--Merchantable volume outside bark to a 6.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Cubic feet													
6			0.63	0.75	0.87	0.98	1.09	1.21	1.32	1.43	1.54			
7			1.72	2.04	2.35	2.66	2.97	3.28	3.58	3.88	4.18	4.48		
8			2.84	3.36	3.88	4.39	4.90	5.40	5.90	6.40	6.89	7.38		
9			4.01	4.75	5.48	6.20	6.92	7.63	8.34	9.04	9.74	10.43	11.12	11.81
10					7.18	8.12	9.06	10.00	10.92	11.84	12.75	13.66	14.57	15.47
11						10.17	11.34	12.51	13.67	14.82	15.96	17.10	18.23	19.36
12									16.59	17.99	19.38	20.76	22.13	23.50
13										21.36	23.01	24.65	26.28	27.90
14												28.78	30.68	32.58

Volume includes merchantable stem with bark above a 6-inch stump height to a 6.0-inch top diameter outside bark. Block indicates extent of data.

Table 12.--Merchantable volume inside bark to a 6.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	- - -	- - -	- - -	- - -	- - -	- - -	- - Cubic	feet - -	- - -	- - -	- - -	- - -	- - -	- - -
6			0.33	0.40	0.48	0.55	0.63	0.71	0.79	0.87	0.95			
7			1.15	1.40	1.66	1.93	2.20	2.47	2.75	3.03	3.31	3.59		
8			1.97	2.42	2.87	3.32	3.79	4.26	4.74	5.22	5.70	6.19		
9			2.84	3.47	4.12	4.78	5.45	6.12	6.81	7.50	8.20	8.90	9.61	10.32
10					5.45	6.32	7.20	8.10	9.00	9.91	10.83	11.76	12.70	13.64
11						7.95	9.07	10.19	11.33	12.48	13.64	14.81	15.99	17.18
12									13.81	15.21	16.62	18.05	19.49	20.94
13										18.12	19.80	21.50	23.21	24.94
14												25.16	27.17	29.19

Volume includes merchantable stem without bark above a 6-inch stump height to a 6.0-inch top diameter outside bark.
Block indicates extent of data.

Table 13.--Total green weight (wood + bark)

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
2	9	12	15											
3	19	25	32	39	45	52	59							
4	32	44	55	67	79	91	103	115	127					
5	50	67	85	103	121	139	157	176	194	213				
6			120	146	171	197	223	249	275	302	328			
7			162	196	230	265	300	335	370	405	441	476		
8			209	253	297	342	387	432	478	523	569	615		
9			262	317	373	429	485	542	599	656	713	771	828	886
10					456	525	593	663	732	802	873	943	1014	1085
11						630	712	796	879	963	1047	1132	1217	1302
12									1039	1138	1237	1337	1438	1538
13										1326	1442	1559	1676	1793
14												1797	1931	2067

Weight includes entire stem with bark above a 6-inch stump height. Block indicates extent of data.

Table 14.--Total dry weight (wood only)

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
2	3	4	6											
3	6	9	12	15	18	21	24							
4	11	15	20	25	30	36	41	47	53					
5	16	23	31	38	46	54	63	72	81	90				
6			43	54	65	77	89	101	113	126	139			
7			57	72	87	102	118	134	151	168	186	203		
8			74	92	111	131	152	173	194	216	238	261		
9			92	115	139	164	189	215	242	269	297	325	354	383
10					169	199	230	262	295	328	362	396	431	467
11						238	275	313	352	392	432	474	516	558
12									415	461	509	557	607	657
13										536	591	648	705	763
14												744	810	876

Weight includes entire stem without bark above a 6-inch stump height. Block indicates extent of data.

Table 15.--Merchantable green weight (wood + bark) to a 2.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
5	48	65	82	99	117	134	152	170	187	205				
6			118	143	168	193	219	244	270	296	321			
7			160	193	227	262	296	331	365	400	435	470		
8			207	251	295	339	384	429	474	519	564	610		
9			260	315	371	426	482	538	596	652	709	766	824	881
10					454	522	591	660	729	799	869	939	1009	1080
11						628	710	793	876	960	1044	1128	1213	1298
12									1036	1135	1234	1334	1435	1534
13										1324	1440	1556	1673	1790
14												1794	1929	2064

Weight includes merchantable stem with bark above a 6-inch stump height to a 2.0-inch top diameter outside bark. Block indicates extent of data.

Table 16.--Merchantable dry weight (wood only) to a 2.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
5	16	23	30	37	45	53	61	70	78	87				
6			42	53	64	76	87	99	112	124	137			
7			57	71	86	101	117	133	150	167	184	201		
8			73	92	111	131	151	172	193	215	237	259		
9			92	115	138	163	188	214	241	268	296	324	353	382
10					169	199	230	262	294	327	361	395	430	466
11						238	275	313	352	391	432	473	515	557
12									414	461	508	557	606	656
13										535	591	647	704	762
14												743	809	876

Weight includes merchantable stem without bark above a 6-inch stump height to a 2.0-inch top diameter outside bark.
Block indicates extent of data.

Table 17.--Merchantable green weight (wood + bark) to a 4.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	- - -	- - -	- - -	- - -	- - -	- - -	Pounds	- - -	- - -	- - -	- - -	- - -	- - -	- - -
5	32	44	55	67	79	91	103	114	127	139				
6			96	117	137	158	179	199	220	241	263			
7			142	172	202	232	262	293	324	355	386	417		
8			192	232	273	314	355	397	438	480	522	564		
9			247	299	351	404	457	510	564	618	672	726	781	835
10					437	503	569	635	702	769	836	904	971	1039
11						610	690	771	852	933	1015	1097	1179	1261
12									1014	1111	1208	1305	1403	1501
13										1302	1415	1530	1645	1760
14												1770	1903	2036

Weight includes merchantable stem with bark above a 6-inch stump height to a 4.0-inch top diameter outside bark. Block indicates extent of data.

Table 18.--Merchantable dry weight (wood only) to a 4.0-inch top diameter

D.b.h. (inches)	Height (feet)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
5	11	16	21	26	32	37	43	49	55	62				
6			36	45	54	64	73	84	94	105	115			
7			52	65	78	92	106	121	136	151	167	182		
8			69	86	104	123	142	161	181	202	223	244		
9			88	110	133	156	181	206	231	257	284	311	338	366
10					164	193	223	254	286	318	351	384	418	452
11						233	269	306	344	383	423	463	504	545
12									408	454	500	548	596	646
13										529	584	639	696	753
14												736	801	868

Weight includes merchantable stem without bark above a 6-inch stump height to a 4.0-inch top diameter outside bark. Block indicates extent of data.

Table 19.--Merchantable green weight (wood + bark) to a 6.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
6			28	34	40	46	52	58	64	71	77			
7			85	102	120	138	157	175	193	212	230	249		
8			143	173	203	234	264	295	326	357	388	420		
9			204	247	290	334	378	422	466	511	555	600	645	690
10					383	440	498	557	615	674	733	792	851	911
11						554	627	700	774	848	922	996	1071	1146
12									943	1033	1124	1215	1306	1397
13										1231	1339	1447	1556	1664
14												1694	1821	1948

Weight includes merchantable stem with bark above a 6-inch stump height to a 6.0-inch top diameter outside bark.
Block indicates extent of data.

Table 20.--Merchantable dry weight (wood only) to a 6.0-inch top diameter

D.b.h. (inches)	Height (feet) 15	20	25	30	35	40	45	50	55	60	65	70	75	80
	Pounds													
6			12	15	18	21	25	28	32	35	39			
7			33	41	49	58	67	77	86	96	106	116		
8			53	67	81	95	110	125	141	156	173	189		
9			75	94	113	133	154	175	197	219	242	265	288	312
10					147	173	200	228	256	285	314	344	375	406
11						216	249	283	319	355	391	428	466	505
12									385	428	473	518	563	610
13										507	559	612	666	721
14												712	775	839

Weight includes merchantable stem without bark above a 6-inch stump height to a 6.0-inch top diameter outside bark.
Block indicates extent of data.

Green and dry weights can be similarly estimated with equations (5), (6), (7), and (8).

Outside- and inside-bark diameters at the top of the first 16.5-foot log (i.e., at 17 feet aboveground assuming a 0.5-foot stump) can be estimated from equations (9) and (11) as follows:

$$d_o = 1.129318\,(10.5)^{0.899034}\,(65)^{-0.685006} \times (65-17)^{0.737518} = 9.3 \text{ inches}$$

$$d_i = 0.770783\,(10.5)^{0.883723}\,(65)^{-0.619672} \times (65-17)^{0.764991} = 9.0 \text{ inches}$$

The height corresponding to a diameter o.b. of 6 inches can be estimated from equation (10):

$$h = 65 - [0.84798\,(10.5)^{-1.2190}\,(65)^{0.9288} \times (6)^{1.3559}] = 38.5 \text{ feet}$$

The corresponding height for a diameter i.b. of 6 inches from equation (12) is:

$$h = 65 - [1.405410\,(10.5)^{-1.155207}\,(65)^{0.810039} \times (6)^{1.307206}] = 36.6 \text{ feet}$$

4. Site Index

The yield of an unthinned plantation is largely determined by three factors:

1. age of the plantation
2. stand density (expressed here as number of surviving stems per acre)
3. innate productivity of the site upon which the plantation is growing

Site productivity is usually expressed in terms of site index, which is defined as the average height that would be attained by dominant and codominant trees at some specified index age. The conventional index age for southern pine plantations is 25 years.

No site index curves or equations for site-prepared loblolly pine plantations in the Lower Coastal Plain existed before this study. Ring-count data collected from the dominant and codominant stem analysis trees sampled in 1977 formed the basis for an investigation of height-growth patterns that was reported by Pienaar and Shiver (1980). Their results showed that the sample plots came from two soil strata (A and B) with significantly different height-growth patterns. Plots classified as Group B had the following characteristics:

- very poorly drained (SCS drainage class)
- A1 horizon ranging from 7 to 24 inches in thickness
- organic matter content of the A1 horizon equal to or greater than 10 percent

Virtually all plots in this group were on North Carolina pocosin and river swamp soils in areas that had been extensively ditched to remove excess water. The effect of ditching on growth could not be tested; however, it is unlikely that the site index relationships observed in ditched areas would be appropriate for similar soils that have not been ditched.

The soils in Group B are classified as Humaquepts, Paleaquults, and Umbraquults. The specific soil series sampled were:

Humaquepts	Paleaquults	Umbraquults
Ballahack	Bayboro	Byars
Torhunta	Pantego	

All other soil series sampled were placed in Group A. The distributions of sample plots by taxonomic group and soil series for Group A and Group B are shown in table 21. Separate distributions of the plots by age, site index, and number of trees per acre for Soil Groups A and B are given in table 22.

Separate site index equations were developed for use with Group A and Group B soils (Pienaar and Shiver 1980). Each of these equations defined an anamorphic

Table 21.--Distribution of sample plots by soil group, taxonomic group, and soil series

Taxonomic group and soil series	Number of plots
SOIL GROUP A	
Haplaquods	
Leon	1
Ridgeland	2
Sapelo	1
	4
Haplohumods	
Echaw	3
	3
Hapludults	
Altavista	2
Autryville	1
Bertie	5
Chrisolm	2
Coosaw	4
Craven	10
Eddings	1
Eulonia	5
Eunola	8
Kalmia	4
Kenansville	7
Nemours	3
	52
Ochraquults	
Augusta	1
Bladen	3
Coxville	2
Leaf	14
Lenoir	3
Lynchburg	3
Tomotley	3
Wahee	12
Williman	1
	42
Paleaquults	
Plummer	2
Rainsq	2
	4
Paleudults	
Onslow	1
Blanton	4
Foreston	1
Goldsboro	7
Norfolk	9
Ocilla	5
Wagrum	2
	29
Quartzipsamments	
Chipley	12
Kureb	1
Lakeland	4
Pactolus	1
	18
Udipsamments	
Wando	2
	2
Umbraquults	
Cape Fear	1
	1
Total	155
SOIL GROUP B	
Humaquepts	
Ballahack	6
Torhunta	1
	7
Paleaquults	
Bayboro	4
Pantego	14
	18
Umbraquults	
Byars	1
	1
Total	26
Grand Total	181

Table 22.--Distribution of yield plots by age, site index, and number of trees per acre for Soil Groups A and B

Age class	Site class	Trees per acre 300	400	500	600	700	800	900	Row total
				SOIL GROUP A					
	40			3		1			4
	50		2	5	7	2			16
10	60		3	1	3	4	2		13
	70			3	4	2			9
	80		3	3					6
	40		3	2	3	3	1		12
	50	1	2	8	7	6	2	1	27
15	60		7	10	8	6	1	3	35
	70	1	3	9	6	1	1	1	22
	80	2	5	4		1	1		13
	40		2	2					4
	50		1	2	4		2		9
20	60	1	2	4	5				12
	70	2	3			1			6
	80	1	2						3
	40			1					1
25	60	2	1	3					6
	70				1				1
30	50				1				1
Column total		10	39	60	49	27	10	5	200
				SOIL GROUP B					
	60			1					1
10	70					1			1
	80			1			1		2
	60								1
15	70		1		1				2
	80		2						2
	60				1				1
20	70		2	3	4	2			11
	80	1	1	1	1	1			5
Column total		1	6	6	7	4	1	1	26

series[1] of site index curves. The Group A site index equation was derived from the stem analysis data from 308 felled sample trees in 154 plantations. The data base used for the Group B site index equation came from 50 sample trees in 25 plantations. Distribution of sample trees by age and height class is shown in table 23.

Height remeasurement data collected in 1981 offered an alternative to the use of stem analysis data for the development of site index equations. Of the 130 remeasured plots, 122 were located on Group A soils. Average heights of dominants and codominants for these plots in 1977 and 1981 were compared with height trends predicted by the Pienaar and Shiver site index curves. Actual growth compared well with the curves for plots with moderate site index values. Examination of the growth data for plots with more extreme site indices, however, indicated that low site index plots showed a height development pattern with less curvature than that observed on the moderate site index plots, while high site index plots displayed more curvature than the moderate site plots. These trends indicated that an equation capable of generating a polymorphic family of site index curves was needed for plantations on Group A soils.

An equation form previously used by Clutter and Lenhart (1968) and Clutter and Jones (1980) was successfully fitted to the remeasurement data from the 122 Soil Group A plots. The resulting equation was:

$$\log_e(H_{D2}) = \beta_2 A_2^{-1} - \beta_3 + [\log_e(H_{D1}) - \beta_2 A_1^{-1} + \beta_3] \exp[\beta_1 (A_1^{-1} - A_2^{-1})] \quad (13)$$

where:

A_1 = plot age at the beginning of the growth period
A_2 = plot age at the end of the growth period
H_{D1} = average height of dominant and codominant trees at the beginning of the growth period

[1]In an anamorphic series of site index curves, a constant proportionality relationship exists for any pair of curves in the series. This pattern is not present in a polymorphic series.

Table 23.--Distribution of sample trees by age and height class

Age (years)	Height class (feet) 15	25	35	45	55	65	75	Total
10	1	7	40	16				64
11		4	20	19	5			48
12		2	17	20	7			46
13			4	14	8			26
14			2	6	16			24
15				12	12	6		30
16			2	6	4	10		22
17				1	9	10		20
18				1	9	9	1	20
19				4	7	12	3	26
20					4	8	4	16
21					3	2	1	6
22					1	1		2
23				1	1			2
24						2		2
25					1	1		2
26								
27								
28								2
Total	1	13	85	100	87	63	9	358

H_{D2} = average height of dominant and codominant trees at the end of the growth period
β_1 = -4.69839
β_2 = -37.22042
β_3 = -0.67644, and $\log_e(X)$ denotes the natural logarithm of the quantity X, and exp is the exponential function

If A_2 is set equal to 25 years, H_{D2} is then, by definition, equal to site index. This substitution in (13) results in the site index equation,

$$\log_e(S) = -0.81238 + [1.20676 \log_e(H_D) + 44.91596A^{-1} - 0.81630] \times \exp(-4.69839A^{-1}) \qquad (14)$$

where:
S = site index (base age 25 years)
A = stand age
H_D = average height of dominants and codominants at age A

Equation (14) is easily inverted to obtain an equation for average dominant height as a function of stand age and site index.

$$\log_e(H_D) = 0.67644 - 37.22042A^{-1} + 0.82867 \times [\log_e(S) + 0.81238] \exp(4.69838A^{-1}) \qquad (15)$$

The above equations should be used to predict site index and average height of dominants and codominants in stands growing on soils classified as Group A. The site index curves defined by equation (15) are shown in figure 2.

The 182 plots installed in 1977 included 26 on Group B soils. Twenty-two of these were clearcut or thinned before the 1981 remeasurement. As a result, remeasured height data were available for only four plots on Group B soils. In view of the small sample size, no attempt was made to develop new site index curves for Group B soils and the original equations developed by Pienaar and Shiver (1980) are recommended for application in this stratum. These equations are:

Site index

$$S = H_D\left[\frac{0.7476}{1 - \exp(-0.5507\ A)}\right]^{1.4350} \qquad (16)$$

Average dominant height

$$H_D = S[1.3376\ (1 - \exp(-0.05507\ A))]^{1.4350} \qquad (17)$$

where S, H_D, and A are as defined above. Group B site index curves defined by equation (17) are shown in figure 3.

Estimating site index for a particular plantation requires examination of soil characteristics to place the plantation in Soil Group A or B, and determination of plantation age and average height of dominants and codominants. Site index can then be calculated by inserting these data into the proper equation or by interpolating the site index curves shown in figure 2 or 3.

5. Per Acre Volume and Weight Yields

Measurement data collected on the 226 yield plots described in section 2 were used to develop equations for predicting stand structure and per acre yields. The overall approach involves the prediction of a diameter distribution and associated heights by 1-inch diameter class for any given combination of plantation age, site index, number of stems per acre, and soil group. Once heights and number of stems per acre by d.b.h. class have been determined, per acre volumes or weights can be calculated easily by applying the appropriate individual tree volume or weight equation and accumulating yields over the occupied diameter classes (Bennett and Clutter 1968).

The statistical distribution used to describe the relative frequencies of trees in the various d.b.h. classes is the three-parameter Weibull distribution (Bailey and Dell 1973). Details of the analysis used to develop the prediction system are available in Smith (1978). When tree diameters have a Weibull distribution, the proportion, P, of the population diameters that exceeds a lower limit, D_L, but is less than an upper limit D_U, is given by

$$P(D_L, D_U) = \exp\{-[(D_L - a)/b]^c\} - \exp\{-[(D_U - a)/b]^c\} \qquad (18)$$

where a, b, and c are the parameters that determine the characteristics of the particular Weibull distribution involved, and exp denotes the exponential function. In the system described here, values for these parameters are obtained as functions of plantation age, average height of dominants and codominants, and number of trees per acre at the prediction age. It should be noted that the

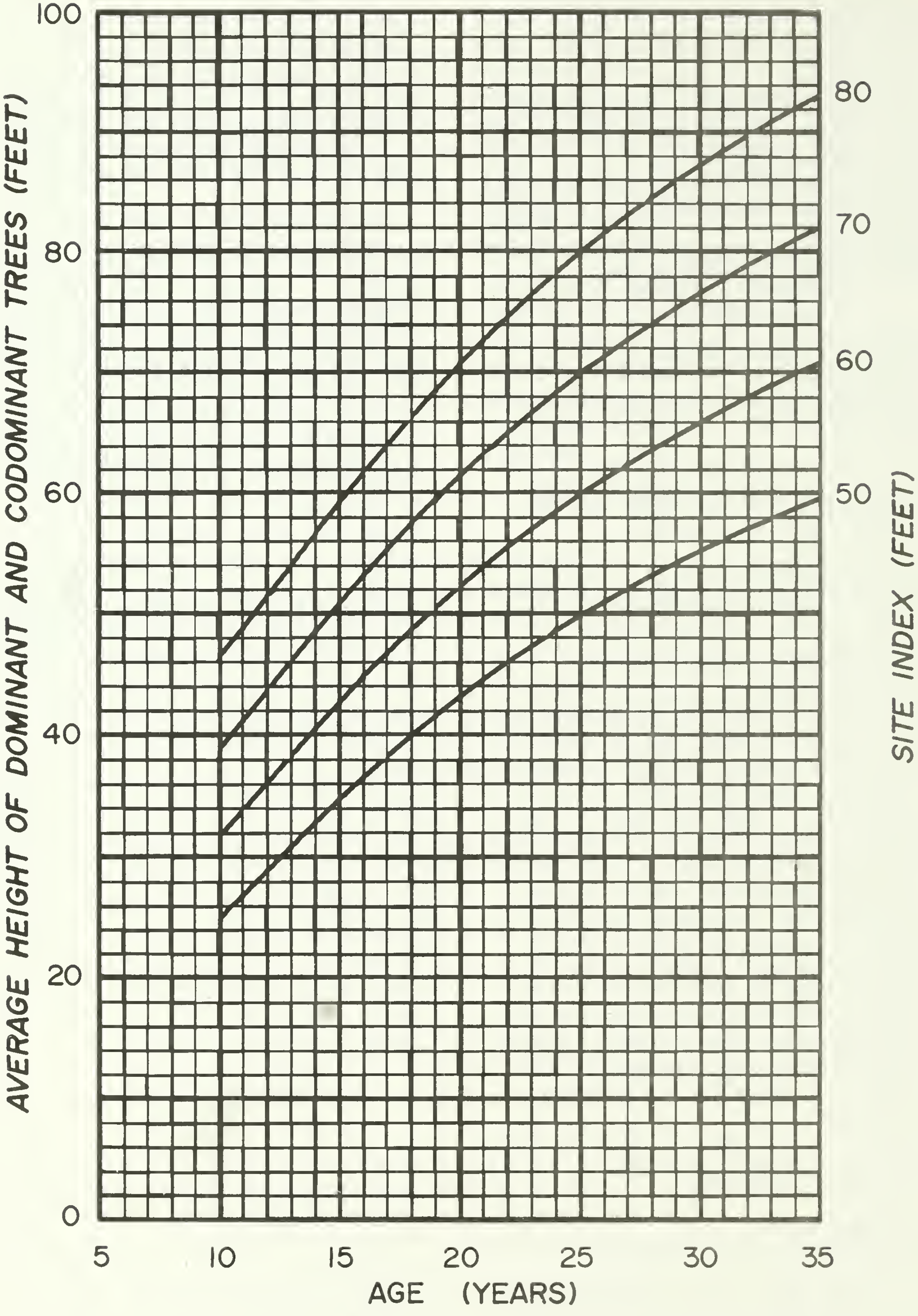

Figure 2.--Site index curves for Soil Group A.

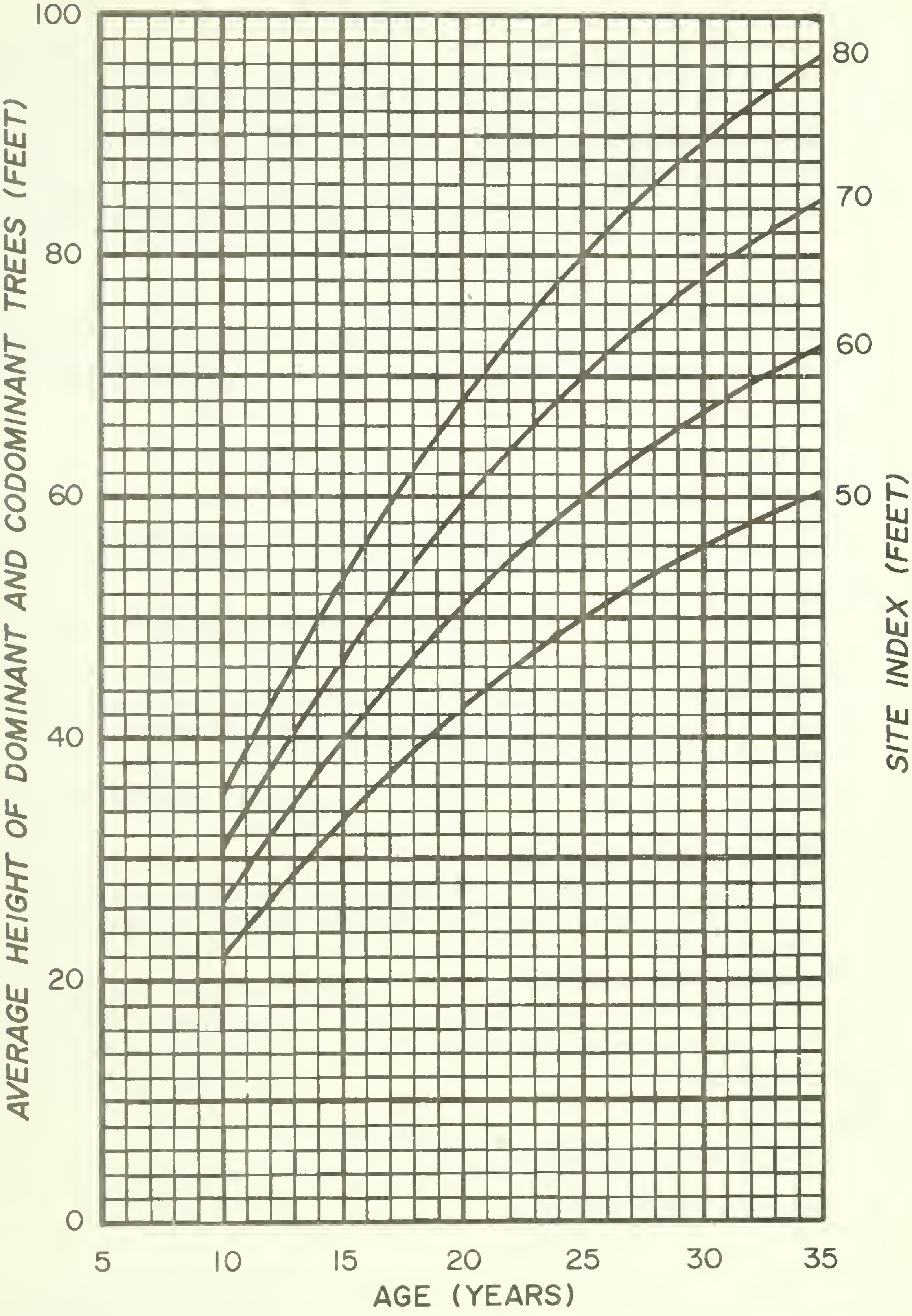

Figure 3.--Site index curves for Soil Group B.

average height of dominants is a function of plantation age and site index and can always be estimated from these two factors by using either equation (15) or equation (17), depending upon the soil group involved. The equations for predicting the Weibull parameters a, b, and c are shown below:

Soil Group A

$$a = A^{0.5}[0.2576A^{0.5} - 0.1073\log_e(N)] \quad (19)$$

$$b = \exp[2.2978 - 1.2111(A/H_D) - 0.0192(N/H_D)] \quad (20)$$

$$c = \exp[1.5518 - 0.0339A + 0.0714\log_e(A)] \quad (21)$$

Soil Group B

$$a = A^{0.5}[0.4912A^{0.5} - 0.2139\log_e(N)] \quad (22)$$

$$b = \exp[2.5829 - 0.0359A - 0.000672N] \quad (23)$$

$$c = \exp[5.0037 - 0.1495A - 22.3577/A] \quad (24)$$

where:

A = plantation age (years)
H_D = average height of dominants and codominants (feet)
N = number of surviving trees per acre at age A, and
$\log_e$ = natural logarithm

A single equation can be used with both soil groups to predict total tree height for each d.b.h. class. This equation is

$$H = H_D\{0.6046 + 0.0449(H_D/A) + 0.7385\log_e[CDF(D) + 1] - 0.0862(H_D/A) \times \log_e[CDF(D) + 1]\} \quad (25)$$

where:

H = total tree height (feet)
D = d.b.h. (inches)
A = plantation age
H_D = average height of dominants and codominants

The notation CDF(D) denotes the Weibull cumulative distribution function value associated with the d.b.h. value, D, and is defined as

$$CDF(D) = 1 - \exp\{-[(D - a)/b]^c\} \quad (26)$$

where a, b, and c are the Weibull parameter estimates.

Example Applications

The use of these equations is illustrated below in a calculation of the expected outside-bark, per acre, total-volume yield (5-inch d.b.h. class and above) for a Soil Group A plantation 30 years of age with a site index of 60 feet and 450 stems per acre (table 24). We first use equation (15) to calculate H_D:

$$\log_e(H_D) = 0.67644 - 37.22042(1/30) + 0.82867[\log_e(60) + 0.81238] \times \exp[4.69839(1/30)] = 4.19187$$

$$H_D = 66.1012 \text{ feet}$$

The a, b, and c parameter estimates for the diameter frequency distribution are obtained as

$$a = (30)^{0.5}[0.2576(30)^{0.5} - 0.1073\log_e(450)] = 4.137557$$

$$b = \exp[2.2978 - 1.2111(30/66.1012) - 0.0192(450/66.1012)] = 5.040141$$

$$c = \exp[1.5518 - 0.0339(30) + 0.0714\log_e(30)] = 2.176342$$

With these parameter estimates, equation (18) can be written as

$$P(D_L, D_U = \exp\{-[(D_L - 4.137557)/5.040141]^{2.176342}\} - \exp\{-[(D_U - 4.137557)/5.040141]^{2.176342}\} \quad (27)$$

and equation (26) becomes

$$CDF(D) = 1 - \exp\{-[(D - 4.137557)/5.040141]^{2.176342}\} \quad (28)$$

Since the a-parameter estimates the smallest diameter of the population, the smallest occupied 1-inch class in this sample is the 4-inch class with a lower limit equal to the a-parameter

Table 24.--Calculation of stand structure and estimated yield per acre (total volume, outside bark) for a Soil Group A plantation at age = 30 years, site index = feet, and stems per acre = 450

D.b.h. class	D_L	D_U	Class midpoint	Class frequency	Average height	Volume per tree	Volume per class
- - - - -	- - - - - *Inches*	- - - - -	- - - - -	*Number*	*Feet*	- - - - *Cubic*	*feet* - - -
4	4.137557	4.5	4.318779	1.46	46.53		
5	4.5	5.5	5.0	23.90	47.27	3.00	71.71
6	5.5	6.5	6.0	53.33	50.23	4.48	238.92
7	6.5	7.5	7.0	73.98	54.69	6.49	480.10
8	7.5	8.5	8.0	80.54	59.45	9.04	728.09
9	8.5	9.5	9.0	73.51	63.62	12.03	884.27
10	9.5	10.5	10.0	57.75	66.81	15.37	887.66
11	10.5	11.5	11.0	39.56	68.98	18.97	750.49
12	11.5	12.5	12.0	23.79	70.31	22.76	541.36
13	12.5	13.5	13.0	12.60	71.04	26.75	336.92
14	13.5	14.5	14.0	5.88	71.39	30.92	181.94
15	14.5	15.5	15.0	2.43	71.55	35.31	85.72
16	15.5	16.5	16.0	1.27	71.61	39.93	50.71
						Total estimated yield	5237.89

All calculated values in this table were obtained by using the computer program in Appendix II. Since the computer does not round intermediate results, computations with the table values will often produce results that differ slightly from those generated by the computer.

value and an upper limit of 4.5 inches. Diameter classes in the upper tail of the distribution containing less than 0.5 trees are not considered and their frequencies are included in the frequency for the largest class containing 0.5 trees or more before this inclusion.

Computation of the values shown in table 24 is illustrated below for the 8-inch d.b.h. class. The relative class frequency is obtained from equation (27) as

$$
\begin{aligned}
P(7.5,8.5) &= \exp\{-[(7.5 - 4.137557)/5.040141]^{2.176342}\} \\
&\quad - \exp\{-[(8.5 - 4.137557)/5.040141]^{2.176342}\} \\
&= 0.178980
\end{aligned}
$$

and the stems per acre value is calculated as

$$
\begin{aligned}
\text{stems per acre} &= 450(0.178980) \\
&= 80.54
\end{aligned}
$$

The average height for each class is calculated as the height associated with the midpoint d.b.h. value. For the 8-inch class from equation (28)

$$
\begin{aligned}
CDF(8.0) &= 1 - \exp\{-[(8.0 - 4.137557)/5.040141]^{2.176342}\} \\
&= 0.428989
\end{aligned}
$$

so that the estimated average height from equation (25) is obtained as

$$
\begin{aligned}
H &= 66.1012[0.6046 + 0.0449(66.1012/30) \\
&\quad + 0.7385\log_e(1.428989) \\
&\quad - 0.0862(66.1012/30)\log_e(1.428989)] \\
&= 59.45 \text{ feet}
\end{aligned}
$$

The per tree volume is calculated using equation (1) as

$$
\begin{aligned}
TV_o &= 0.00395569(8.0)^{1.8945}(59.45)^{0.9288} \\
&= 9.04 \text{ cubic feet}
\end{aligned}
$$

Multiplication of this per tree volume by the class frequency of 80.54 gives the volume per class for the 8-inch class; i.e., 728.09 cubic feet. Accumulation of the volume per class values over the occupied classes gives a total volume estimate of 5237.89 cubic feet per acre.

Tables 25 and 26 contain predicted stand structure and per acre volumetric yields by selected combinations of site index, age, and number of trees per acre for Soil Group A and Soil Group B plantations, respectively. Per tree volumes in the calculations involved were obtained by using equations (1), (2), (3), and (4). Per acre weight yields by combinations of site index, plantation age, and number of trees per acre for Soil Groups A and B are shown in tables 27 and 28. Equations (5), (6), (7), and (8) were used to calculate per tree weights in the computation of these tables. Soil Group A tables include predictions for site indices 50, 60, 70, and 80. For each age and site index combination, predictions are given for number of trees per acre from 300 up to a reasonable maximum number tabulated below:

	Site Index			
Age	50	60	70	80
10	800	800	800	800
15	800	800	800	800
20	800	600	600	600
25	600	500	500	500
30	500	400	400	300

Because of the limited amount of data available for Soil Group B plantations, predictions are given only for site indices 60, 70, and 80 at the selected combinations of age and numbers of trees per acre tabulated below:

	Site Index		
Age	60	70	80
10	500	600	700
15	500	600	700
20	500	600	700

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)

SITE INDEX 50   AGE 10   STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	6	0.1	18	--	--	--	--	--	--	--	--
3	28	1.4	19	--	--	--	--	--	--	--	--
4	64	5.6	20	--	--	--	--	--	--	--	--
5	90	12.3	23	139	96	134	93	93	62	--	--
6	74	14.5	25	175	124	172	122	142	99	47	25
7	31	8.3	27	103	74	102	73	91	65	56	38
8	6	2.1	27	26	19	26	19	24	17	18	13
	300	44.3	--	443	313	434	307	350	243	122	76

SITE INDEX 50   AGE 10   STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	18	--	--	--	--	--	--	--	--
2	14	0.3	18	--	--	--	--	--	--	--	--
3	54	2.7	19	--	--	--	--	--	--	--	--
4	111	9.7	21	--	--	--	--	--	--	--	--
5	127	17.3	24	204	143	198	138	137	91	--	--
6	73	14.4	26	179	128	176	125	146	102	49	25
7	18	4.8	27	60	43	59	43	53	38	33	22
8	1	0.5	27	6	5	6	5	6	4	4	3
	400	49.7	--	450	319	439	311	341	236	86	51

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	2	0.0	18	--	--	--	--	--	--	--	--
2	26	0.6	18	--	--	--	--	--	--	--	--
3	95	4.7	19	--	--	--	--	--	--	--	--
4	168	14.7	22	--	--	--	--	--	--	--	--
5	148	20.1	25	247	174	239	168	165	111	--	--
6	54	10.6	27	135	96	132	95	109	77	36	19
7	7	1.8	27	22	16	22	16	20	14	12	8
	500	52.5	--	404	286	393	279	294	203	49	27

SITE INDEX 50 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	4	0.0	18	--	--	--	--	--	--	--	--
2	47	1.0	18	--	--	--	--	--	--	--	--
3	153	7.5	20	--	--	--	--	--	--	--	--
4	226	19.7	23	--	--	--	--	--	--	--	--
5	140	19.1	26	241	171	233	165	162	109	--	--
6	29	5.6	27	72	51	70	50	58	41	19	10
7	1	0.4	27	5	3	4	3	4	3	2	2
	600	53.3	--	317	225	308	219	224	153	22	12

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	8	0.0	18	--	--	--	--	--	--	--	--
2	79	1.7	18	--	--	--	--	--	--	--	--
3	230	11.3	21	--	--	--	--	--	--	--	--
4	267	23.3	25	--	--	--	--	--	--	--	--
5	106	14.4	27	185	132	179	127	124	84	--	--
6	10	2.0	27	25	18	25	18	21	15	7	4
	700	52.8	--	211	150	204	145	145	99	7	4

SITE INDEX 50 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	14	0.1	18	--	--	--	--	--	--	--	--
2	128	2.8	19	--	--	--	--	--	--	--	--
3	321	15.8	22	--	--	--	--	--	--	--	--
4	274	23.9	25	--	--	--	--	--	--	--	--
5	60	8.2	27	107	76	104	74	72	49	--	--
6	2	0.4	27	5	4	5	4	4	3	1	1
	800	51.2	--	112	80	109	78	76	52	1	1

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	25	--	--	--	--	--	--	--	--
3	11	0.6	25	--	--	--	--	--	--	--	--
4	35	3.1	26	--	--	--	--	--	--	--	--
5	64	8.7	29	121	88	117	85	81	56	--	--
6	78	15.4	32	233	172	228	169	189	138	63	34
7	64	17.2	35	277	209	274	207	245	184	152	107
8	34	11.7	37	195	149	194	148	180	138	137	102
9	10	4.6	38	77	60	77	59	73	56	61	47
10	2	1.1	38	18	14	17	13	17	13	15	11
	300	62.3	--	920	692	907	682	785	585	428	302

SITE INDEX 50 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	3	0.1	25	--	--	--	--	--	--	--	--
3	22	1.1	25	--	--	--	--	--	--	--	--
4	60	5.3	27	--	--	--	--	--	--	--	--
5	100	13.7	30	197	143	190	138	132	92	--	--
6	107	21.0	34	330	246	324	242	268	197	89	49
7	72	19.3	36	319	242	315	239	282	213	175	124
8	29	10.0	37	168	129	167	128	155	119	118	88
9	6	2.7	38	45	35	45	35	43	33	36	27
10	1	0.4	38	6	5	6	5	6	4	5	4
	400	73.5	--	1064	799	1047	786	885	657	423	292

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	6	0.1	25	--	--	--	--	--	--	--	--
3	37	1.8	25	--	--	--	--	--	--	--	--
4	94	8.2	28	--	--	--	--	--	--	--	--
5	141	19.2	31	287	210	277	203	192	134	--	--
6	130	25.5	35	411	308	403	303	334	247	111	61
7	70	18.6	37	312	238	309	235	276	209	171	122
8	20	7.0	38	118	90	117	90	109	83	83	62
9	3	1.3	38	21	16	21	16	20	16	17	13
	500	81.7	--	1149	863	1127	847	931	689	382	258

SITE INDEX 50 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	10	0.2	25	--	--	--	--	--	--	--	--
3	58	2.9	26	--	--	--	--	--	--	--	--
4	137	12.0	28	--	--	--	--	--	--	--	--
5	183	25.0	32	385	284	372	274	258	181	--	--
6	141	27.7	36	458	346	450	339	373	277	124	69
7	58	15.5	37	263	201	260	199	233	177	144	103
8	11	4.0	38	67	51	66	51	62	47	47	35
9	1	0.4	38	7	5	7	5	7	5	5	4
	600	87.6	--	1180	887	1156	868	931	687	321	211

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	16	0.4	25	--	--	--	--	--	--	--	--
3	87	4.3	26	--	--	--	--	--	--	--	--
4	189	16.5	29	--	--	--	--	--	--	--	--
5	222	30.3	33	480	356	465	344	322	228	--	--
6	139	27.3	36	459	348	451	341	373	278	124	69
7	42	11.1	37	190	145	188	143	168	128	104	75
8	5	1.9	38	32	24	31	24	29	22	22	17
	700	91.6	--	1161	873	1135	853	892	656	251	160

SITE INDEX 50 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	26	0.6	25	--	--	--	--	--	--	--	--
3	125	6.1	26	--	--	--	--	--	--	--	--
4	248	21.7	30	--	--	--	--	--	--	--	--
5	251	34.2	34	558	416	540	402	374	266	--	--
6	123	24.1	37	412	313	404	307	335	250	111	62
7	25	6.7	38	116	88	114	87	102	78	63	45
8	2	0.6	38	11	8	11	8	10	8	8	6
	800	94.0	--	1096	825	1069	805	821	602	183	113

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	3	0.2	30	--	--	--	--	--	--	--	--
4	19	1.6	31	--	--	--	--	--	--	--	--
5	43	5.8	33	92	69	89	66	62	44	--	--
6	64	12.5	37	214	162	210	159	174	130	58	32
7	69	18.3	41	339	263	335	260	300	231	186	135
8	55	19.0	44	371	293	368	291	342	270	260	200
9	31	13.9	46	278	222	277	221	264	210	221	174
10	13	7.0	47	142	114	141	113	136	109	121	96
11	4	2.4	47	48	39	48	39	47	38	43	34
12	1	0.6	47	12	10	12	10	12	10	11	9
	300	81.4	--	1496	1171	1480	1159	1336	1042	899	682

SITE INDEX 50 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	7	0.3	30	--	--	--	--	--	--	--	--
4	33	2.8	31	--	--	--	--	--	--	--	--
5	68	9.3	34	151	113	146	109	101	72	--	--
6	94	18.4	38	325	248	319	243	264	198	88	49
7	91	24.4	42	463	361	458	357	409	318	254	186
8	64	22.2	45	440	349	437	346	406	321	309	239
9	31	13.7	46	276	221	275	220	261	209	219	173
10	10	5.6	47	113	91	112	90	108	87	96	77
11	3	1.7	47	33	27	33	27	33	26	30	24
	400	98.3	--	1801	1409	1780	1393	1583	1232	996	747

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	13	0.6	31	--	--	--	--	--	--	--	--
4	51	4.5	32	--	--	--	--	--	--	--	--
5	99	13.5	35	225	169	218	163	151	108	--	--
6	125	24.6	39	447	343	439	337	363	275	121	68
7	110	29.4	43	570	447	564	442	504	393	313	230
8	66	23.2	45	466	371	463	368	431	342	327	254
9	27	11.8	46	241	193	240	192	228	183	191	151
10	7	3.8	47	77	62	77	62	74	60	66	53
11	1	0.8	47	16	13	16	13	16	13	15	12
	500	112.3	--	2043	1598	2016	1577	1767	1372	1033	767

SITE INDEX 50 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	30	--	--	--	--	--	--	--	--
3	21	1.0	31	--	--	--	--	--	--	--	--
4	75	6.5	32	--	--	--	--	--	--	--	--
5	135	18.4	36	314	236	304	228	211	151	--	--
6	157	30.9	40	574	443	564	435	467	355	155	88
7	123	32.8	44	649	511	642	505	574	449	356	262
8	63	22.1	46	450	358	446	356	415	330	316	245
9	21	9.2	47	188	151	187	150	178	142	149	118
10	4	2.3	47	46	37	46	37	44	36	39	31
11	1	0.3	47	7	5	7	5	7	5	6	5
	600	123.6	--	2228	1742	2196	1716	1895	1469	1022	750

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	30	--	--	--	--	--	--	--	--
3	31	1.5	31	--	--	--	--	--	--	--	--
4	104	9.1	33	--	--	--	--	--	--	--	--
5	176	24.0	37	418	316	405	305	280	202	--	--
6	187	36.7	41	698	541	685	531	568	433	189	107
7	128	34.3	45	689	544	682	538	610	478	378	280
8	56	19.4	46	398	317	395	315	367	292	279	217
9	14	6.4	47	131	105	130	105	124	99	104	82
10	2	1.3	47	26	21	26	21	25	20	22	18
	700	132.6	--	2360	1845	2323	1815	1974	1526	972	704

SITE INDEX 50 AGE 20 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.1	30	--	--	--	--	--	--	--	--
3	45	2.2	31	--	--	--	--	--	--	--	--
4	140	12.2	33	--	--	--	--	--	--	--	--
5	220	30.0	38	536	406	518	393	359	260	--	--
6	211	41.5	42	808	629	793	617	657	504	219	125
7	126	33.7	45	686	543	678	537	607	477	377	279
8	45	15.7	47	323	258	320	256	298	237	227	176
9	9	4.0	47	82	66	81	65	77	62	65	51
10	1	0.6	47	11	9	11	9	11	9	10	8
	800	139.9	--	2445	1911	2403	1877	2009	1549	896	639

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	7	0.6	35	--	--	--	--	--	--	--	--
5	27	3.7	36	64	48	62	47	43	31	--	--
6	49	9.6	40	177	136	173	133	144	109	48	27
7	62	16.5	44	327	257	323	254	289	226	179	132
8	60	20.9	48	442	355	439	352	408	327	310	243
9	46	20.3	51	448	365	446	363	424	345	356	286
10	28	15.3	53	346	284	344	283	332	273	294	241
11	14	9.0	54	204	169	204	169	198	164	182	150
12	5	4.1	54	93	77	93	77	91	76	85	71
13	2	1.8	54	42	35	42	35	41	34	39	32
	300	101.8	--	2142	1726	2125	1713	1971	1585	1493	1181

SITE INDEX 50 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	14	1.2	35	--	--	--	--	--	--	--	--
5	45	6.1	37	108	81	104	79	72	52	--	--
6	74	14.6	41	274	212	269	208	223	170	74	42
7	87	23.2	45	472	373	467	369	417	328	259	192
8	78	27.1	49	586	473	582	469	541	435	412	323
9	54	23.9	52	537	438	534	436	508	415	426	344
10	29	16.1	53	367	302	366	301	353	291	313	256
11	13	8.3	54	189	156	188	156	184	152	168	139
12	4	3.2	54	73	61	73	61	72	60	67	56
13	1	1.2	54	26	22	26	22	26	21	24	20
	400	124.9	--	2632	2119	2609	2101	2396	1924	1743	1372

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.1	35	--	--	--	--	--	--	--	--
4	24	2.1	35	--	--	--	--	--	--	--	--
5	67	9.1	38	162	123	156	118	108	78	--	--
6	103	20.2	42	387	301	380	295	315	241	105	60
7	112	30.0	46	624	496	617	490	551	436	342	254
8	92	32.3	50	711	575	706	571	657	530	499	394
9	58	25.8	52	587	480	584	478	556	455	466	377
10	28	15.4	54	355	292	353	291	341	281	302	248
11	10	6.9	54	158	131	158	130	153	127	140	116
12	3	2.3	54	52	43	52	43	51	42	47	39
13	1	0.6	54	15	12	15	12	14	12	14	11
	500	144.8	--	3050	2453	3020	2430	2747	2202	1916	1499

SITE INDEX 50 AGE 25 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	2	0.1	35	--	--	--	--	--	--	--	--
4	37	3.2	35	--	--	--	--	--	--	--	--
5	93	12.6	38	228	173	220	167	153	111	--	--
6	134	26.3	43	516	402	506	395	419	322	140	80
7	137	36.5	47	775	618	766	611	685	544	425	318
8	104	36.2	51	809	656	803	652	747	605	568	449
9	59	26.1	53	598	491	595	488	567	464	475	385
10	25	13.8	54	317	262	316	261	305	252	270	222
11	8	5.3	54	121	100	121	100	118	98	108	89
12	2	1.7	54	40	33	39	33	39	32	36	30
	600	161.7	--	3404	2736	3367	2707	3033	2427	2022	1572

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
5	13	1.8	38	33	25	32	24	22	16	--	--
6	36	7.2	41	135	105	133	103	110	84	37	21
7	53	14.2	45	289	229	286	226	256	201	159	117
8	58	20.2	50	445	359	441	357	411	331	312	246
9	52	22.8	54	531	437	528	434	503	413	421	342
10	39	21.1	57	510	424	508	423	490	408	434	359
11	25	16.3	58	402	338	401	337	391	328	358	300
12	14	10.7	59	265	224	264	223	259	219	243	205
13	6	5.9	60	147	125	147	125	145	123	138	117
14	3	2.8	60	70	59	70	59	69	59	66	56
15	1	1.6	60	40	34	40	34	39	34	38	33
	300	124.7	--	2866	2359	2850	2345	2694	2216	2205	1796

SITE INDEX 50 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	1	0.1	38	--	--	--	--	--	--	--	--
5	25	3.4	39	62	47	60	45	41	30	--	--
6	57	11.2	42	215	167	211	164	175	134	58	33
7	77	20.5	46	428	341	424	337	379	300	235	175
8	79	27.5	51	618	502	614	499	571	463	434	344
9	66	29.1	55	690	569	686	566	653	539	547	446
10	46	25.1	57	614	513	612	511	591	493	523	434
11	27	18.0	59	446	376	445	375	434	365	397	333
12	14	10.8	60	269	227	268	227	263	223	246	208
13	6	5.5	60	136	115	135	115	133	113	127	108
14	2	2.3	60	58	49	58	49	57	48	55	47
15	1	1.1	60	28	24	28	24	28	24	27	23
	400	154.5	--	3564	2930	3540	2911	3325	2731	2649	2151

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 50 AGE 30 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	3	0.3	38	--	--	--	--	--	--	--	--
5	39	5.3	39	98	75	95	73	66	48	--	--
6	80	15.8	43	310	241	304	237	252	193	84	48
7	102	27.3	48	582	465	575	460	515	409	319	239
8	99	34.5	52	792	646	786	641	732	595	556	442
9	78	34.4	56	827	685	823	681	783	648	656	537
10	51	27.7	58	684	572	682	570	658	551	583	485
11	28	18.4	59	458	386	457	385	445	375	408	343
12	13	10.1	60	252	213	252	213	247	209	231	195
13	5	4.6	60	115	98	115	98	113	96	108	91
14	2	1.8	60	44	37	44	37	43	37	42	35
15	1	0.7	60	18	15	18	15	18	15	17	15
	500	180.8	--	4181	3434	4151	3410	3872	3176	3003	2430

SITE INDEX 60 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	3	0.1	24	--	--	--	--	--	--	--	--
3	16	0.8	24	--	--	--	--	--	--	--	--
4	39	3.4	25	--	--	--	--	--	--	--	--
5	67	9.1	28	122	87	118	84	81	56	--	--
6	78	15.4	30	219	160	215	157	178	128	59	32
7	60	16.1	32	241	179	238	177	213	158	132	92
8	28	9.8	34	149	112	148	111	137	103	104	77
9	7	3.1	34	47	35	47	35	44	34	37	28
10	1	0.5	34	7	5	7	5	7	5	6	5
	300	58.2	--	784	579	772	571	661	483	339	233

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	7	0.2	24	--	--	--	--	--	--	--	--
3	29	1.4	24	--	--	--	--	--	--	--	--
4	68	6.0	26	--	--	--	--	--	--	--	--
5	105	14.3	29	197	142	191	137	132	91	--	--
6	104	20.5	31	301	222	296	218	245	178	82	44
7	62	16.7	33	254	190	251	188	225	167	139	98
8	20	7.0	34	107	80	106	80	99	74	75	55
9	3	1.4	34	21	16	21	16	20	15	17	12
	400	67.4	--	880	650	864	639	720	525	312	209

SITE INDEX 60 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	24	--	--	--	--	--	--	--	--
2	13	0.3	24	--	--	--	--	--	--	--	--
3	49	2.4	25	--	--	--	--	--	--	--	--
4	108	9.4	27	--	--	--	--	--	--	--	--
5	146	19.9	30	284	206	275	199	190	132	--	--
6	119	23.4	32	354	262	347	257	287	210	96	52
7	52	14.0	34	216	162	213	160	191	142	118	83
8	11	3.7	34	57	43	56	42	52	39	40	29
9	1	0.4	34	6	4	5	4	5	4	4	3
	500	73.5	--	915	676	897	663	726	527	258	167

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	2	0.0	24	--	--	--	--	--	--	--	--
2	21	0.5	24	--	--	--	--	--	--	--	--
3	78	3.9	25	--	--	--	--	--	--	--	--
4	157	13.7	27	--	--	--	--	--	--	--	--
5	184	25.1	31	369	269	357	260	247	172	--	--
6	118	23.1	33	356	265	350	260	290	212	96	53
7	35	9.4	34	146	110	144	108	129	96	80	56
8	4	1.4	34	22	17	22	17	20	15	16	11
	600	77.1	--	893	661	873	645	686	496	192	120

SITE INDEX 60 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	3	0.0	24	--	--	--	--	--	--	--	--
2	34	0.8	24	--	--	--	--	--	--	--	--
3	118	5.8	25	--	--	--	--	--	--	--	--
4	214	18.7	28	--	--	--	--	--	--	--	--
5	211	28.7	32	434	318	420	308	291	204	--	--
6	99	19.5	33	305	227	299	223	248	182	83	45
7	18	4.9	34	77	58	76	57	68	51	42	30
8	1	0.4	34	6	4	6	4	5	4	4	3
	700	78.8	--	821	608	801	592	612	440	129	78

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	5	0.0	24	--	--	--	--	--	--	--	--
2	53	1.2	24	--	--	--	--	--	--	--	--
3	171	8.4	26	--	--	--	--	--	--	--	--
4	275	24.0	29	--	--	--	--	--	--	--	--
5	217	29.6	32	457	337	443	326	306	216	--	--
6	70	13.8	34	218	163	214	160	177	130	59	32
7	7	2.0	34	31	23	30	23	27	20	17	12
	800	79.0	--	706	523	687	508	510	366	76	44

SITE INDEX 60 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	31	--	--	--	--	--	--	--	--
3	7	0.4	32	--	--	--	--	--	--	--	--
4	23	2.0	33	--	--	--	--	--	--	--	--
5	46	6.3	35	103	77	100	75	69	49	--	--
6	65	12.7	38	224	171	219	167	182	137	61	34
7	68	18.1	41	338	263	334	260	298	231	185	135
8	51	17.9	44	348	275	345	273	321	253	244	188
9	27	11.9	45	236	188	235	187	224	178	188	148
10	9	5.1	46	102	82	102	81	98	79	87	69
11	2	1.5	46	30	24	30	24	29	24	27	22
	300	76.0	--	1381	1079	1365	1067	1222	950	791	595

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	31	--	--	--	--	--	--	--	--
3	14	0.7	32	--	--	--	--	--	--	--	--
4	40	3.5	33	--	--	--	--	--	--	--	--
5	73	9.9	36	168	126	162	122	112	80	--	--
6	95	18.6	39	336	258	330	253	273	206	91	51
7	88	23.6	42	451	353	446	349	399	310	247	181
8	57	19.9	44	394	312	391	310	364	287	277	213
9	24	10.7	46	215	171	213	170	203	162	170	134
10	6	3.5	46	70	56	69	56	67	54	59	47
11	1	0.7	46	14	11	14	11	13	11	12	10
	400	91.2	--	1646	1286	1625	1270	1431	1110	857	637

SITE INDEX 60 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	3	0.1	31	--	--	--	--	--	--	--	--
3	23	1.1	32	--	--	--	--	--	--	--	--
4	61	5.3	33	--	--	--	--	--	--	--	--
5	105	14.4	36	248	187	240	180	166	119	--	--
6	126	24.7	40	456	352	448	345	371	281	123	70
7	103	27.6	43	538	422	532	418	476	371	295	217
8	56	19.5	45	391	310	388	308	361	286	274	212
9	19	8.3	46	166	133	165	132	158	126	132	104
10	4	2.2	46	43	35	43	35	42	33	37	29
	500	103.2	--	1842	1438	1816	1418	1573	1217	862	632

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	6	0.1	31	--	--	--	--	--	--	--	--
3	35	1.7	32	--	--	--	--	--	--	--	--
4	89	7.7	34	--	--	--	--	--	--	--	--
5	143	19.5	37	343	260	332	251	230	166	--	--
6	155	30.4	41	575	445	564	437	467	356	156	88
7	110	29.5	44	585	461	579	456	517	405	321	237
8	49	17.1	45	345	274	342	272	318	253	242	188
9	13	5.5	46	111	89	110	88	105	84	88	70
10	2	1.0	46	19	16	19	16	19	15	17	13
	600	112.5	--	1979	1544	1947	1520	1657	1279	823	595

SITE INDEX 60 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	9	0.2	31	--	--	--	--	--	--	--	--
3	51	2.5	32	--	--	--	--	--	--	--	--
4	122	10.7	34	--	--	--	--	--	--	--	--
5	184	25.1	38	452	344	438	333	303	220	--	--
6	179	35.1	42	679	528	667	519	552	423	184	105
7	109	29.1	45	584	461	578	456	517	405	321	237
8	38	13.4	46	272	216	270	215	251	199	191	148
9	7	3.2	46	64	51	63	51	60	48	51	40
10	1	0.4	46	7	6	7	6	7	6	6	5
	700	119.6	--	2058	1606	2022	1578	1690	1301	752	534

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	14	0.3	31	--	--	--	--	--	--	--	--
3	71	3.5	32	--	--	--	--	--	--	--	--
4	163	14.3	35	--	--	--	--	--	--	--	--
5	227	30.9	39	571	436	553	422	383	279	--	--
6	195	38.3	43	756	590	742	579	614	472	205	117
7	99	26.4	45	536	424	530	419	474	373	294	218
8	27	9.3	46	190	151	189	150	176	139	133	104
9	4	1.6	46	33	26	33	26	31	25	26	21
	800	124.7	--	2085	1627	2046	1596	1677	1288	658	459

SITE INDEX 60 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	2	0.1	38	--	--	--	--	--	--	--	--
4	13	1.2	38	--	--	--	--	--	--	--	--
5	31	4.3	40	81	62	78	60	54	40	--	--
6	50	9.8	43	196	153	192	150	159	123	53	30
7	61	16.3	47	345	276	342	273	305	242	190	142
8	58	20.3	51	454	369	451	366	420	340	319	252
9	43	19.2	54	445	366	443	364	422	347	353	287
10	25	13.7	55	324	268	322	267	311	258	276	227
11	11	7.3	56	173	144	172	144	168	140	154	128
12	4	2.8	56	67	56	67	56	65	55	61	51
13	1	0.9	56	22	18	22	18	22	18	20	17
	300	95.9	--	2107	1712	2089	1698	1926	1562	1426	1135

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top--					
						2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	5	0.2	38	--	--	--	--	--	--	--	--
4	23	2.0	39	--	--	--	--	--	--	--	--
5	50	6.8	41	131	100	126	97	87	64	--	--
6	75	14.7	44	300	235	294	231	244	188	81	47
7	85	22.8	48	494	396	489	392	437	348	271	203
8	75	26.0	52	595	484	590	481	549	446	417	331
9	50	22.1	54	521	429	518	427	493	406	413	337
10	25	13.8	56	329	273	328	272	317	263	280	231
11	9	6.3	56	149	124	148	124	144	120	132	110
12	3	2.0	56	47	39	47	39	46	39	43	36
13	1	0.5	56	12	10	12	10	12	10	11	9
	400	117.2	--	2576	2092	2552	2073	2329	1885	1649	1305

SITE INDEX 60 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top--					
						2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	8	0.4	38	--	--	--	--	--	--	--	--
4	35	3.1	39	--	--	--	--	--	--	--	--
5	72	9.9	42	192	148	186	144	129	95	--	--
6	103	20.2	45	420	331	412	325	341	265	114	66
7	109	29.1	50	646	520	639	514	571	457	354	267
8	88	30.5	53	709	579	704	575	655	534	498	396
9	53	23.2	55	551	455	549	453	522	431	438	357
10	23	12.6	56	301	250	300	249	290	241	256	212
11	7	4.8	56	114	95	113	95	111	92	101	84
12	2	1.4	56	34	28	34	28	33	28	31	26
	500	135.2	--	2967	2408	2936	2383	2651	2142	1792	1408

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	13	0.7	38	--	--	--	--	--	--	--	--
4	51	4.4	39	--	--	--	--	--	--	--	--
5	99	13.5	42	267	207	258	200	179	132	--	--
6	133	26.1	46	554	438	543	430	450	351	150	87
7	131	35.1	51	793	640	784	633	701	563	435	329
8	96	33.5	54	789	646	783	642	728	595	554	442
9	51	22.6	55	540	447	538	445	512	423	429	351
10	19	10.5	56	252	210	251	209	242	202	215	177
11	5	3.3	56	79	66	78	65	76	64	70	58
12	1	0.8	56	18	15	18	15	17	15	16	14
	600	150.4	--	3291	2669	3253	2639	2906	2344	1868	1458

SITE INDEX 60 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	5	0.5	43	--	--	--	--	--	--	--	--
5	21	2.8	44	58	45	56	44	39	29	--	--
6	38	7.5	47	162	128	159	126	131	103	44	25
7	52	13.8	51	315	255	312	252	279	224	173	131
8	56	19.5	55	471	388	467	385	435	357	330	265
9	50	21.9	59	555	464	552	462	525	439	440	364
10	37	20.0	62	523	443	521	441	503	426	446	375
11	23	15.0	63	398	339	397	339	387	330	354	301
12	12	9.2	64	246	211	245	210	240	206	225	193
13	5	4.6	65	123	106	123	106	121	104	115	99
14	2	1.9	65	50	43	50	43	50	43	48	41
15	1	0.8	65	21	18	21	18	21	18	20	18
	300	117.6	--	2922	2440	2904	2425	2732	2279	2196	1812

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	10	0.9	43	--	--	--	--	--	--	--	--
5	34	4.6	45	95	75	92	72	64	48	--	--
6	58	11.4	48	250	199	245	195	203	159	68	39
7	74	19.8	52	462	375	456	371	408	330	253	193
8	75	26.3	56	650	538	645	534	600	495	456	368
9	63	27.8	60	715	600	711	597	677	568	567	470
10	43	23.5	62	622	527	620	525	598	507	530	446
11	24	16.2	64	431	368	430	367	419	358	384	327
12	11	9.0	64	240	205	239	205	235	201	220	188
13	4	4.0	65	107	92	107	92	105	90	100	86
14	2	1.9	65	50	43	50	43	49	42	47	41
	400	145.4	--	3621	3021	3595	3000	3358	2798	2624	2158

SITE INDEX 60 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.0	43	--	--	--	--	--	--	--	--
4	17	1.5	43	--	--	--	--	--	--	--	--
5	49	6.7	45	142	111	137	107	95	71	--	--
6	81	15.9	49	352	282	346	276	287	225	95	56
7	98	26.2	53	621	507	614	501	549	445	341	260
8	94	32.9	58	827	686	820	681	763	632	580	469
9	74	32.5	61	849	714	844	710	804	676	674	560
10	47	25.6	63	681	578	679	576	655	556	580	490
11	24	16.0	64	430	367	429	366	418	357	383	326
12	10	8.0	65	215	184	214	184	210	180	197	168
13	3	3.2	65	85	73	84	73	83	72	79	68
14	1	1.2	65	33	28	33	28	33	28	31	27
	500	169.8	--	4234	3530	4201	3503	3897	3243	2960	2425

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 60 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top--					
						2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
5	10	1.4	47	30	24	29	23	20	15	--	--
6	29	5.6	49	126	100	123	99	102	80	34	20
7	44	11.6	53	275	224	272	221	243	197	151	115
8	51	17.8	58	447	371	444	368	413	342	314	254
9	50	22.0	62	584	493	581	491	553	467	464	387
10	42	23.0	65	635	543	632	541	611	522	540	460
11	31	20.6	68	585	505	583	504	568	491	520	448
12	21	16.1	70	463	403	462	402	453	394	424	369
13	12	11.0	71	319	279	318	278	314	274	298	260
14	6	6.7	71	192	168	192	168	190	166	182	160
15	3	3.5	71	102	90	102	89	101	89	98	86
16	1	1.7	72	48	42	48	42	47	42	46	41
17	1	1.0	72	29	25	29	25	29	25	28	25
	300	142.1	--	3834	3267	3815	3251	3643	3104	3099	2623

SITE INDEX 60 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top--					
						2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	1	0.1	47	--	--	--	--	--	--	--	--
5	19	2.6	47	56	44	54	43	38	28	--	--
6	44	8.7	50	198	159	194	156	161	127	54	32
7	63	16.9	54	408	334	403	330	361	293	224	171
8	71	24.6	59	632	527	627	523	584	485	444	360
9	66	29.1	63	786	666	782	662	744	630	624	522
10	53	28.9	66	809	694	806	691	779	667	689	588
11	37	24.6	69	704	609	702	607	684	592	626	540
12	23	18.1	70	524	456	523	455	512	446	480	417
13	13	11.6	71	337	295	336	294	331	290	315	275
14	6	6.5	71	189	166	189	165	186	163	179	157
15	3	3.2	72	93	81	92	81	92	80	89	78
16	1	2.0	72	59	52	59	52	58	51	57	50
	400	177.1	--	4794	4081	4768	4060	4529	3854	3779	3191

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	30	--	--	--	--	--	--	--	--
3	10	0.5	31	--	--	--	--	--	--	--	--
4	27	2.4	32	--	--	--	--	--	--	--	--
5	50	6.8	33	109	81	105	78	73	52	--	--
6	68	13.4	36	223	169	219	166	182	135	60	33
7	68	18.1	38	316	242	312	239	279	213	173	124
8	47	16.3	40	291	226	289	225	269	209	205	155
9	21	9.1	41	165	129	164	128	156	122	131	101
10	5	2.9	41	53	42	53	42	51	40	45	35
11	1	0.5	41	9	7	9	7	9	7	8	7
	300	70.2	--	1167	896	1152	885	1019	778	623	456

SITE INDEX 70 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	4	0.1	30	--	--	--	--	--	--	--	--
3	19	0.9	31	--	--	--	--	--	--	--	--
4	47	4.1	32	--	--	--	--	--	--	--	--
5	80	10.9	34	178	132	172	128	119	85	--	--
6	99	19.4	37	332	252	326	247	270	202	90	50
7	85	22.7	39	404	311	399	308	357	273	221	160
8	47	16.5	41	299	233	296	231	276	214	210	159
9	15	6.8	41	124	97	123	97	118	92	98	76
10	3	1.6	41	29	22	28	22	27	22	24	19
	400	83.1	--	1364	1047	1345	1033	1166	888	644	464

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 500

	Stems			Total vol.		Merchantable volume to top--					
	per	Basal	Avg.	(ft³)		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.								
(in)	(no.)	(ft²)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	30	--	--	--	--	--	--	--	--
2	8	0.2	30	--	--	--	--	--	--	--	--
3	31	1.5	31	--	--	--	--	--	--	--	--
4	73	6.3	32	--	--	--	--	--	--	--	--
5	116	15.9	35	263	197	254	190	176	126	--	--
6	129	25.2	38	441	336	433	330	358	269	119	67
7	93	24.8	40	449	347	444	343	397	305	246	178
8	40	14.0	41	256	200	254	198	237	184	180	137
9	9	4.1	41	74	58	74	58	70	55	59	46
10	1	0.6	41	10	8	10	8	10	8	9	7
	500	92.6	--	1493	1146	1469	1127	1248	947	613	434

SITE INDEX 70 AGE 10 STEMS/ACRE 600

	Stems			Total vol.		Merchantable volume to top--					
	per	Basal	Avg.	(ft³)		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.								
(in)	(no.)	(ft²)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	30	--	--	--	--	--	--	--	--
2	13	0.3	31	--	--	--	--	--	--	--	--
3	48	2.3	31	--	--	--	--	--	--	--	--
4	106	9.3	33	--	--	--	--	--	--	--	--
5	157	21.4	36	363	272	351	263	243	174	--	--
6	152	29.9	39	533	408	524	401	434	327	144	81
7	90	24.0	40	440	341	435	338	389	300	242	175
8	29	10.1	41	185	144	183	143	171	133	130	99
9	5	2.0	41	37	29	37	29	35	27	29	23
	600	99.3	--	1558	1195	1530	1173	1272	961	545	378

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	2	0.0	30	--	--	--	--	--	--	--	--
2	19	0.4	31	--	--	--	--	--	--	--	--
3	70	3.4	31	--	--	--	--	--	--	--	--
4	148	12.9	34	--	--	--	--	--	--	--	--
5	199	27.2	37	470	355	455	343	315	227	--	--
6	166	32.6	39	591	454	580	446	481	363	160	90
7	77	20.6	41	380	295	376	292	336	259	209	152
8	17	6.0	41	111	87	110	86	102	80	78	59
9	2	0.7	41	13	10	13	10	12	10	10	8
	700	103.8	--	1566	1201	1534	1177	1247	939	457	309

SITE INDEX 70 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	3	0.0	30	--	--	--	--	--	--	--	--
2	29	0.6	31	--	--	--	--	--	--	--	--
3	100	4.9	32	--	--	--	--	--	--	--	--
4	197	17.2	34	--	--	--	--	--	--	--	--
5	239	32.6	37	576	436	558	422	386	279	--	--
6	166	32.5	40	599	461	588	453	487	369	162	91
7	58	15.4	41	286	222	283	220	253	195	157	114
8	9	3.1	41	57	44	56	44	53	41	40	30
	800	106.3	--	1518	1164	1485	1139	1178	885	359	236

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	39	--	--	--	--	--	--	--	--
3	5	0.3	39	--	--	--	--	--	--	--	--
4	17	1.5	40	--	--	--	--	--	--	--	--
5	36	4.9	41	94	73	91	70	63	46	--	--
6	54	10.6	44	214	168	210	165	174	135	58	33
7	63	16.9	48	360	287	356	284	318	253	198	148
8	57	20.0	50	444	360	440	357	410	331	312	246
9	39	17.2	53	393	322	391	320	372	304	312	252
10	19	10.5	54	242	200	242	199	233	192	206	169
11	7	4.4	54	101	84	101	84	98	81	90	74
12	2	1.4	54	32	26	32	26	31	26	29	24
	300	87.6	--	1881	1520	1863	1506	1700	1370	1204	948

SITE INDEX 70 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	39	--	--	--	--	--	--	--	--
3	10	0.5	39	--	--	--	--	--	--	--	--
4	29	2.5	40	--	--	--	--	--	--	--	--
5	56	7.7	42	151	117	146	113	101	75	--	--
6	80	15.8	45	326	257	320	252	265	205	88	51
7	87	23.3	49	506	406	501	402	448	357	278	209
8	71	24.8	51	560	455	556	452	517	420	393	312
9	42	18.6	53	429	352	426	350	406	333	340	276
10	17	9.5	54	220	181	219	181	211	174	187	154
11	5	3.2	54	73	60	72	60	70	58	65	53
12	1	0.7	54	16	14	16	14	16	13	15	12
	400	106.5	--	2281	1842	2257	1823	2035	1636	1366	1067

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.1	39	--	--	--	--	--	--	--	--
3	16	0.8	39	--	--	--	--	--	--	--	--
4	44	3.9	40	--	--	--	--	--	--	--	--
5	81	11.1	43	222	172	215	166	149	110	--	--
6	109	21.5	46	453	358	444	351	368	287	123	71
7	109	29.2	50	648	521	641	516	573	458	356	268
8	80	27.8	52	637	519	632	516	588	479	447	355
9	41	17.9	54	416	342	414	341	394	324	331	269
10	14	7.5	54	174	144	174	143	168	138	148	122
11	3	2.2	54	51	42	50	42	49	41	45	37
	500	121.9	--	2601	2099	2570	2075	2289	1837	1449	1122

SITE INDEX 70 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	4	0.1	39	--	--	--	--	--	--	--	--
3	24	1.2	39	--	--	--	--	--	--	--	--
4	63	5.5	41	--	--	--	--	--	--	--	--
5	111	15.1	43	307	239	297	231	206	153	--	--
6	140	27.5	47	591	469	580	460	480	375	160	93
7	128	34.3	50	772	624	764	617	683	548	424	320
8	83	28.8	53	667	545	662	541	616	502	469	373
9	36	15.7	54	367	302	365	300	347	286	291	237
10	10	5.3	54	122	101	122	101	118	97	104	86
11	2	1.1	54	26	21	26	21	25	21	23	19
	600	134.6	--	2853	2301	2816	2272	2476	1983	1470	1128

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	6	0.1	39	--	--	--	--	--	--	--	--
3	34	1.7	39	--	--	--	--	--	--	--	--
4	87	7.6	41	--	--	--	--	--	--	--	--
5	145	19.8	44	408	318	395	308	273	204	--	--
6	171	33.6	48	734	585	721	574	597	468	199	116
7	142	37.9	51	868	703	858	695	767	617	476	361
8	80	27.8	53	649	531	644	527	599	489	456	363
9	28	12.6	54	294	242	292	241	278	229	233	190
10	6	3.3	54	76	63	76	63	74	61	65	54
11	1	0.5	54	11	9	11	9	11	9	10	8
	700	144.8	--	3041	2452	2998	2417	2600	2078	1439	1092

SITE INDEX 70 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	9	0.2	39	--	--	--	--	--	--	--	--
3	47	2.3	39	--	--	--	--	--	--	--	--
4	115	10.1	41	--	--	--	--	--	--	--	--
5	183	24.9	45	523	409	506	396	350	262	--	--
6	200	39.3	49	875	699	859	686	711	560	237	139
7	149	39.9	52	923	749	913	741	816	658	506	385
8	72	25.0	54	588	482	583	478	543	444	413	330
9	21	9.2	54	215	177	214	176	203	167	170	139
10	4	2.0	54	46	38	46	38	44	36	39	32
	800	152.8	--	3169	2554	3120	2515	2668	2128	1365	1024

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	2	0.1	46	--	--	--	--	--	--	--	--
4	10	0.9	46	--	--	--	--	--	--	--	--
5	25	3.4	48	75	60	73	58	50	38	--	--
6	41	8.1	51	187	150	183	147	152	120	50	30
7	54	14.3	54	346	283	342	280	306	249	190	145
8	56	19.6	58	498	414	494	411	460	382	350	284
9	48	21.3	61	560	472	557	470	531	447	445	370
10	33	18.2	64	491	418	489	416	472	402	418	354
11	19	12.3	65	333	285	332	284	324	277	296	253
12	8	6.4	66	174	149	173	149	170	146	159	137
13	3	2.5	66	69	59	69	59	68	58	64	55
14	1	0.9	66	25	22	25	22	25	21	24	20
	300	108.1	--	2758	2312	2738	2297	2557	2141	1996	1648

SITE INDEX 70 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	4	0.2	46	--	--	--	--	--	--	--	--
4	18	1.5	46	--	--	--	--	--	--	--	--
5	39	5.4	48	120	95	116	92	81	61	--	--
6	62	12.2	52	285	230	280	226	231	184	77	46
7	76	20.4	56	502	412	496	408	444	363	275	212
8	75	26.3	59	678	566	673	562	627	522	476	387
9	60	26.4	62	704	595	700	592	667	563	559	467
10	38	20.6	64	559	476	557	475	538	458	476	403
11	19	12.4	65	337	289	336	288	328	281	300	257
12	7	5.6	66	153	132	153	131	150	129	140	120
13	2	1.9	66	52	44	51	44	51	44	48	42
14	1	0.6	66	15	13	15	13	15	13	14	12
	400	133.3	--	3405	2853	3379	2831	3130	2617	2366	1946

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	6	0.3	46	--	--	--	--	--	--	--	--
4	27	2.3	47	--	--	--	--	--	--	--	--
5	57	7.7	49	175	140	170	135	118	89	--	--
6	86	16.8	52	399	323	392	317	324	258	108	64
7	100	26.7	57	670	552	662	546	592	485	368	283
8	93	32.4	60	849	710	842	705	784	655	596	486
9	68	30.1	63	812	687	808	684	769	650	644	539
10	39	21.3	65	583	497	580	495	560	478	496	421
11	17	11.4	65	311	267	310	266	302	259	277	237
12	6	4.5	66	122	105	122	105	119	103	112	96
13	2	1.5	66	42	36	41	36	41	35	39	33
	500	155.0	--	3962	3317	3928	3289	3610	3014	2639	2160

SITE INDEX 70 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	10	0.5	46	--	--	--	--	--	--	--	--
4	38	3.3	47	--	--	--	--	--	--	--	--
5	77	10.5	49	241	192	234	186	162	123	--	--
6	112	21.9	53	528	429	519	421	429	343	143	85
7	124	33.2	58	844	698	835	690	747	614	463	358
8	108	37.7	61	1001	840	994	834	925	774	703	575
9	73	32.3	64	879	745	874	742	832	705	697	585
10	38	20.6	65	567	484	565	482	545	466	483	410
11	15	9.7	66	266	228	265	228	258	222	237	203
12	4	3.3	66	89	77	89	77	88	75	82	70
13	1	0.9	66	24	21	24	21	24	21	23	20
	600	173.9	--	4441	3715	4399	3681	4010	3343	2831	2306

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	4	0.4	51	--	--	--	--	--	--	--	--
5	17	2.3	52	55	44	53	43	37	28	--	--
6	32	6.3	55	155	127	152	124	126	101	42	25
7	45	11.9	59	310	257	307	254	274	226	170	132
8	51	17.8	63	487	411	483	408	450	379	342	281
9	49	21.7	67	621	532	618	529	588	503	493	417
10	41	22.1	70	653	566	651	564	629	544	556	479
11	29	19.0	72	572	499	570	498	555	485	508	443
12	18	13.8	74	418	367	417	367	409	360	383	336
13	9	8.4	75	256	226	256	226	252	222	239	211
14	4	4.4	75	132	117	132	117	130	115	125	111
15	2	1.9	75	57	50	57	50	56	50	54	48
16	1	0.9	75	28	25	28	24	27	24	27	24
	300	130.9	--	3744	3221	3723	3204	3533	3039	2940	2508

SITE INDEX 70 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	8	0.7	51	--	--	--	--	--	--	--	--
5	27	3.7	53	90	72	87	70	60	46	--	--
6	48	9.5	56	238	195	234	191	194	156	64	39
7	64	17.2	60	455	379	450	375	402	333	250	195
8	70	24.5	64	683	578	678	574	631	533	479	396
9	64	28.5	68	827	710	822	706	783	672	656	557
10	50	27.4	71	819	711	816	708	788	684	697	602
11	33	22.1	73	669	585	667	584	650	569	595	519
12	19	14.8	74	453	398	452	397	443	390	415	364
13	9	8.4	75	255	225	254	224	250	221	238	210
14	4	3.9	75	119	105	119	105	117	104	113	100
15	2	2.1	75	63	56	63	56	62	55	60	54
	400	162.8	--	4670	4014	4641	3991	4380	3763	3567	3035

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.0	51	--	--	--	--	--	--	--	--
4	14	1.2	51	--	--	--	--	--	--	--	--
5	40	5.4	53	132	107	128	103	89	68	--	--
6	67	13.1	57	334	274	328	269	272	220	91	54
7	86	22.9	61	616	514	609	508	544	452	338	264
8	90	31.3	65	885	751	878	746	817	692	621	514
9	78	34.7	69	1019	877	1013	873	965	830	808	688
10	58	31.6	72	951	827	948	824	915	796	810	701
11	36	23.8	74	726	636	724	634	705	618	646	564
12	19	14.9	75	455	400	454	399	445	392	416	366
13	8	7.7	75	234	207	234	207	230	203	219	193
14	3	3.3	75	99	88	99	88	98	87	94	83
15	1	1.5	75	45	40	45	40	45	40	43	38
	500	191.3	--	5496	4722	5460	4692	5125	4398	4086	3467

SITE INDEX 70 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
5	8	1.1	56	29	24	28	23	20	15	--	--
6	24	4.7	58	122	100	120	99	99	80	33	20
7	37	10.0	61	270	226	267	223	239	199	148	116
8	45	15.9	66	452	384	448	381	417	354	317	263
9	47	20.7	70	619	535	616	532	587	506	492	420
10	42	23.2	74	721	630	718	628	693	606	613	534
11	34	22.7	77	724	640	722	638	704	622	644	568
12	25	19.6	80	637	568	636	567	624	556	584	519
13	16	15.1	81	496	444	495	443	487	437	463	415
14	10	10.5	82	343	309	343	308	339	305	325	293
15	5	6.5	82	213	192	213	192	210	190	204	184
16	3	3.6	83	118	107	118	107	117	106	114	103
17	1	1.8	83	59	54	59	54	59	53	58	52
18	1	1.3	83	42	38	41	38	41	37	41	37
	300	156.7	--	4846	4250	4825	4233	4636	4067	4036	3524

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 70 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	1	0.1	55	--	--	--	--	--	--	--	--
5	15	2.1	56	54	44	52	42	36	28	--	--
6	37	7.3	58	191	158	188	155	155	126	52	31
7	55	14.6	62	400	336	395	332	354	295	219	172
8	64	22.2	67	642	548	637	544	593	505	451	375
9	63	27.9	72	846	733	842	730	802	694	672	575
10	55	30.0	75	944	828	941	825	908	797	804	701
11	43	28.1	78	908	804	905	802	882	781	807	713
12	30	23.3	80	761	679	760	678	745	665	697	621
13	19	17.1	81	563	504	562	503	553	496	526	471
14	10	11.2	82	369	332	368	331	364	327	349	315
15	5	6.6	82	215	194	215	194	213	192	206	186
16	2	3.4	83	113	102	112	102	112	101	109	98
17	1	1.6	83	53	48	53	48	52	47	51	46
18	1	1.0	83	33	30	33	30	33	30	32	29
	400	196.4	--	6092	5339	6063	5316	5802	5085	4976	4336

SITE INDEX 80 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	38	--	--	--	--	--	--	--	--
3	8	0.4	38	--	--	--	--	--	--	--	--
4	21	1.8	39	--	--	--	--	--	--	--	--
5	40	5.4	40	103	79	99	76	69	50	--	--
6	58	11.5	42	223	174	219	171	182	139	60	34
7	66	17.6	45	355	280	351	277	314	246	195	144
8	55	19.4	47	400	320	397	317	370	295	281	219
9	33	14.6	48	306	246	304	245	289	233	243	193
10	13	7.1	49	149	121	149	120	143	116	127	102
11	4	2.4	49	50	41	50	40	48	39	44	36
	300	80.3	--	1585	1260	1569	1247	1415	1119	950	728

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	3	0.1	38	--	--	--	--	--	--	--	--
3	14	0.7	38	--	--	--	--	--	--	--	--
4	35	3.0	39	--	--	--	--	--	--	--	--
5	63	8.6	41	165	127	160	123	111	81	--	--
6	87	17.1	43	338	264	332	259	275	211	91	52
7	89	23.8	45	487	386	482	382	431	339	267	198
8	65	22.7	47	476	381	472	378	439	351	334	261
9	32	14.1	48	297	239	295	238	281	227	236	188
10	10	5.3	49	111	90	110	89	106	86	94	76
11	2	1.2	49	25	20	25	20	24	20	22	18
	400	96.6	--	1898	1507	1875	1489	1667	1315	1044	793

SITE INDEX 80 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	5	0.1	38	--	--	--	--	--	--	--	--
3	22	1.1	38	--	--	--	--	--	--	--	--
4	53	4.7	39	--	--	--	--	--	--	--	--
5	92	12.6	41	244	188	236	182	164	120	--	--
6	118	23.1	44	465	365	457	358	378	292	126	72
7	108	28.9	46	601	477	594	472	531	419	329	245
8	67	23.6	48	498	399	494	396	460	368	349	273
9	26	11.7	48	247	199	246	198	234	189	196	156
10	6	3.2	49	68	55	67	55	65	53	58	46
11	1	0.5	49	10	8	10	8	9	8	9	7
	500	109.4	--	2132	1691	2103	1669	1841	1449	1067	800

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	38	--	--	--	--	--	--	--	--
2	9	0.2	38	--	--	--	--	--	--	--	--
3	33	1.6	38	--	--	--	--	--	--	--	--
4	77	6.7	40	--	--	--	--	--	--	--	--
5	126	17.2	42	339	262	328	253	227	168	--	--
6	149	29.2	45	597	469	586	460	485	376	162	93
7	121	32.3	47	678	540	671	534	600	475	372	277
8	63	21.9	48	466	374	462	371	430	345	327	256
9	19	8.4	49	178	143	177	143	168	136	141	113
10	3	1.7	49	37	30	37	30	35	29	31	25
	600	119.3	--	2294	1819	2260	1792	1946	1527	1033	764

SITE INDEX 80 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	38	--	--	--	--	--	--	--	--
2	13	0.3	38	--	--	--	--	--	--	--	--
3	47	2.3	39	--	--	--	--	--	--	--	--
4	106	9.3	40	--	--	--	--	--	--	--	--
5	165	22.5	43	449	348	435	337	301	223	--	--
6	177	34.8	45	721	569	708	558	586	455	195	113
7	125	33.3	47	707	565	699	558	625	496	388	290
8	52	18.3	48	391	314	388	312	361	289	274	215
9	12	5.2	49	110	89	110	89	104	84	87	70
10	1	0.7	49	15	12	15	12	14	11	12	10
	700	126.6	--	2393	1896	2354	1865	1992	1559	957	697

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	2	0.0	38	--	--	--	--	--	--	--	--
2	19	0.4	38	--	--	--	--	--	--	--	--
3	66	3.2	39	--	--	--	--	--	--	--	--
4	142	12.4	41	--	--	--	--	--	--	--	--
5	207	28.2	43	571	444	553	429	383	284	--	--
6	200	39.2	46	824	652	809	640	670	522	223	129
7	119	31.7	48	681	544	673	538	602	478	374	279
8	39	13.6	49	292	235	290	234	270	217	205	161
9	7	2.9	49	62	50	62	50	59	47	49	39
	800	131.8	--	2431	1925	2387	1890	1983	1548	851	609

SITE INDEX 80 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	4	0.2	47	--	--	--	--	--	--	--	--
4	14	1.2	47	--	--	--	--	--	--	--	--
5	29	4.0	49	90	72	87	69	60	46	--	--
6	46	9.0	51	210	169	206	166	171	136	57	34
7	58	15.4	54	373	305	368	302	329	268	204	157
8	58	20.1	58	506	420	502	417	467	387	355	287
9	46	20.1	60	519	435	516	433	491	412	412	341
10	28	15.0	62	393	332	391	331	378	320	334	281
11	12	8.2	62	214	182	214	182	208	177	191	162
12	4	3.1	63	82	70	82	70	80	68	75	64
13	1	0.9	63	25	21	24	21	24	21	23	20
	300	97.4	--	2411	2006	2391	1990	2210	1834	1651	1346

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	1	0.0	46	--	--	--	--	--	--	--	--
3	8	0.4	47	--	--	--	--	--	--	--	--
4	23	2.0	47	--	--	--	--	--	--	--	--
5	46	6.3	49	143	114	138	110	96	73	--	--
6	69	13.5	52	319	258	313	253	259	207	86	51
7	81	21.7	55	534	439	528	434	473	386	293	225
8	75	26.3	58	671	558	666	554	619	514	471	382
9	54	23.8	61	619	521	616	518	586	493	491	408
10	29	15.6	62	410	347	408	346	394	334	349	294
11	11	7.2	63	189	161	189	160	184	156	168	143
12	3	2.3	63	59	50	59	50	57	49	54	46
13	1	0.5	63	13	11	13	11	13	11	12	11
	400	119.6	--	2957	2459	2930	2437	2682	2223	1925	1560

SITE INDEX 80 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	46	--	--	--	--	--	--	--	--
3	12	0.6	47	--	--	--	--	--	--	--	--
4	35	3.0	48	--	--	--	--	--	--	--	--
5	66	9.0	50	208	166	201	160	139	106	--	--
6	95	18.6	53	445	361	437	354	362	289	120	72
7	105	28.1	56	703	579	695	572	621	509	386	297
8	90	31.5	59	812	678	806	673	750	624	570	464
9	58	25.5	61	671	565	667	562	635	535	532	443
10	27	14.6	62	385	326	383	325	370	314	328	276
11	9	5.6	63	148	126	148	126	144	123	132	112
12	2	1.6	63	42	36	42	36	41	35	39	33
	500	138.2	--	3414	2836	3379	2808	3063	2534	2107	1697

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	3	0.1	46	--	--	--	--	--	--	--	--
3	18	0.9	47	--	--	--	--	--	--	--	--
4	49	4.3	48	--	--	--	--	--	--	--	--
5	90	12.2	50	285	228	276	221	191	146	--	--
6	123	24.1	54	586	477	575	468	476	381	159	95
7	128	34.3	57	870	718	860	710	769	631	477	369
8	101	35.2	60	919	769	912	763	849	708	645	526
9	58	25.5	62	673	568	670	565	638	537	534	446
10	23	12.5	62	331	281	330	280	318	270	282	238
11	6	4.0	63	105	89	105	89	102	87	93	79
12	1	0.9	63	23	19	23	19	22	19	21	18
	600	154.0	--	3792	3149	3751	3114	3366	2780	2211	1769

SITE INDEX 80 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	5	0.1	46	--	--	--	--	--	--	--	--
3	26	1.3	47	--	--	--	--	--	--	--	--
4	67	5.8	48	--	--	--	--	--	--	--	--
5	117	16.0	51	377	302	365	292	252	193	--	--
6	153	30.1	55	740	603	726	592	602	483	200	120
7	150	40.0	58	1026	849	1014	840	907	747	563	436
8	107	37.3	61	984	824	976	818	909	759	691	564
9	54	23.8	62	632	534	629	531	599	505	502	419
10	18	9.9	63	262	223	261	222	252	214	223	188
11	4	2.6	63	67	57	67	57	65	56	60	51
12	1	0.4	63	11	9	11	9	11	9	10	8
	700	167.2	--	4099	3401	4050	3361	3597	2966	2249	1786

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
2	7	0.1	46	--	--	--	--	--	--	--	--
3	35	1.7	47	--	--	--	--	--	--	--	--
4	87	7.6	49	--	--	--	--	--	--	--	--
5	148	20.2	52	483	387	467	375	323	248	--	--
6	184	36.2	55	903	738	886	724	734	591	244	146
7	167	44.7	59	1161	964	1148	953	1027	847	637	495
8	108	37.7	61	1001	840	993	834	924	774	703	575
9	47	20.9	62	557	471	554	468	528	446	442	369
10	13	7.2	63	192	163	191	162	185	157	163	138
11	2	1.6	63	43	36	43	36	41	35	38	32
	800	178.1	--	4339	3598	4282	3552	3762	3097	2228	1755

SITE INDEX 80 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	1	0.1	54	--	--	--	--	--	--	--	--
4	9	0.7	55	--	--	--	--	--	--	--	--
5	21	2.8	56	73	60	71	58	49	38	--	--
6	35	7.0	59	183	151	180	148	149	121	50	30
7	48	12.8	62	349	292	345	289	308	257	191	150
8	53	18.6	66	528	449	524	446	488	414	371	307
9	49	21.8	69	643	554	640	551	609	524	510	435
10	38	20.9	72	629	548	627	546	605	527	536	464
11	24	16.1	74	493	432	492	431	479	420	439	384
12	13	10.0	75	308	271	307	270	301	265	282	248
13	5	5.0	75	152	134	151	134	149	132	142	125
14	2	1.9	75	58	52	58	52	58	51	55	49
15	1	0.7	75	21	19	21	19	21	19	21	18
	300	118.4	--	3438	2962	3417	2944	3217	2768	2596	2210

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	3	0.1	54	--	--	--	--	--	--	--	--
4	14	1.3	55	--	--	--	--	--	--	--	--
5	33	4.5	56	116	94	112	91	78	60	--	--
6	53	10.4	59	278	230	273	226	226	184	75	46
7	69	18.3	63	508	427	502	422	449	375	279	219
8	73	25.3	67	732	625	727	620	676	576	514	427
9	64	28.1	70	838	724	834	720	794	685	665	568
10	46	25.0	73	761	663	758	661	732	638	648	561
11	27	17.7	74	545	478	544	477	530	465	485	424
12	13	10.0	75	306	270	305	269	300	264	280	247
13	5	4.4	75	133	118	133	118	131	116	125	110
14	2	1.9	75	56	50	56	50	56	49	53	47
	400	147.0	--	4274	3679	4245	3654	3971	3412	3124	2650

SITE INDEX 80 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	5	0.3	54	--	--	--	--	--	--	--	--
4	22	1.9	55	--	--	--	--	--	--	--	--
5	47	6.4	57	167	137	162	132	112	87	--	--
6	73	14.4	60	388	322	381	316	315	258	105	64
7	91	24.3	64	682	575	675	569	603	506	374	295
8	92	32.0	68	937	801	930	795	865	738	658	548
9	76	33.4	71	1008	872	1003	868	955	826	800	684
10	51	27.7	73	848	740	845	738	816	712	722	627
11	27	18.0	74	555	487	554	486	539	474	494	432
12	12	9.1	75	280	247	279	246	274	241	256	226
13	4	3.5	75	108	95	107	95	106	93	100	89
14	1	1.2	75	38	33	38	33	37	33	36	32
	500	172.1	--	5011	4310	4973	4278	4623	3968	3546	2997

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	8	0.4	54	--	--	--	--	--	--	--	--
4	31	2.7	55	--	--	--	--	--	--	--	--
5	64	8.7	57	228	187	221	180	153	119	--	--
6	96	18.8	61	513	426	503	419	417	341	139	85
7	114	30.5	65	869	734	859	726	768	645	477	377
8	110	38.3	69	1135	973	1126	966	1048	896	797	666
9	85	37.7	72	1146	994	1141	989	1086	941	910	780
10	53	28.9	74	892	780	889	777	858	750	760	660
11	26	17.2	75	531	466	529	465	516	453	472	414
12	10	7.8	75	239	211	239	210	234	206	219	193
13	3	2.6	75	80	71	80	71	79	70	75	66
14	1	0.8	75	23	21	23	21	23	20	22	20
	600	194.2	--	5657	4862	5610	4823	5182	4443	3870	3260

SITE INDEX 80 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	4	0.3	60	--	--	--	--	--	--	--	--
5	14	1.9	61	54	45	52	43	36	29	--	--
6	28	5.4	63	153	129	151	126	125	103	42	25
7	40	10.6	67	311	264	307	261	275	232	170	136
8	47	16.4	71	502	433	498	430	463	399	352	296
9	48	21.0	75	670	586	667	583	635	555	532	460
10	42	22.9	79	753	666	750	664	724	641	641	564
11	32	21.4	82	718	640	716	639	697	623	638	568
12	22	17.2	83	583	524	582	523	570	513	534	479
13	13	11.9	84	405	366	404	365	398	360	378	342
14	7	7.1	85	241	218	241	218	238	216	229	207
15	3	3.6	85	123	112	123	112	122	111	118	107
16	1	1.6	85	54	49	54	49	53	48	52	47
17	1	0.8	86	27	25	27	25	27	25	27	24
	300	142.1	--	4594	4056	4572	4037	4364	3852	3713	3256

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	7	0.6	60	--	--	--	--	--	--	--	--
5	23	3.1	61	88	73	85	70	59	47	--	--
6	42	8.2	64	234	196	230	193	190	157	63	39
7	57	15.3	68	455	388	450	384	403	341	250	199
8	65	22.8	72	708	613	703	608	654	564	497	419
9	64	28.1	76	907	795	902	791	859	753	720	624
10	54	29.2	80	971	861	968	858	934	828	827	729
11	39	25.9	82	877	783	874	781	852	762	780	695
12	25	19.6	84	670	602	669	601	655	590	614	551
13	14	12.7	85	435	393	434	392	428	386	406	367
14	7	7.0	85	240	217	240	217	237	215	228	206
15	3	3.3	85	113	102	113	102	112	101	108	98
16	1	1.9	85	63	57	63	57	62	57	61	55
	400	177.8	--	5760	5082	5729	5056	5444	4800	4553	3984

SITE INDEX 80 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	11	1.0	60	--	--	--	--	--	--	--	--
5	33	4.5	62	128	106	124	103	86	68	--	--
6	58	11.3	65	327	275	321	270	266	220	88	55
7	76	20.4	69	616	526	609	520	545	463	338	270
8	84	29.4	73	925	802	918	796	854	739	649	549
9	79	34.8	77	1138	1001	1132	996	1078	947	903	785
10	64	34.7	81	1164	1034	1160	1030	1120	994	991	875
11	44	29.3	83	997	892	994	889	968	867	886	791
12	27	20.9	84	717	645	716	644	702	632	657	591
13	14	12.7	85	435	393	435	393	428	387	407	367
14	6	6.5	85	223	202	223	202	220	199	211	192
15	2	2.8	85	96	87	96	87	95	86	92	84
16	1	1.4	85	47	43	47	43	47	42	45	41
	500	209.8	--	6813	6007	6774	5973	6408	5645	5269	4601

Continued

Table 25.--Volume yields per acre for loblolly pine in Soil Group A (in cubic feet)--Contd.

SITE INDEX 80 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
5	7	1.0	65	29	24	28	24	20	16	--	--
6	21	4.1	66	122	103	119	101	99	82	33	20
7	33	8.9	70	271	232	268	230	240	204	149	119
8	41	14.4	74	460	400	457	398	425	369	323	274
9	44	19.5	79	650	573	646	570	615	542	516	450
10	42	22.8	83	788	704	785	701	758	677	671	596
11	36	23.5	87	836	754	834	752	812	733	744	669
12	28	21.7	89	786	715	785	713	769	700	720	654
13	20	18.1	91	661	605	660	604	650	595	618	565
14	13	13.6	92	500	460	499	459	493	454	474	436
15	8	9.3	93	342	316	342	315	339	312	328	303
16	4	5.8	93	213	197	213	197	211	195	206	190
17	2	3.3	94	121	112	121	112	120	111	117	109
18	1	1.7	94	62	58	62	58	62	58	61	57
19	1	1.3	94	47	44	47	44	47	44	46	43
	300	169.2	--	5888	5296	5866	5277	5659	5091	5004	4485

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)

SITE INDEX 60 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	19	--	--	--	--	--	--	--	--
3	10	0.5	19	--	--	--	--	--	--	--	--
4	24	2.1	20	--	--	--	--	--	--	--	--
5	44	6.0	21	62	42	60	41	42	27	--	--
6	64	12.6	22	137	95	134	93	111	76	37	19
7	76	20.4	24	233	165	230	163	206	145	128	85
8	73	25.4	26	305	219	303	217	282	202	214	150
9	55	24.4	27	302	219	300	218	286	208	240	172
10	32	17.5	28	220	161	219	161	212	155	188	137
11	14	9.2	28	116	85	115	85	112	83	103	76
12	4	3.4	29	42	31	42	31	41	31	39	29
13	1	1.0	29	12	9	12	9	12	9	11	8
	400	122.5	--	1429	1027	1416	1019	1304	935	959	675

SITE INDEX 60 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	4	0.1	19	--	--	--	--	--	--	--	--
3	18	0.9	20	--	--	--	--	--	--	--	--
4	42	3.6	20	--	--	--	--	--	--	--	--
5	72	9.8	22	104	71	101	69	70	46	--	--
6	96	18.9	23	212	148	208	146	173	119	57	29
7	102	27.2	25	323	230	319	228	286	202	177	118
8	83	29.1	27	360	260	357	258	332	240	253	178
9	51	22.6	28	286	209	285	208	271	198	227	164
10	23	12.4	28	157	115	157	115	151	111	134	98
11	7	4.6	29	58	43	58	42	56	41	51	38
12	2	1.2	29	15	11	15	11	15	11	14	10
	500	130.4	--	1516	1088	1500	1077	1354	968	914	635

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	19	--	--	--	--	--	--	--	--
2	8	0.2	19	--	--	--	--	--	--	--	--
3	31	1.5	20	--	--	--	--	--	--	--	--
4	67	5.9	21	--	--	--	--	--	--	--	--
5	108	14.7	22	161	111	155	107	108	71	--	--
6	131	25.7	24	300	211	294	207	243	169	81	42
7	120	32.2	26	395	283	391	280	349	249	217	145
8	81	28.3	28	359	261	356	259	332	240	252	178
9	38	17.0	28	217	159	216	158	206	150	172	125
10	12	6.6	29	84	62	84	62	81	59	71	52
11	3	1.8	29	22	16	22	16	22	16	20	15
	600	133.7	--	1538	1103	1519	1089	1340	955	814	557

SITE INDEX 60 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	19	--	--	--	--	--	--	--	--
2	15	0.3	19	--	--	--	--	--	--	--	--
3	50	2.4	20	--	--	--	--	--	--	--	--
4	102	8.9	21	--	--	--	--	--	--	--	--
5	150	20.5	23	232	161	225	156	156	103	--	--
6	162	31.9	25	385	273	378	268	313	219	104	54
7	126	33.5	27	424	306	419	302	375	269	233	157
8	66	23.2	28	298	217	296	216	276	200	210	149
9	23	10.0	28	128	94	128	94	122	89	102	74
10	5	2.5	29	32	24	32	23	31	23	27	20
11	1	0.4	29	5	3	5	3	4	3	4	3
	700	133.6	--	1505	1079	1483	1063	1276	906	680	457

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.0	29	--	--	--	--	--	--	--	--
4	9	0.8	29	--	--	--	--	--	--	--	--
5	28	3.9	30	55	40	54	39	37	26	--	--
6	57	11.2	32	167	124	164	121	136	99	45	25
7	83	22.3	35	356	268	352	265	315	236	195	138
8	91	31.7	38	541	416	537	413	500	383	380	285
9	72	31.9	40	570	445	567	443	540	421	452	349
10	40	21.8	42	399	315	398	314	384	303	340	267
11	15	9.6	43	178	141	177	140	172	137	158	125
12	4	3.0	43	54	43	54	43	53	42	50	40
	400	136.2	--	2320	1793	2302	1779	2137	1648	1620	1228

SITE INDEX 60 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	3	0.1	29	--	--	--	--	--	--	--	--
4	18	1.6	29	--	--	--	--	--	--	--	--
5	51	7.0	30	103	75	99	72	69	48	--	--
6	94	18.4	33	285	212	279	208	231	170	77	42
7	121	32.3	36	538	409	532	405	476	360	295	210
8	110	38.5	40	682	529	677	525	630	488	479	362
9	68	30.2	42	555	435	552	433	525	412	440	342
10	27	14.8	43	274	216	273	216	263	208	233	183
11	6	4.2	43	77	61	77	61	75	60	69	54
12	1	0.7	43	12	10	12	10	12	10	11	9
	500	147.8	--	2525	1948	2502	1930	2282	1754	1604	1203

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	6	0.3	29	--	--	--	--	--	--	--	--
4	33	2.9	29	--	--	--	--	--	--	--	--
5	85	11.6	31	174	128	168	123	117	82	--	--
6	139	27.4	34	440	330	432	324	357	264	119	65
7	155	41.4	38	718	550	710	544	635	484	394	283
8	114	39.7	41	725	566	720	562	670	521	509	387
9	52	22.9	42	427	336	425	334	404	318	339	264
10	13	7.3	43	137	108	136	108	132	104	116	92
11	2	1.3	43	23	19	23	19	23	18	21	16
	600	154.8	--	2643	2036	2613	2014	2337	1791	1498	1107

SITE INDEX 60 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	12	0.6	29	--	--	--	--	--	--	--	--
4	57	5.0	30	--	--	--	--	--	--	--	--
5	131	17.9	32	276	203	267	196	185	130	--	--
6	190	37.3	36	623	471	612	462	507	377	169	93
7	176	46.9	40	844	652	835	645	746	573	463	335
8	98	34.3	42	641	502	636	498	592	463	450	344
9	30	13.4	43	253	199	252	198	239	189	201	156
10	5	2.7	43	51	40	50	40	49	39	43	34
	700	158.2	--	2688	2068	2651	2040	2318	1770	1326	962

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 400

	Stems			Total vol.		Merchantable volume to top--					
	per	Basal	Avg.	(ft^3)		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.								
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	1	0.1	37	--	--	--	--	--	--	--	--
5	17	2.3	37	41	31	40	30	28	20	--	--
6	45	8.9	39	160	123	157	121	130	99	43	24
7	70	18.6	42	356	279	352	275	315	245	195	143
8	80	27.8	46	570	454	566	451	526	419	400	311
9	73	32.2	50	696	564	692	561	659	534	552	442
10	54	29.7	52	663	544	660	542	638	523	564	460
11	33	22.0	54	500	413	498	412	486	402	445	367
12	17	13.1	54	301	250	300	249	294	245	275	229
13	7	6.3	55	145	121	145	121	142	119	135	113
14	2	2.5	55	56	47	56	47	55	46	53	44
15	1	1.0	55	22	18	22	18	22	18	21	18
	400	164.5	--	3509	2844	3488	2828	3295	2668	2685	2151

SITE INDEX 60 AGE 20 STEMS/ACRE 500

	Stems			Total vol.		Merchantable volume to top--					
	per	Basal	Avg.	(ft^3)		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.								
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	4	0.3	37	--	--	--	--	--	--	--	--
5	33	4.6	37	81	61	78	59	54	39	--	--
6	74	14.5	40	268	206	263	202	218	165	72	41
7	102	27.1	44	539	424	532	419	476	373	295	218
8	105	36.5	48	774	621	768	617	715	573	543	425
9	84	37.3	51	829	676	825	672	785	639	658	530
10	54	29.7	53	676	556	673	555	650	535	575	471
11	28	18.5	54	424	352	423	351	412	342	378	312
12	11	9.0	55	207	172	206	172	202	169	189	158
13	4	3.4	55	78	65	78	65	77	64	73	61
14	1	1.3	55	29	24	29	24	28	24	27	23
	500	182.1	--	3904	3159	3876	3137	3618	2923	2812	2239

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	9	0.8	37	--	--	--	--	--	--	--	--
5	57	7.7	38	139	105	134	102	93	67	--	--
6	109	21.4	41	408	316	401	310	332	253	110	63
7	136	36.3	46	746	591	737	584	659	520	409	304
8	125	43.5	50	952	769	945	763	879	709	669	526
9	88	38.8	52	881	721	876	718	834	682	699	566
10	48	26.1	54	602	497	600	495	579	478	513	421
11	20	13.3	55	307	255	306	254	299	248	273	226
12	7	5.1	55	118	98	118	98	115	96	108	90
13	2	1.8	55	41	34	41	34	41	34	39	32
	600	194.8	--	4194	3387	4158	3360	3831	3087	2819	2227

SITE INDEX 60 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	20	1.7	37	--	--	--	--	--	--	--	--
5	88	12.0	39	219	167	212	161	147	107	--	--
6	151	29.7	43	582	454	572	446	473	364	158	90
7	169	45.2	47	959	766	949	757	848	673	526	393
8	137	47.7	51	1072	870	1064	864	990	802	753	596
9	82	36.3	53	839	689	835	686	795	652	666	541
10	37	20.1	54	469	387	467	386	451	373	399	328
11	12	8.1	55	188	157	188	156	183	152	168	139
12	3	2.4	55	55	46	55	45	54	45	50	42
13	1	0.6	55	13	11	13	11	13	11	12	10
	700	203.9	--	4397	3546	4353	3512	3953	3177	2731	2138

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	23	--	--	--	--	--	--	--	--
3	10	0.5	23	--	--	--	--	--	--	--	--
4	24	2.1	24	--	--	--	--	--	--	--	--
5	44	6.0	25	73	51	71	50	49	33	--	--
6	64	12.6	27	160	114	157	112	130	91	43	23
7	76	20.4	28	270	197	267	194	239	173	148	101
8	73	25.4	30	352	260	350	258	325	240	247	178
9	55	24.4	32	347	260	346	258	329	246	276	204
10	32	17.5	33	253	191	252	190	243	183	215	161
11	14	9.2	33	133	100	132	100	129	98	118	89
12	4	3.4	33	49	37	48	37	47	36	44	34
13	1	1.0	33	14	10	14	10	13	10	13	10
	400	122.5	--	1651	1220	1636	1210	1505	1110	1105	799

SITE INDEX 70 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	4	0.1	23	--	--	--	--	--	--	--	--
3	18	0.9	23	--	--	--	--	--	--	--	--
4	42	3.6	24	--	--	--	--	--	--	--	--
5	72	9.8	26	122	86	118	83	82	55	--	--
6	96	18.9	28	247	178	243	175	201	142	67	35
7	102	27.2	30	374	274	370	271	331	241	205	141
8	83	29.1	31	415	308	412	306	383	284	291	211
9	51	22.6	32	329	247	327	245	311	233	261	193
10	23	12.4	33	180	136	180	136	174	131	154	115
11	7	4.6	33	66.	50	66	50	64	49	59	45
12	2	1.2	33	18	13	18	13	17	13	16	12
	500	130.4	--	1751	1292	1732	1279	1563	1148	1053	752

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	23	--	--	--	--	--	--	--	--
2	8	0.2	23	--	--	--	--	--	--	--	--
3	31	1.5	24	--	--	--	--	--	--	--	--
4	67	5.9	25	--	--	--	--	--	--	--	--
5	108	14.7	26	188	133	182	129	126	85	--	--
6	131	25.7	29	347	252	341	247	282	202	94	50
7	120	32.2	31	456	336	451	332	403	296	250	173
8	81	28.3	32	413	308	410	306	382	284	290	211
9	38	17.0	33	249	188	248	187	236	177	198	147
10	12	6.6	33	96	73	96	73	93	70	82	62
11	3	1.8	33	25	19	25	19	25	19	23	17
	600	133.7	--	1775	1309	1753	1293	1547	1133	937	659

SITE INDEX 70 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³) o.b.	Total vol. (ft³) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	23	--	--	--	--	--	--	--	--
2	15	0.3	23	--	--	--	--	--	--	--	--
3	50	2.4	24	--	--	--	--	--	--	--	--
4	102	8.9	25	--	--	--	--	--	--	--	--
5	150	20.5	27	271	194	262	187	181	124	--	--
6	162	31.9	30	446	325	437	319	362	260	121	64
7	126	33.5	31	488	362	483	358	432	318	268	186
8	66	23.2	33	343	257	340	255	317	236	241	176
9	23	10.0	33	147	111	147	110	140	105	117	87
10	5	2.5	33	37	28	37	28	35	27	31	24
11	1	0.4	33	5	4	5	4	5	4	5	4
	700	133.6	--	1737	1280	1711	1261	1472	1074	782	540

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.0	35	--	--	--	--	--	--	--	--
4	9	0.8	35	--	--	--	--	--	--	--	--
5	28	3.9	36	65	49	63	47	44	31	--	--
6	57	11.2	38	196	150	193	147	159	120	53	30
7	83	22.3	41	414	322	410	318	366	283	227	165
8	91	31.7	44	626	496	621	492	578	457	440	339
9	72	31.9	47	657	527	653	525	622	499	521	414
10	40	21.8	49	459	372	457	371	441	358	390	315
11	15	9.6	50	204	166	203	166	198	161	181	147
12	4	3.0	50	62	51	62	51	61	50	57	47
	400	136.2	--	2683	2132	2662	2116	2470	1959	1870	1457

SITE INDEX 70 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	3	0.1	35	--	--	--	--	--	--	--	--
4	18	1.6	35	--	--	--	--	--	--	--	--
5	51	7.0	36	121	91	117	88	81	58	--	--
6	94	18.4	39	333	255	327	251	271	204	90	51
7	121	32.3	43	624	489	617	484	552	430	343	251
8	110	38.5	46	787	628	782	623	727	578	553	430
9	68	30.2	48	638	514	634	512	604	487	506	404
10	27	14.8	49	314	255	313	254	302	245	267	216
11	6	4.2	50	89	72	88	72	86	70	79	64
12	1	0.7	50	14	12	14	12	14	11	13	11
	500	147.8	--	2920	2317	2892	2295	2637	2085	1851	1426

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	6	0.3	35	--	--	--	--	--	--	--	--
4	33	2.9	35	--	--	--	--	--	--	--	--
5	85	11.6	37	204	155	198	149	137	99	--	--
6	139	27.4	41	512	396	503	389	417	317	139	79
7	155	41.4	45	830	655	821	648	734	576	456	336
8	114	39.7	48	835	669	829	664	771	617	586	458
9	52	22.9	49	490	397	488	395	464	375	389	311
10	13	7.3	50	157	128	156	127	151	123	134	108
11	2	1.3	50	27	22	27	22	26	21	24	19
	600	154.8	--	3056	2421	3021	2394	2700	2128	1727	1312

SITE INDEX 70 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	12	0.6	35	--	--	--	--	--	--	--	--
4	57	5.0	36	--	--	--	--	--	--	--	--
5	131	17.9	38	323	246	313	237	216	157	--	--
6	190	37.3	42	724	564	711	553	589	451	196	112
7	176	46.9	46	974	774	963	765	861	680	534	397
8	98	34.3	49	737	593	731	589	680	546	517	406
9	30	13.4	50	290	235	289	234	275	223	230	185
10	5	2.7	50	58	47	58	47	56	45	49	40
	700	158.2	--	3106	2458	3064	2425	2677	2103	1527	1139

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	1	0.1	44	--	--	--	--	--	--	--	--
5	17	2.3	44	49	38	47	37	33	24	--	--
6	45	8.9	46	189	149	185	147	153	120	51	30
7	70	18.6	50	416	336	411	332	368	295	228	172
8	80	27.8	54	662	543	657	539	611	500	465	372
9	73	32.2	58	804	670	799	667	761	634	638	526
10	54	29.7	61	763	644	761	641	734	619	650	545
11	33	22.0	62	574	488	573	487	558	474	511	433
12	17	13.1	63	345	295	344	294	338	289	316	270
13	7	6.3	64	166	142	166	142	163	140	155	133
14	2	2.5	64	64	55	64	55	63	55	61	52
15	1	1.0	64	25	22	25	22	25	21	24	21
	400	164.5	--	4057	3382	4033	3363	3808	3172	3099	2554

SITE INDEX 70 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	4	0.3	44	--	--	--	--	--	--	--	--
5	33	4.6	45	95	75	92	72	64	48	--	--
6	74	14.5	48	314	250	308	245	255	200	85	50
7	102	27.1	52	627	509	620	503	555	447	344	261
8	105	36.5	56	896	740	889	735	828	682	629	507
9	84	37.3	60	956	801	951	797	905	758	759	628
10	54	29.7	62	777	658	774	655	748	633	662	557
11	28	18.5	63	488	415	486	414	474	404	434	368
12	11	9.0	64	237	203	237	203	232	199	217	186
13	4	3.4	64	90	77	90	77	89	76	84	72
14	1	1.3	64	33	28	33	28	32	28	31	27
	500	182.1	--	4514	3756	4481	3730	4182	3474	3245	2656

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	9	0.8	44	--	--	--	--	--	--	--	--
5	57	7.7	45	164	128	158	124	110	82	--	--
6	109	21.4	49	478	382	469	375	388	306	129	76
7	136	36.3	54	866	707	856	699	766	622	475	363
8	125	43.5	58	1100	914	1092	907	1016	842	772	625
9	88	38.8	61	1014	853	1009	849	960	808	805	669
10	48	26.1	63	692	587	689	585	665	564	589	497
11	20	13.3	63	353	301	352	300	343	292	314	267
12	7	5.1	64	135	116	135	115	132	113	124	106
13	2	1.8	64	47	41	47	41	47	40	44	38
	600	194.8	--	4848	4028	4807	3995	4427	3669	3252	2641

SITE INDEX 70 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	20	1.7	44	--	--	--	--	--	--	--	--
5	88	12.0	46	258	203	250	196	173	130	--	--
6	151	29.7	50	680	547	668	537	553	438	184	108
7	169	45.2	55	1112	913	1099	903	983	803	610	469
8	137	47.7	59	1236	1032	1227	1025	1142	951	868	706
9	82	36.3	62	965	814	960	810	914	771	766	639
10	37	20.1	63	538	457	536	456	518	440	458	387
11	12	8.1	64	216	185	216	184	210	179	192	164
12	3	2.4	64	63	54	63	54	61	53	58	49
13	1	0.6	64	15	13	15	13	15	13	14	12
	700	203.9	--	5083	4217	5033	4176	4568	3776	3150	2535

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	2	0.0	27	--	--	--	--	--	--	--	--
3	10	0.5	27	--	--	--	--	--	--	--	--
4	24	2.1	28	--	--	--	--	--	--	--	--
5	44	6.0	29	84	61	81	59	56	39	--	--
6	64	12.6	31	183	134	179	132	149	108	49	27
7	76	20.4	33	308	230	304	227	272	202	169	118
8	73	25.4	35	399	302	396	300	369	278	280	207
9	55	24.4	36	392	300	390	299	371	284	311	235
10	32	17.5	37	285	220	284	219	274	212	243	186
11	14	9.2	37	149	116	149	115	145	112	133	103
12	4	3.4	38	55	42	54	42	53	42	50	39
13	1	1.0	38	15	12	15	12	15	12	14	11
	400	122.5	--	1871	1417	1854	1405	1705	1288	1250	926

SITE INDEX 80 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
2	4	0.1	27	--	--	--	--	--	--	--	--
3	18	0.9	27	--	--	--	--	--	--	--	--
4	42	3.6	28	--	--	--	--	--	--	--	--
5	72	9.8	30	140	102	135	98	94	65	--	--
6	96	18.9	32	282	209	277	205	229	167	76	41
7	102	27.2	34	424	319	420	315	375	280	233	164
8	83	29.1	36	469	357	465	354	433	329	329	244
9	51	22.6	37	371	285	369	283	351	269	294	223
10	23	12.4	37	203	157	202	156	195	151	173	133
11	7	4.6	38	75	58	74	58	72	56	66	51
12	2	1.2	38	20	15	20	15	19	15	18	14
	500	130.4	--	1983	1500	1962	1485	1770	1332	1190	871

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	27	--	--	--	--	--	--	--	--
2	8	0.2	27	--	--	--	--	--	--	--	--
3	31	1.5	28	--	--	--	--	--	--	--	--
4	67	5.9	29	--	--	--	--	--	--	--	--
5	108	14.7	31	215	157	208	152	144	100	--	--
6	131	25.7	33	395	294	388	289	321	235	107	58
7	120	32.2	35	516	390	510	386	457	343	283	200
8	81	28.3	36	466	356	463	354	431	328	327	244
9	38	17.0	37	281	216	279	215	266	205	223	170
10	12	6.6	38	108	84	108	84	104	81	92	71
11	3	1.8	38	29	22	29	22	28	22	25	20
	600	133.7	--	2011	1519	1986	1500	1751	1314	1058	763

SITE INDEX 80 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
1	1	0.0	27	--	--	--	--	--	--	--	--
2	15	0.3	27	--	--	--	--	--	--	--	--
3	50	2.4	28	--	--	--	--	--	--	--	--
4	102	8.9	29	--	--	--	--	--	--	--	--
5	150	20.5	32	309	227	299	219	207	145	--	--
6	162	31.9	34	506	378	496	371	411	303	137	75
7	126	33.5	36	551	419	545	414	488	368	303	215
8	66	23.2	37	386	296	383	294	357	273	271	203
9	23	10.0	38	166	128	165	127	157	121	132	100
10	5	2.5	38	41	32	41	32	40	31	35	27
11	1	0.4	38	6	5	6	5	6	4	5	4
	700	133.6	--	1966	1484	1937	1462	1665	1245	883	624

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 . AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	1	0.0	41	--	--	--	--	--	--	--	--
4	9	0.8	41	--	--	--	--	--	--	--	--
5	28	3.9	42	76	58	73	56	51	37	--	--
6	57	11.2	44	226	177	222	174	183	142	61	35
7	83	22.3	47	473	378	468	373	419	332	260	194
8	91	31.7	51	711	577	705	572	656	531	499	395
9	72	31.9	54	742	610	738	607	703	578	589	479
10	40	21.8	56	517	429	515	428	497	413	440	363
11	15	9.6	56	229	191	229	191	223	186	204	170
12	4	3.0	57	70	59	70	59	69	57	64	54
	400	136.2	--	3044	2479	3020	2460	2800	2276	2117	1689

SITE INDEX 80 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	3	0.1	41	--	--	--	--	--	--	--	--
4	18	1.6	41	--	--	--	--	--	--	--	--
5	51	7.0	42	140	108	135	105	94	69	--	--
6	94	18.4	45	382	301	375	295	310	241	103	60
7	121	32.3	49	711	571	703	565	629	502	390	293
8	110	38.5	53	891	728	885	723	823	671	626	498
9	68	30.2	55	719	594	715	591	681	562	571	466
10	27	14.8	56	354	294	352	293	340	283	301	249
11	6	4.2	56	100	83	100	83	97	81	89	74
12	1	0.7	57	16	13	16	13	16	13	15	12
	500	147.8	--	3312	2693	3280	2668	2989	2422	2094	1652

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	6	0.3	41	--	--	--	--	--	--	--	--
4	33	2.9	41	--	--	--	--	--	--	--	--
5	85	11.6	43	236	183	228	177	158	117	--	--
6	139	27.4	47	586	465	575	456	476	372	159	92
7	155	41.4	51	942	762	932	754	833	670	517	391
8	114	39.7	54	943	774	936	768	871	713	662	530
9	52	22.9	56	552	457	549	455	523	433	438	359
10	13	7.3	56	177	147	176	146	170	141	150	124
11	2	1.3	57	30	25	30	25	29	25	27	22
	600	154.8	--	3466	2814	3426	2782	3060	2471	1953	1519

SITE INDEX 80 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
3	12	0.6	41	--	--	--	--	--	--	--	--
4	57	5.0	42	--	--	--	--	--	--	--	--
5	131	17.9	44	371	290	359	280	249	186	--	--
6	190	37.3	49	825	659	810	647	671	528	223	131
7	176	46.9	53	1102	897	1090	887	975	788	605	461
8	98	34.3	55	831	684	824	679	767	631	583	468
9	30	13.4	56	327	271	325	270	309	257	259	213
10	5	2.7	57	65	54	65	54	63	52	56	46
	700	158.2	--	3522	2856	3474	2818	3034	2441	1726	1318

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	1	0.1	52	--	--	--	--	--	--	--	--
5	17	2.3	52	56	45	55	44	38	29	--	--
6	45	8.9	54	218	177	214	174	177	142	59	35
7	70	18.6	58	477	395	471	390	422	347	262	203
8	80	27.8	62	753	635	748	630	696	585	529	434
9	73	32.2	66	911	778	906	774	863	736	723	610
10	54	29.7	69	862	745	859	742	830	716	734	631
11	33	22.0	71	648	563	646	562	629	548	576	500
12	17	13.1	72	389	340	388	339	380	333	356	311
13	7	6.3	72	187	164	187	164	184	162	175	153
14	2	2.5	72	72	64	72	64	71	63	69	60
15	1	1.0	72	28	25	28	25	28	25	27	24
	400	164.5	--	4602	3931	4574	3908	4318	3685	3510	2962

SITE INDEX 80 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total vol. (ft^3) o.b.	Total vol. (ft^3) i.b.	Merchantable volume to top-- 2 inches o.b.	2 inches i.b.	4 inches o.b.	4 inches i.b.	6 inches o.b.	6 inches i.b.
4	4	0.3	52	--	--	--	--	--	--	--	--
5	33	4.6	52	110	89	107	86	74	57	--	--
6	74	14.5	55	361	295	355	290	294	237	98	59
7	102	27.1	60	717	597	709	591	634	525	393	307
8	105	36.5	64	1018	862	1010	856	940	795	715	590
9	84	37.3	68	1081	928	1076	924	1024	878	858	728
10	54	29.7	70	877	760	874	757	844	731	747	643
11	28	18.5	72	549	479	548	478	534	465	489	425
12	11	9.0	72	267	234	267	234	262	229	245	214
13	4	3.4	72	101	89	101	89	100	88	95	83
14	1	1.3	72	37	32	37	32	36	32	35	31
	500	182.1	--	5120	4366	5083	4336	4741	4036	3674	3080

Continued

Table 26.--Volume yields per acre for loblolly pine in Soil Group B (in cubic feet)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	9	0.8	52	--	--	--	--	--	--	--	--
5	57	7.7	53	189	153	183	147	127	98	--	--
6	109	21.4	57	548	450	538	442	446	361	148	89
7	136	36.3	62	987	827	976	818	873	727	542	425
8	125	43.5	66	1247	1062	1237	1054	1151	978	875	726
9	88	38.8	69	1145	987	1139	982	1085	934	909	774
10	48	26.1	71	780	677	777	675	750	651	664	573
11	20	13.3	72	397	347	396	346	386	337	353	308
12	7	5.1	72	152	133	152	133	149	130	139	122
13	2	1.8	72	53	47	53	47	52	46	50	44
	600	194.8	--	5499	4682	5452	4643	5019	4262	3681	3061

SITE INDEX 80 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total vol. (ft³)		Merchantable volume to top-- 2 inches		4 inches		6 inches	
				o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	20	1.7	52	--	--	--	--	--	--	--	--
5	88	12.0	54	298	241	288	233	199	154	--	--
6	151	29.7	58	779	643	765	631	633	515	211	128
7	169	45.2	64	1264	1065	1250	1053	1118	936	694	547
8	137	47.7	68	1398	1196	1388	1187	1291	1102	982	818
9	82	36.3	71	1088	941	1083	936	1031	890	864	738
10	37	20.1	72	606	527	604	525	583	507	516	446
11	12	8.1	72	244	213	243	212	237	207	217	189
12	3	2.4	72	71	62	71	62	69	61	65	57
13	1	0.6	72	17	15	17	15	17	15	16	14
	700	203.9	--	5765	4902	5708	4854	5178	4386	3563	2936

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)

SITE INDEX 50 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	6	0.1	18	--	--	--	--	--	--	--	--
3	28	1.4	19	--	--	--	--	--	--	--	--
4	64	5.6	20	--	--	--	--	--	--	--	--
5	90	12.3	23	70	25	68	24	46	17	--	--
6	74	14.5	25	90	32	88	32	72	27	21	9
7	31	8.3	27	53	19	53	19	47	17	28	11
8	6	2.1	27	14	5	14	5	12	5	9	4
	300	44.3	--	227	81	222	80	177	66	58	24

Merchantable weight to top-- (2, 4, 6 inches)

SITE INDEX 50 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	1	0.0	18	--	--	--	--	--	--	--	--
2	14	0.3	18	--	--	--	--	--	--	--	--
3	54	2.7	19	--	--	--	--	--	--	--	--
4	111	9.7	21	--	--	--	--	--	--	--	--
5	127	17.3	24	104	37	101	36	68	26	--	--
6	73	14.4	26	93	33	91	33	74	28	22	9
7	18	4.8	27	31	11	31	11	27	10	16	6
8	1	0.5	27	3	1	3	1	3	1	2	1
	400	49.7	--	231	83	225	81	172	64	40	17

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 10 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	2	0.0	18	--	--	--	--	--	--	--	--
2	26	0.6	18	--	--	--	--	--	--	--	--
3	95	4.7	19	--	--	--	--	--	--	--	--
4	168	14.7	22	--	--	--	--	--	--	--	--
5	148	20.1	25	126	46	122	44	82	31	--	--
6	54	10.6	27	70	25	68	25	56	21	16	7
7	7	1.8	27	12	4	11	4	10	4	6	2
	500	52.5	--	208	75	202	73	148	56	22	9

SITE INDEX 50 AGE 10 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	4	0.0	18	--	--	--	--	--	--	--	--
2	47	1.0	18	--	--	--	--	--	--	--	--
3	153	7.5	20	--	--	--	--	--	--	--	--
4	226	19.7	23	--	--	--	--	--	--	--	--
5	140	19.1	26	124	45	120	44	81	31	--	--
6	29	5.6	27	37	13	36	13	30	11	9	4
7	1	0.4	27	2	1	2	1	2	1	1	--
	600	53.3	--	163	59	158	58	113	43	10	4

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	8	0.0	18	--	--	--	--	--	--	--	--
2	79	1.7	18	--	--	--	--	--	--	--	--
3	230	11.3	21	--	--	--	--	--	--	--	--
4	267	23.3	25	--	--	--	--	--	--	--	--
5	106	14.4	27	96	35	92	34	62	24	--	--
6	10	2.0	27	13	5	13	5	11	4	3	1
	700	52.8	--	109	40	105	39	73	28	3	1

SITE INDEX 50 AGE 10. STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	14	0.1	18	--	--	--	--	--	--	--	--
2	128	2.8	19	--	--	--	--	--	--	--	--
3	321	15.8	22	--	--	--	--	--	--	--	--
4	274	23.9	25	--	--	--	--	--	--	--	--
5	60	8.2	27	55	20	53	20	36	14	--	--
6	2	0.4	27	3	1	3	1	2	1	1	--
	800	51.2	--	58	21	56	21	38	15	1	0

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50   AGE 15   STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	25	--	--	--	--	--	--	--	--
3	11	0.6	25	--	--	--	--	--	--	--	--
4	35	3.1	26	--	--	--	--	--	--	--	--
5	64	8.7	29	63	23	61	23	41	16	--	--
6	78	15.4	32	123	46	121	45	99	38	29	13
7	64	17.2	35	149	56	147	56	130	50	78	32
8	34	11.7	37	106	40	105	40	97	37	72	29
9	10	4.6	38	42	16	42	16	40	15	33	13
10	2	1.1	38	10	4	10	4	9	3	8	3
	300	62.3	--	492	185	485	183	416	161	219	90

SITE INDEX 50   AGE 15   STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	3	0.1	25	--	--	--	--	--	--	--	--
3	22	1.1	25	--	--	--	--	--	--	--	--
4	60	5.3	27	--	--	--	--	--	--	--	--
5	100	13.7	30	103	38	99	37	67	26	--	--
6	107	21.0	34	176	66	172	65	141	55	41	19
7	72	19.3	36	172	65	170	65	150	58	90	37
8	29	10.0	37	91	35	90	34	84	32	62	25
9	6	2.7	38	25	9	24	9	23	9	19	8
10	1	0.4	38	3	1	3	1	3	1	3	1
	400	73.5	--	569	214	559	212	468	182	215	89

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	6	0.1	25	--	--	--	--	--	--	--	--
3	37	1.8	25	--	--	--	--	--	--	--	--
4	94	8.2	28	--	--	--	--	--	--	--	--
5	141	19.2	31	151	56	145	55	98	39	--	--
6	130	25.5	35	220	83	215	82	176	69	51	23
7	70	18.6	37	169	64	167	64	148	58	88	37
8	20	7.0	38	64	24	63	24	59	23	44	18
9	3	1.3	38	12	4	12	4	11	4	9	4
	500	81.7	--	614	232	602	229	491	192	192	81

SITE INDEX 50 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	10	0.2	25	--	--	--	--	--	--	--	--
3	58	2.9	26	--	--	--	--	--	--	--	--
4	137	12.0	28	--	--	--	--	--	--	--	--
5	183	25.0	32	203	77	196	74	132	53	--	--
6	141	27.7	36	246	93	241	92	197	78	58	26
7	58	15.5	37	142	54	141	54	125	49	74	31
8	11	4.0	38	36	14	36	14	33	13	25	10
9	1	0.4	38	4	1	4	1	4	1	3	1
	600	87.6	--	631	239	617	235	490	193	160	68

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	16	0.4	25	--	--	--	--	--	--	--	--
3	87	4.3	26	--	--	--	--	--	--	--	--
4	189	16.5	29	--	--	--	--	--	--	--	--
5	222	30.3	33	254	96	245	94	166	66	--	--
6	139	27.3	36	247	94	242	93	198	78	58	26
7	42	11.1	37	103	39	101	39	90	35	54	22
8	5	1.9	38	17	7	17	6	16	6	12	5
	700	91.6	--	621	236	606	232	469	186	123	53

SITE INDEX 50 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	26	0.6	25	--	--	--	--	--	--	--	--
3	125	6.1	26	--	--	--	--	--	--	--	--
4	248	21.7	30	--	--	--	--	--	--	--	--
5	251	34.2	34	297	113	286	110	193	78	--	--
6	123	24.1	37	222	85	217	84	177	70	52	24
7	25	6.7	38	63	24	62	24	55	21	33	14
8	2	0.6	38	6	2	6	2	5	2	4	2
	800	94.0	--	587	224	571	220	431	172	89	39

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	3	0.2	30	--	--	--	--	--	--	--	--
4	19	1.6	31	--	--	--	--	--	--	--	--
5	43	5.8	33	49	19	47	18	32	13	--	--
6	64	12.5	37	115	44	113	43	92	37	27	12
7	69	18.3	41	185	72	183	71	162	64	97	41
8	55	19.0	44	205	80	203	80	188	75	140	58
9	31	13.9	46	155	61	154	60	146	58	121	49
10	13	7.0	47	79	31	79	31	76	30	67	27
11	4	2.4	47	27	11	27	10	26	10	24	10
12	1	0.6	47	7	3	7	3	7	3	6	2
	300	81.4	--	822	319	813	317	729	289	481	199

SITE INDEX 50 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	7	0.3	30	--	--	--	--	--	--	--	--
4	33	2.8	31	--	--	--	--	--	--	--	--
5	68	9.3	34	80	31	78	30	52	21	--	--
6	94	18.4	38	175	68	172	67	140	56	41	19
7	91	24.4	42	254	99	251	98	222	89	133	56
8	64	22.2	45	244	96	242	95	224	89	167	69
9	31	13.7	46	154	60	153	60	145	58	120	49
10	10	5.6	47	63	25	63	25	60	24	53	21
11	3	1.7	47	19	7	19	7	18	7	17	7
	400	98.3	--	990	385	977	381	863	344	530	222

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	13	0.6	31	--	--	--	--	--	--	--	--
4	51	4.5	32	--	--	--	--	--	--	--	--
5	99	13.5	35	120	46	116	45	78	32	--	--
6	125	24.6	39	242	94	238	93	194	78	57	26
7	110	29.4	43	314	123	310	122	275	110	164	70
8	66	23.2	45	259	102	257	101	238	95	177	74
9	27	11.8	46	135	53	134	53	127	50	105	43
10	7	3.8	47	43	17	43	17	41	16	36	15
11	1	0.8	47	9	4	9	4	9	3	8	3
	500	112.3	--	1122	437	1106	433	962	385	546	231

SITE INDEX 50 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	30	--	--	--	--	--	--	--	--
3	21	1.0	31	--	--	--	--	--	--	--	--
4	75	6.5	32	--	--	--	--	--	--	--	--
5	135	18.4	36	168	65	162	63	110	44	--	--
6	157	30.9	40	313	122	306	120	250	101	73	34
7	123	32.8	44	358	141	354	139	313	126	187	80
8	63	22.1	46	250	98	248	98	229	92	171	71
9	21	9.2	47	105	41	104	41	99	39	82	34
10	4	2.3	47	26	10	26	10	25	10	22	9
11	1	0.3	47	4	1	4	1	4	1	3	1
	600	123.6	--	1223	478	1204	472	1030	414	537	229

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	30	--	--	--	--	--	--	--	--
3	31	1.5	31	--	--	--	--	--	--	--	--
4	104	9.1	33	--	--	--	--	--	--	--	--
5	176	24.0	37	224	87	216	84	146	59	--	--
6	187	36.7	41	381	149	373	147	305	124	89	42
7	128	34.3	45	381	150	376	149	334	135	199	85
8	56	19.4	46	221	87	219	87	203	81	151	63
9	14	6.4	47	73	29	73	29	69	27	57	23
10	2	1.3	47	14	6	14	6	14	5	12	5
	700	132.6	--	1295	507	1273	501	1071	432	508	219

SITE INDEX 50 AGE 20 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.1	30	--	--	--	--	--	--	--	--
3	45	2.2	31	--	--	--	--	--	--	--	--
4	140	12.2	33	--	--	--	--	--	--	--	--
5	220	30.0	38	288	112	278	109	188	77	--	--
6	211	41.5	42	442	174	433	171	354	144	103	49
7	126	33.7	45	380	150	375	149	333	135	198	85
8	45	15.7	47	180	71	178	70	165	66	123	51
9	9	4.0	47	46	18	45	18	43	17	36	15
10	1	0.6	47	6	2	6	2	6	2	5	2
	800	139.9	--	1342	527	1316	519	1088	441	465	202

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
4	7	0.6	35	--	--	--	--	--	--	--	--
5	27	3.7	36	34	13	33	13	22	9	--	--
6	49	9.6	40	96	37	94	37	77	31	22	10
7	62	16.5	44	180	71	178	70	158	63	94	40
8	60	20.9	48	247	98	245	97	226	91	169	71
9	46	20.3	51	253	101	251	100	238	96	197	82
10	28	15.3	53	196	78	196	78	188	76	165	68
11	14	9.0	54	117	47	116	46	113	45	103	42
12	5	4.1	54	53	21	53	21	52	21	48	20
13	2	1.8	54	24	9	24	9	23	9	22	9
	300	101.8	--	1200	475	1190	473	1098	443	820	342

SITE INDEX 50 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
4	14	1.2	35	--	--	--	--	--	--	--	--
5	45	6.1	37	58	22	56	22	38	15	--	--
6	74	14.6	41	149	58	146	57	119	48	35	16
7	87	23.2	45	261	103	258	102	229	93	136	59
8	78	27.1	49	328	131	326	130	301	122	224	95
9	54	23.9	52	304	121	302	121	286	116	236	99
10	29	16.1	53	209	84	208	83	200	81	175	73
11	13	8.3	54	108	43	108	43	104	42	95	39
12	4	3.2	54	42	17	42	17	41	16	38	16
13	1	1.2	54	15	6	15	6	15	6	14	6
	400	124.9	--	1474	585	1460	581	1333	540	954	401

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	1	0.1	35	--	--	--	--	--	--	--	--
4	24	2.1	35	--	--	--	--	--	--	--	--
5	67	9.1	38	87	34	84	33	57	23	--	--
6	103	20.2	42	212	83	207	82	169	69	50	23
7	112	30.0	46	346	137	342	136	303	123	181	78
8	92	32.3	50	399	160	396	159	366	149	273	116
9	58	25.8	52	332	133	330	133	313	127	259	108
10	28	15.4	54	202	81	201	81	193	78	170	70
11	10	6.9	54	90	36	90	36	87	35	79	33
12	3	2.3	54	30	12	30	12	29	12	27	11
13	1	0.6	54	8	3	8	3	8	3	8	3
	500	144.8	--	1707	679	1689	674	1527	620	1045	442

SITE INDEX 50 AGE 25 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	2	0.1	35	--	--	--	--	--	--	--	--
4	37	3.2	35	--	--	--	--	--	--	--	--
5	93	12.6	38	123	48	118	46	80	33	--	--
6	134	26.3	43	283	111	277	110	226	92	66	31
7	137	36.5	47	431	172	426	170	378	154	225	98
8	104	36.2	51	455	182	452	181	418	170	311	132
9	59	26.1	53	339	136	337	136	320	130	264	111
10	25	13.8	54	181	72	180	72	173	70	152	63
11	8	5.3	54	69	28	69	28	67	27	61	25
12	2	1.7	54	23	9	23	9	22	9	21	8
	600	161.7	--	1904	758	1882	752	1684	686	1100	468

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
5	13	1.8	38	18	7	17	7	11	5	--	--
6	36	7.2	41	74	29	72	28	59	24	17	8
7	53	14.2	45	160	63	158	63	140	57	84	36
8	58	20.2	50	250	100	248	99	229	93	170	72
9	52	22.8	54	302	121	300	121	284	116	235	99
10	39	21.1	57	292	118	291	118	280	114	245	103
11	25	16.3	58	232	94	231	94	225	92	204	85
12	14	10.7	59	153	62	153	62	150	61	139	58
13	6	5.9	60	86	35	85	35	84	34	79	33
14	3	2.8	60	41	16	40	16	40	16	38	16
15	1	1.6	60	23	9	23	9	23	9	22	9
	300	124.7	--	1629	654	1618	651	1525	621	1234	517

SITE INDEX 50 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	1	0.1	38	--	--	--	--	--	--	--	--
5	25	3.4	39	33	13	32	13	22	9	--	--
6	57	11.2	42	118	46	115	45	94	38	28	13
7	77	20.5	46	238	94	235	94	208	85	124	54
8	79	27.5	51	348	140	345	139	319	131	238	101
9	66	29.1	55	393	159	390	158	370	152	306	129
10	46	25.1	57	352	143	351	143	338	138	296	124
11	27	18.0	59	258	104	257	104	249	102	227	95
12	14	10.8	60	156	63	155	63	152	62	141	59
13	6	5.5	60	79	32	79	32	77	31	73	30
14	2	2.3	60	34	14	34	14	33	13	32	13
15	1	1.1	60	16	7	16	7	16	7	16	6
	400	154.5	--	2024	814	2009	810	1879	768	1479	623

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 50 AGE 30 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	3	0.3	38	--	--	--	--	--	--	--	--
5	39	5.3	39	53	21	51	20	35	14	--	--
6	80	15.8	43	170	67	166	66	136	55	40	19
7	102	27.3	48	324	129	320	128	284	116	169	74
8	99	34.5	52	447	180	443	179	410	168	305	130
9	78	34.4	56	472	191	469	190	445	183	367	156
10	51	27.7	58	393	160	392	159	377	155	330	139
11	28	18.4	59	265	107	264	107	256	105	233	97
12	13	10.1	60	146	59	146	59	143	58	133	55
13	5	4.6	60	67	27	67	27	66	27	62	26
14	2	1.8	60	26	10	25	10	25	10	24	10
15	1	0.7	60	11	4	11	4	10	4	10	4
	500	180.8	--	2373	956	2354	951	2186	896	1674	709

SITE INDEX 60 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	3	0.1	24	--	--	--	--	--	--	--	--
3	16	0.8	24	--	--	--	--	--	--	--	--
4	39	3.4	25	--	--	--	--	--	--	--	--
5	67	9.1	28	63	23	61	22	41	16	--	--
6	78	15.4	30	115	43	113	42	92	35	27	12
7	60	16.1	32	128	48	126	47	112	43	67	27
8	28	9.8	34	80	30	79	29	73	28	54	21
9	7	3.1	34	25	9	25	9	24	9	20	8
10	1	0.5	34	4	1	4	1	4	1	3	1
	300	58.2	--	415	154	408	152	346	132	171	69

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	7	0.2	24	--	--	--	--	--	--	--	--
3	29	1.4	24	--	--	--	--	--	--	--	--
4	68	6.0	26	--	--	--	--	--	--	--	--
5	105	14.3	29	103	38	99	37	67	26	--	--
6	104	20.5	31	159	59	156	58	127	49	37	17
7	62	16.7	33	136	51	134	50	119	45	71	29
8	20	7.0	34	57	21	57	21	52	20	39	15
9	3	1.4	34	11	4	11	4	11	4	9	3
	400	67.4	--	466	173	457	171	376	144	156	64

SITE INDEX 60 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	1	0.0	24	--	--	--	--	--	--	--	--
2	13	0.3	24	--	--	--	--	--	--	--	--
3	49	2.4	25	--	--	--	--	--	--	--	--
4	108	9.4	27	--	--	--	--	--	--	--	--
5	146	19.9	30	148	55	143	54	97	38	--	--
6	119	23.4	32	187	70	184	69	150	58	44	20
7	52	14.0	34	115	43	114	43	101	39	60	25
8	11	3.7	34	30	11	30	11	28	11	21	8
9	1	0.4	34	3	1	3	1	3	1	2	1
	500	73.5	--	484	181	473	178	378	146	127	53

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	2	0.0	24	--	--	--	--	--	--	--	--
2	21	0.5	24	--	--	--	--	--	--	--	--
3	78	3.9	25	--	--	--	--	--	--	--	--
4	157	13.7	27	--	--	--	--	--	--	--	--
5	184	25.1	31	194	72	187	70	126	50	--	--
6	118	23.1	33	189	71	185	70	152	59	44	20
7	35	9.4	34	78	29	77	29	68	26	41	17
8	4	1.4	34	12	4	12	4	11	4	8	3
	600	77.1	--	473	177	461	174	357	139	93	40

SITE INDEX 60 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	3	0.0	24	--	--	--	--	--	--	--	--
2	34	0.8	24	--	--	--	--	--	--	--	--
3	118	5.8	25	--	--	--	--	--	--	--	--
4	214	18.7	28	--	--	--	--	--	--	--	--
5	211	28.7	32	228	86	220	83	149	59	--	--
6	99	19.5	33	162	61	159	60	130	51	38	17
7	18	4.9	34	41	15	41	15	36	14	21	9
8	1	0.4	34	3	1	3	1	3	1	2	1
	700	78.8	--	435	163	423	160	317	124	61	27

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	5	0.0	24	--	--	--	--	--	--	--	--
2	53	1.2	24	--	--	--	--	--	--	--	--
3	171	8.4	26	--	--	--	--	--	--	--	--
4	275	24.0	29	--	--	--	--	--	--	--	--
5	217	29.6	32	241	91	233	89	157	63	--	--
6	70	13.8	34	116	44	114	43	93	36	27	12
7	7	2.0	34	16	6	16	6	14	6	9	4
	800	79.0	--	374	141	363	138	265	104	36	16

SITE INDEX 60 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	31	--	--	--	--	--	--	--	--
3	7	0.4	32	--	--	--	--	--	--	--	--
4	23	2.0	33	--	--	--	--	--	--	--	--
5	46	6.3	35	55	21	53	20	36	14	--	--
6	65	12.7	38	121	46	118	46	97	39	28	13
7	68	18.1	41	185	72	182	71	162	64	96	41
8	51	17.9	44	192	75	191	75	176	70	131	54
9	27	11.9	45	132	51	131	51	124	49	102	42
10	9	5.1	46	57	22	57	22	55	21	48	19
11	2	1.5	46	17	7	17	7	16	6	15	6
	300	76.0	--	758	294	749	292	666	264	421	175

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	31	--	--	--	--	--	--	--	--
3	14	0.7	32	--	--	--	--	--	--	--	--
4	40	3.5	33	--	--	--	--	--	--	--	--
5	73	9.9	36	89	34	86	33	58	24	--	--
6	95	18.6	39	182	70	178	69	146	58	43	20
7	88	23.6	42	248	97	245	96	217	87	129	55
8	57	19.9	44	218	85	216	85	200	80	149	62
9	24	10.7	46	120	47	119	47	113	45	93	38
10	6	3.5	46	39	15	39	15	37	15	33	13
11	1	0.7	46	8	3	8	3	7	3	7	3
	400	91.2	--	903	351	891	348	778	311	453	190

SITE INDEX 60 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	3	0.1	31	--	--	--	--	--	--	--	--
3	23	1.1	32	--	--	--	--	--	--	--	--
4	61	5.3	33	--	--	--	--	--	--	--	--
5	105	14.4	36	133	51	128	50	86	35	--	--
6	126	24.7	40	248	96	243	95	199	80	58	27
7	103	27.6	43	296	116	293	115	259	104	155	66
8	56	19.5	45	217	85	215	84	199	79	148	62
9	19	8.3	46	93	36	92	36	87	35	72	29
10	4	2.2	46	24	9	24	9	23	9	20	8
	500	103.2	--	1010	394	995	390	854	342	453	192

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60   AGE 15   STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	6	0.1	31	--	--	--	--	--	--	--	--
3	35	1.7	32	--	--	--	--	--	--	--	--
4	89	7.7	34	--	--	--	--	--	--	--	--
5	143	19.5	37	184	71	178	69	120	49	--	--
6	155	30.4	41	314	122	307	121	251	102	73	34
7	110	29.5	44	323	127	319	126	283	114	169	72
8	49	17.1	45	191	75	190	75	176	70	131	54
9	13	5.5	46	62	24	62	24	58	23	48	20
10	2	1.0	46	11	4	11	4	10	4	9	4
	600	112.5	--	1085	424	1066	419	898	362	430	184

SITE INDEX 60   AGE 15   STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	9	0.2	31	--	--	--	--	--	--	--	--
3	51	2.5	32	--	--	--	--	--	--	--	--
4	122	10.7	34	--	--	--	--	--	--	--	--
5	184	25.1	38	244	95	235	92	159	65	--	--
6	179	35.1	42	372	146	364	144	298	121	87	41
7	109	29.1	45	323	127	319	126	283	114	169	72
8	38	13.4	46	151	59	150	59	138	55	103	43
9	7	3.2	46	35	14	35	14	33	13	28	11
10	1	0.4	46	4	2	4	2	4	2	3	1
	700	119.6	--	1128	442	1107	436	915	370	390	169

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	14	0.3	31	--	--	--	--	--	--	--	--
3	71	3.5	32	--	--	--	--	--	--	--	--
4	163	14.3	35	--	--	--	--	--	--	--	--
5	227	30.9	39	308	120	298	117	201	83	--	--
6	195	38.3	43	414	163	406	161	332	135	97	46
7	99	26.4	45	296	117	293	116	260	105	155	67
8	27	9.3	46	106	42	105	41	97	39	72	30
9	4	1.6	46	18	7	18	7	17	7	14	6
	800	124.7	--	1143	449	1120	442	907	369	338	148

SITE INDEX 60 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	2	0.1	38	--	--	--	--	--	--	--	--
4	13	1.2	38	--	--	--	--	--	--	--	--
5	31	4.3	40	44	17	42	17	28	12	--	--
6	50	9.8	43	108	42	105	42	86	35	25	12
7	61	16.3	47	192	76	190	76	168	69	100	44
8	58	20.3	51	256	102	254	102	235	96	175	74
9	43	19.2	54	253	102	251	101	238	97	197	83
10	25	13.7	55	185	74	184	74	177	72	155	65
11	11	7.3	56	99	40	99	40	96	39	87	36
12	4	2.8	56	38	15	38	15	37	15	35	14
13	1	0.9	56	13	5	13	5	12	5	12	5
	300	95.9	--	1187	475	1176	472	1079	440	786	332

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 400

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	5	0.2	38	--	--	--	--	--	--	--	--
4	23	2.0	39	--	--	--	--	--	--	--	--
5	50	6.8	41	71	28	68	27	46	19	--	--
6	75	14.7	44	165	65	162	64	132	54	39	18
7	85	22.8	48	276	110	272	109	241	99	144	63
8	75	26.0	52	336	135	333	134	308	126	229	98
9	50	22.1	54	296	119	294	119	279	114	231	97
10	25	13.8	56	188	76	187	76	180	74	158	66
11	9	6.3	56	85	34	85	34	83	34	75	31
12	3	2.0	56	27	11	27	11	26	11	25	10
13	1	0.5	56	7	3	7	3	7	3	6	3
	400	117.2	--	1450	582	1436	577	1303	533	906	386

SITE INDEX 60 AGE 20 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	8	0.4	38	--	--	--	--	--	--	--	--
4	35	3.1	39	--	--	--	--	--	--	--	--
5	72	9.9	42	105	41	101	40	68	28	--	--
6	103	20.2	45	232	92	227	91	185	76	54	26
7	109	29.1	50	362	145	357	144	317	130	189	83
8	88	30.5	53	401	162	398	161	368	151	274	117
9	53	23.2	55	314	127	312	126	296	121	245	103
10	23	12.6	56	172	70	172	69	165	67	145	60
11	7	4.8	56	65	26	65	26	63	26	57	24
12	2	1.4	56	19	8	19	8	19	8	18	7
	500	135.2	--	1670	671	1651	665	1481	608	981	420

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	13	0.7	38	--	--	--	--	--	--	--	--
4	51	4.4	39	--	--	--	--	--	--	--	--
5	99	13.5	42	146	58	140	56	95	40	--	--
6	133	26.1	46	306	122	300	121	245	101	72	34
7	131	35.1	51	445	179	439	178	390	161	232	102
8	96	33.5	54	447	181	443	180	410	169	305	131
9	51	22.6	55	308	125	306	124	290	119	240	101
10	19	10.5	56	144	58	144	58	138	56	121	51
11	5	3.3	56	45	18	45	18	44	18	40	16
12	1	0.8	56	10	4	10	4	10	4	9	4
	600	150.4	--	1851	745	1828	738	1622	668	1019	439

SITE INDEX 60 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	5	0.5	43	--	--	--	--	--	--	--	--
5	21	2.8	44	32	13	31	12	21	9	--	--
6	38	7.5	47	90	36	88	35	72	30	21	10
7	52	13.8	51	177	71	175	71	155	64	92	41
8	56	19.5	55	268	109	265	108	245	102	183	79
9	50	21.9	59	319	130	317	130	300	125	248	106
10	37	20.0	62	303	124	302	124	290	121	254	108
11	23	15.0	63	232	95	231	95	224	93	204	86
12	12	9.2	64	143	59	143	59	140	58	130	55
13	5	4.6	65	72	30	72	30	71	29	67	28
14	2	1.9	65	29	12	29	12	29	12	28	12
15	1	0.8	65	13	5	13	5	12	5	12	5
	300	117.6	--	1677	684	1665	681	1560	646	1239	529

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	10	0.9	43	--	--	--	--	--	--	--	--
5	34	4.6	45	52	21	50	20	34	14	--	--
6	58	11.4	48	139	56	136	55	111	46	32	16
7	74	19.8	52	260	105	257	104	228	94	136	60
8	75	26.3	56	370	151	367	150	340	141	253	110
9	63	27.8	60	411	169	409	168	388	161	320	137
10	43	23.5	62	360	148	359	148	345	144	303	129
11	24	16.2	64	251	103	250	103	243	101	221	94
12	11	9.0	64	140	58	140	57	137	57	127	53
13	4	4.0	65	63	26	62	26	61	25	58	24
14	2	1.9	65	29	12	29	12	29	12	28	11
	400	145.4	--	2076	849	2060	844	1916	796	1478	634

SITE INDEX 60 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	1	0.0	43	--	--	--	--	--	--	--	--
4	17	1.5	43	--	--	--	--	--	--	--	--
5	49	6.7	45	78	31	75	30	51	21	--	--
6	81	15.9	49	196	79	192	78	157	66	46	22
7	98	26.2	53	351	143	346	141	307	128	183	81
8	94	32.9	58	472	193	468	192	433	181	322	140
9	74	32.5	61	489	201	486	201	461	193	381	164
10	47	25.6	63	395	163	394	162	379	158	332	142
11	24	16.0	64	251	103	250	103	243	101	221	93
12	10	8.0	65	125	52	125	51	122	51	114	48
13	3	3.2	65	50	20	49	20	49	20	46	19
14	1	1.2	65	19	8	19	8	19	8	18	8
	500	169.8	--	2426	993	2406	988	2221	925	1663	717

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
5	10	1.4	47	17	7	16	7	11	5	--	--
6	29	5.6	49	70	28	69	28	56	23	16	8
7	44	11.6	53	155	63	153	62	136	57	81	36
8	51	17.8	58	255	105	253	104	234	98	174	76
9	50	22.0	62	337	139	336	139	318	133	263	113
10	42	23.0	65	370	154	368	153	355	149	311	133
11	31	20.6	68	343	143	342	143	332	140	302	129
12	21	16.1	70	273	114	272	114	267	112	248	106
13	12	11.0	71	189	78	188	78	185	77	175	74
14	6	6.7	71	114	47	114	47	112	47	107	45
15	3	3.5	71	61	25	60	25	60	25	58	24
16	1	1.7	72	28	12	28	12	28	12	27	11
17	1	1.0	72	17	7	17	7	17	7	17	7
	300	142.1	--	2229	922	2218	919	2111	884	1779	763

SITE INDEX 60 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	1	0.1	47	--	--	--	--	--	--	--	--
5	19	2.6	47	31	13	30	12	20	9	--	--
6	44	8.7	50	111	45	108	44	88	37	26	13
7	63	16.9	54	231	94	228	93	202	84	121	54
8	71	24.6	59	362	149	359	148	332	139	247	108
9	66	29.1	63	455	189	452	188	429	180	354	153
10	53	28.9	66	473	197	471	196	453	191	397	171
11	37	24.6	69	413	172	412	172	401	169	364	156
12	23	18.1	70	309	129	308	129	302	127	281	120
13	13	11.6	71	199	83	199	83	196	82	185	78
14	6	6.5	71	112	47	112	46	110	46	106	45
15	3	3.2	72	55	23	55	23	54	23	52	22
16	1	2.0	72	35	14	35	14	35	14	34	14
	400	177.1	--	2786	1153	2769	1149	2622	1100	2166	933

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	30	--	--	--	--	--	--	--	--
3	10	0.5	31	--	--	--	--	--	--	--	--
4	27	2.4	32	--	--	--	--	--	--	--	--
5	50	6.8	33	58	22	56	21	38	15	--	--
6	68	13.4	36	120	46	118	45	96	38	28	13
7	68	18.1	38	171	66	169	65	150	59	89	37
8	47	16.3	40	159	61	158	61	146	57	109	44
9	21	9.1	41	91	35	90	35	85	33	71	28
10	5	2.9	41	29	11	29	11	28	11	25	10
11	1	0.5	41	5	2	5	2	5	2	5	2
	300	70.2	--	633	242	625	240	548	215	326	134

SITE INDEX 70 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	4	0.1	30	--	--	--	--	--	--	--	--
3	19	0.9	31	--	--	--	--	--	--	--	--
4	47	4.1	32	--	--	--	--	--	--	--	--
5	80	10.9	34	94	36	91	35	61	25	--	--
6	99	19.4	37	179	68	175	67	143	57	42	19
7	85	22.7	39	220	84	217	84	192	76	115	48
8	47	16.5	41	164	63	162	63	150	59	112	46
9	15	6.8	41	68	26	68	26	64	25	53	21
10	3	1.6	41	16	6	16	6	15	6	13	5
	400	83.1	--	740	284	729	281	626	247	335	139

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	30	--	--	--	--	--	--	--	--
2	8	0.2	30	--	--	--	--	--	--	--	--
3	31	1.5	31	--	--	--	--	--	--	--	--
4	73	6.3	32	--	--	--	--	--	--	--	--
5	116	15.9	35	140	54	135	52	91	37	--	--
6	129	25.2	38	238	91	233	90	191	76	56	26
7	93	24.8	40	245	94	242	94	214	85	128	54
8	40	14.0	41	140	54	139	54	129	51	96	39
9	9	4.1	41	41	16	41	16	38	15	32	13
10	1	0.6	41	6	2	6	2	5	2	5	2
	500	92.6	--	810	311	796	307	669	265	316	133

SITE INDEX 70 AGE 10 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	30	--	--	--	--	--	--	--	--
2	13	0.3	31	--	--	--	--	--	--	--	--
3	48	2.3	31	--	--	--	--	--	--	--	--
4	106	9.3	33	--	--	--	--	--	--	--	--
5	157	21.4	36	194	74	187	72	126	51	--	--
6	152	29.9	39	289	111	283	110	231	92	68	31
7	90	24.0	40	240	93	238	92	211	84	126	53
8	29	10.1	41	101	39	101	39	93	37	69	28
9	5	2.0	41	20	8	20	8	19	7	16	6
	600	99.3	--	845	326	828	321	680	271	278	119

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	2	0.0	30	--	--	--	--	--	--	--	--
2	19	0.4	31	--	--	--	--	--	--	--	--
3	70	3.4	31	--	--	--	--	--	--	--	--
4	148	12.9	34	--	--	--	--	--	--	--	--
5	199	27.2	37	252	97	243	95	164	67	--	--
6	166	32.6	39	321	124	314	122	257	103	75	35
7	77	20.6	41	208	81	205	80	182	72	109	46
8	17	6.0	41	61	23	60	23	56	22	42	17
9	2	0.7	41	7	3	7	3	7	3	6	2
	700	103.8	--	848	328	830	323	666	267	231	100

SITE INDEX 70 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	3	0.0	30	--	--	--	--	--	--	--	--
2	29	0.6	31	--	--	--	--	--	--	--	--
3	100	4.9	32	--	--	--	--	--	--	--	--
4	197	17.2	34	--	--	--	--	--	--	--	--
5	239	32.6	37	310	120	299	117	202	82	--	--
6	166	32.5	40	325	126	319	125	261	105	76	35
7	58	15.4	41	157	61	155	60	137	55	82	35
8	9	3.1	41	31	12	31	12	29	11	21	9
	800	106.3	--	823	319	803	313	628	253	179	79

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	39	--	--	--	--	--	--	--	--
3	5	0.3	39	--	--	--	--	--	--	--	--
4	17	1.5	40	--	--	--	--	--	--	--	--
5	36	4.9	41	51	20	49	20	33	14	--	--
6	54	10.6	44	118	47	116	46	94	39	28	13
7	63	16.9	48	200	80	198	79	176	72	105	45
8	57	20.0	50	250	100	248	99	229	93	170	72
9	39	17.2	53	223	89	221	89	210	85	173	73
10	19	10.5	54	138	55	137	55	132	54	116	48
11	7	4.4	54	58	23	58	23	56	23	51	21
12	2	1.4	54	18	7	18	7	18	7	17	7
	300	87.6	--	1056	421	1045	418	948	386	659	279

SITE INDEX 70 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	39	--	--	--	--	--	--	--	--
3	10	0.5	39	--	--	--	--	--	--	--	--
4	29	2.5	40	--	--	--	--	--	--	--	--
5	56	7.7	42	82	33	79	32	54	22	--	--
6	80	15.8	45	180	71	176	70	144	59	42	20
7	87	23.3	49	283	113	279	112	248	102	148	64
8	71	24.8	51	316	127	313	126	290	118	215	92
9	42	18.6	53	243	98	242	97	229	93	189	80
10	17	9.5	54	125	50	125	50	120	49	105	44
11	5	3.2	54	41	17	41	17	40	16	36	15
12	1	0.7	54	9	4	9	4	9	4	8	3
	400	106.5	--	1280	512	1265	508	1133	463	745	318

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.1	39	--	--	--	--	--	--	--	--
3	16	0.8	39	--	--	--	--	--	--	--	--
4	44	3.9	40	--	--	--	--	--	--	--	--
5	81	11.1	43	121	48	117	47	79	33	--	--
6	109	21.5	46	250	100	245	98	200	83	59	28
7	109	29.2	50	363	145	358	144	318	131	189	83
8	80	27.8	52	360	145	357	144	330	135	246	105
9	41	17.9	54	236	95	235	95	223	91	184	77
10	14	7.5	54	99	40	99	40	95	39	83	35
11	3	2.2	54	29	12	29	12	28	11	25	10
	500	121.9	--	1458	585	1440	579	1273	523	786	338

SITE INDEX 70 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	4	0.1	39	--	--	--	--	--	--	--	--
3	24	1.2	39	--	--	--	--	--	--	--	--
4	63	5.5	41	--	--	--	--	--	--	--	--
5	111	15.1	43	168	67	162	65	110	46	--	--
6	140	27.5	47	328	131	321	129	262	109	77	37
7	128	34.3	50	433	174	428	173	379	157	226	99
8	83	28.8	53	377	152	374	151	346	142	258	110
9	36	15.7	54	208	84	207	84	196	80	162	68
10	10	5.3	54	70	28	70	28	67	27	59	24
11	2	1.1	54	15	6	15	6	14	6	13	5
	600	134.6	--	1599	642	1576	636	1375	566	794	344

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	6	0.1	39	--	--	--	--	--	--	--	--
3	34	1.7	39	--	--	--	--	--	--	--	--
4	87	7.6	41	--	--	--	--	--	--	--	--
5	145	19.8	44	223	89	216	87	146	61	--	--
6	171	33.6	48	408	164	400	161	327	136	96	46
7	142	37.9	51	487	197	481	195	427	177	255	112
8	80	27.8	53	367	148	364	148	337	139	251	107
9	28	12.6	54	167	67	166	67	158	64	130	55
10	6	3.3	54	44	18	43	17	42	17	37	15
11	1	0.5	54	6	3	6	3	6	3	6	2
	700	144.8	--	1703	686	1677	678	1442	596	773	338

SITE INDEX 70 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	9	0.2	39	--	--	--	--	--	--	--	--
3	47	2.3	39	--	--	--	--	--	--	--	--
4	115	10.1	41	--	--	--	--	--	--	--	--
5	183	24.9	45	287	115	277	112	187	79	--	--
6	200	39.3	49	487	196	478	193	390	163	114	55
7	149	39.9	52	519	210	513	208	455	189	271	120
8	72	25.0	54	333	135	330	134	305	126	227	98
9	21	9.2	54	122	49	121	49	115	47	95	40
10	4	2.0	54	26	10	26	10	25	10	22	9
	800	152.8	--	1775	716	1745	707	1478	613	730	321

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	2	0.1	46	--	--	--	--	--	--	--	--
4	10	0.9	46	--	--	--	--	--	--	--	--
5	25	3.4	48	42	17	40	16	27	12	--	--
6	41	8.1	51	104	42	102	42	84	35	24	12
7	54	14.3	54	196	80	193	79	171	72	102	45
8	56	19.6	58	285	117	283	116	261	109	195	85
9	48	21.3	61	323	133	322	133	305	127	252	108
10	33	18.2	64	285	118	284	117	273	114	239	102
11	19	12.3	65	194	80	194	80	188	78	171	73
12	8	6.4	66	102	42	101	42	99	41	92	39
13	3	2.5	66	40	17	40	17	40	16	37	16
14	1	0.9	66	15	6	15	6	14	6	14	6
	300	108.1	--	1586	652	1574	648	1463	611	1127	486

SITE INDEX 70 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	4	0.2	46	--	--	--	--	--	--	--	--
4	18	1.5	46	--	--	--	--	--	--	--	--
5	39	5.4	48	67	27	64	26	43	19	--	--
6	62	12.2	52	160	65	156	64	128	54	37	18
7	76	20.4	56	285	117	281	116	249	105	149	66
8	75	26.3	59	389	160	386	159	357	150	265	116
9	60	26.4	62	407	168	405	168	384	161	317	137
10	38	20.6	64	325	135	324	134	312	130	273	117
11	19	12.4	65	197	81	196	81	191	80	173	74
12	7	5.6	66	90	37	89	37	87	36	81	34
13	2	1.9	66	30	12	30	12	30	12	28	12
14	1	0.6	66	9	4	9	4	9	4	8	3
	400	133.3	--	1958	806	1941	801	1789	750	1333	577

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	6	0.3	46	--	--	--	--	--	--	--	--
4	27	2.3	47	--	--	--	--	--	--	--	--
5	57	7.7	49	97	40	94	38	63	27	--	--
6	86	16.8	52	224	91	219	90	179	76	52	26
7	100	26.7	57	381	156	376	155	333	140	199	89
8	93	32.4	60	488	201	484	200	447	188	333	146
9	68	30.1	63	470	195	467	194	443	186	366	158
10	39	21.3	65	339	141	338	140	325	136	285	122
11	17	11.4	65	182	75	181	75	176	73	160	68
12	6	4.5	66	71	29	71	29	70	29	65	27
13	2	1.5	66	24	10	24	10	24	10	23	9
	500	155.0	--	2276	939	2255	932	2061	866	1482	646

SITE INDEX 70 AGE 20 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	10	0.5	46	--	--	--	--	--	--	--	--
4	38	3.3	47	--	--	--	--	--	--	--	--
5	77	10.5	49	134	55	129	53	87	37	--	--
6	112	21.9	53	297	122	291	120	238	101	70	34
7	124	33.2	58	481	198	475	196	421	178	251	113
8	108	37.7	61	576	239	571	237	528	223	393	173
9	73	32.3	64	509	211	506	211	480	202	397	172
10	38	20.6	65	330	137	329	137	316	133	277	119
11	15	9.7	66	155	64	155	64	151	63	137	58
12	4	3.3	66	52	22	52	22	51	21	48	20
13	1	0.9	66	14	6	14	6	14	6	13	6
	600	173.9	--	2550	1053	2524	1045	2287	964	1586	694

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	4	0.4	51	--	--	--	--	--	--	--	--
5	17	2.3	52	31	13	30	12	20	9	--	--
6	32	6.3	55	88	36	86	36	70	30	21	10
7	45	11.9	59	177	73	175	73	155	66	92	42
8	51	17.8	63	281	117	279	116	258	109	192	85
9	49	21.7	67	362	152	360	151	341	145	282	123
10	41	22.1	70	384	161	382	161	368	156	323	140
11	29	19.0	72	338	142	337	142	327	139	298	129
12	18	13.8	74	248	104	248	104	242	103	225	97
13	9	8.4	75	153	64	152	64	150	63	142	61
14	4	4.4	75	79	33	79	33	77	33	74	32
15	2	1.9	75	34	14	34	14	34	14	32	14
16	1	0.9	75	17	7	16	7	16	7	16	7
	300	130.9	--	2191	917	2178	913	2059	874	1696	739

SITE INDEX 70 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	8	0.7	51	--	--	--	--	--	--	--	--
5	27	3.7	53	50	21	49	20	33	14	--	--
6	48	9.5	56	135	56	132	55	108	46	32	16
7	64	17.2	60	261	108	257	107	228	97	136	62
8	70	24.5	64	395	165	392	164	363	154	270	120
9	64	28.5	68	483	203	480	202	455	194	376	165
10	50	27.4	71	482	203	480	203	462	197	405	177
11	33	22.1	73	396	167	395	167	384	163	349	151
12	19	14.8	74	269	113	268	113	263	111	244	105
13	9	8.4	75	152	64	151	64	149	63	141	60
14	4	3.9	75	71	30	71	30	70	29	67	28
15	2	2.1	75	38	16	38	16	37	16	36	15
	400	162.8	--	2731	1145	2713	1140	2551	1085	2055	899

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	1	0.0	51	--	--	--	--	--	--	--	--
4	14	1.2	51	--	--	--	--	--	--	--	--
5	40	5.4	53	74	31	71	30	48	21	--	--
6	67	13.1	57	189	78	186	77	152	65	44	22
7	86	22.9	61	353	147	349	146	309	132	184	84
8	90	31.3	65	513	215	509	214	471	201	350	156
9	78	34.7	69	596	251	593	250	562	240	464	204
10	58	31.6	72	561	237	558	236	537	229	471	206
11	36	23.8	74	430	182	429	181	417	177	379	164
12	19	14.9	75	270	114	270	114	264	112	245	106
13	8	7.7	75	140	59	139	59	137	58	130	55
14	3	3.3	75	59	25	59	25	58	25	56	24
15	1	1.5	75	27	11	27	11	27	11	26	11
	500	191.3	--	3213	1349	3189	1342	2981	1271	2349	1031

SITE INDEX 70 AGE 30 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
5	8	1.1	56	16	7	16	7	11	5	--	--
6	24	4.7	58	69	29	68	28	55	24	16	8
7	37	10.0	61	155	65	153	64	136	58	81	37
8	45	15.9	66	262	110	260	109	240	103	179	80
9	47	20.7	70	363	154	361	153	342	147	283	125
10	42	23.2	74	426	181	425	181	409	175	358	157
11	34	22.7	77	432	184	430	183	418	180	380	166
12	25	19.6	80	382	163	381	163	373	160	347	151
13	16	15.1	81	298	127	298	127	293	125	277	120
14	10	10.5	82	207	88	207	88	204	87	195	84
15	5	6.5	82	129	55	128	55	127	54	123	53
16	3	3.6	83	72	30	72	30	71	30	69	30
17	1	1.8	83	36	15	36	15	36	15	35	15
18	1	1.3	83	25	11	25	11	25	11	25	10
	300	156.7	--	2873	1218	2859	1214	2739	1174	2367	1036

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 30 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	1	0.1	55	--	--	--	--	--	--	--	--
5	15	2.1	56	30	13	29	12	20	9	--	--
6	37	7.3	58	109	45	106	45	87	37	25	13
7	55	14.6	62	230	96	227	95	201	86	120	55
8	64	22.2	67	374	157	370	156	343	147	255	114
9	63	27.9	72	497	211	495	210	469	202	387	172
10	55	30.0	75	560	238	557	238	536	231	470	207
11	43	28.1	78	542	231	540	231	525	226	477	209
12	30	23.3	80	456	195	455	195	446	192	415	181
13	19	17.1	81	338	144	338	144	332	143	314	137
14	10	11.2	82	222	95	222	95	219	94	210	91
15	5	6.6	82	130	55	130	55	129	55	124	53
16	2	3.4	83	68	29	68	29	67	29	66	28
17	1	1.6	83	32	14	32	14	32	13	31	13
18	1	1.0	83	20	8	20	8	20	8	20	8
	400	196.4	--	3609	1532	3591	1527	3425	1471	2913	1280

SITE INDEX 80 AGE 10 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	38	--	--	--	--	--	--	--	--
3	8	0.4	38	--	--	--	--	--	--	--	--
4	21	1.8	39	--	--	--	--	--	--	--	--
5	40	5.4	40	56	22	54	21	36	15	--	--
6	58	11.5	42	122	48	120	47	98	40	29	13
7	66	17.6	45	196	77	194	77	172	69	102	44
8	55	19.4	47	223	88	221	87	205	82	152	64
9	33	14.6	48	171	68	170	67	161	65	133	55
10	13	7.1	49	84	33	84	33	80	32	70	29
11	4	2.4	49	28	11	28	11	27	11	25	10
	300	80.3	--	880	347	870	344	779	314	512	215

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 400

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
2	3	0.1	38	--	--	--	--	--	--	--	--
3	14	0.7	38	--	--	--	--	--	--	--	--
4	35	3.0	39	--	--	--	--	--	--	--	--
5	63	8.6	41	90	35	87	34	59	24	--	--
6	87	17.1	43	185	73	182	72	148	61	43	20
7	89	23.8	45	270	107	266	106	236	96	141	61
8	65	22.7	47	265	105	263	104	243	98	181	76
9	32	14.1	48	166	66	165	65	157	63	130	53
10	10	5.3	49	62	24	62	24	60	24	52	21
11	2	1.2	49	14	5	14	5	13	5	12	5
	400	96.6	--	1053	416	1039	412	917	370	560	237

SITE INDEX 80 AGE 10 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
2	5	0.1	38	--	--	--	--	--	--	--	--
3	22	1.1	38	--	--	--	--	--	--	--	--
4	53	4.7	39	--	--	--	--	--	--	--	--
5	92	12.6	41	133	52	128	51	86	36	--	--
6	118	23.1	44	256	101	251	100	205	84	60	28
7	108	28.9	46	333	132	329	131	292	119	174	75
8	67	23.6	48	278	110	276	110	255	103	190	80
9	26	11.7	48	139	55	138	55	131	52	108	45
10	6	3.2	49	38	15	38	15	36	15	32	13
11	1	0.5	49	5	2	5	2	5	2	5	2
	500	109.4	--	1182	467	1165	463	1010	410	568	243

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	38	--	--	--	--	--	--	--	--
2	9	0.2	38	--	--	--	--	--	--	--	--
3	33	1.6	38	--	--	--	--	--	--	--	--
4	77	6.7	40	--	--	--	--	--	--	--	--
5	126	17.2	42	185	73	178	71	120	50	--	--
6	149	29.2	45	329	130	322	128	263	108	77	37
7	121	32.3	47	377	150	372	148	330	134	197	85
8	63	21.9	48	260	103	258	103	239	97	178	75
9	19	8.4	49	100	39	99	39	94	38	78	32
10	3	1.7	49	21	8	21	8	20	8	17	7
	600	119.3	--	1271	504	1251	498	1066	435	547	236

SITE INDEX 80 AGE 10 STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	38	--	--	--	--	--	--	--	--
2	13	0.3	38	--	--	--	--	--	--	--	--
3	47	2.3	39	--	--	--	--	--	--	--	--
4	106	9.3	40	--	--	--	--	--	--	--	--
5	165	22.5	43	245	97	236	94	160	67	--	--
6	177	34.8	45	398	158	390	156	319	131	93	44
7	125	33.3	47	394	157	389	155	345	141	206	89
8	52	18.3	48	219	87	217	86	200	81	149	63
9	12	5.2	49	62	24	61	24	58	23	48	20
10	1	0.7	49	8	3	8	3	8	3	7	3
	700	126.6	--	1325	526	1302	520	1090	446	503	219

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	2	0.0	38	--	--	--	--	--	--	--	--
2	19	0.4	38	--	--	--	--	--	--	--	--
3	66	3.2	39	--	--	--	--	--	--	--	--
4	142	12.4	41	--	--	--	--	--	--	--	--
5	207	28.2	43	312	124	301	121	204	85	--	--
6	200	39.2	46	456	182	447	179	365	151	107	51
7	119	31.7	48	379	151	375	150	332	136	198	86
8	39	13.6	49	164	65	162	65	150	61	112	47
9	7	2.9	49	35	14	35	14	33	13	27	11
	800	131.8	--	1346	536	1319	528	1083	446	444	195

SITE INDEX 80 AGE 15 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	4	0.2	47	--	--	--	--	--	--	--	--
4	14	1.2	47	--	--	--	--	--	--	--	--
5	29	4.0	49	50	20	48	20	33	14	--	--
6	46	9.0	51	118	48	115	47	94	40	28	13
7	58	15.4	54	211	86	208	85	185	77	110	49
8	58	20.1	58	289	118	287	118	265	111	197	86
9	46	20.1	60	299	123	297	122	281	117	232	100
10	28	15.0	62	227	93	226	93	218	90	191	81
11	12	8.2	62	124	51	124	51	121	50	110	46
12	4	3.1	63	48	19	48	19	47	19	43	18
13	1	0.9	63	14	6	14	6	14	6	13	6
	300	97.4	--	1380	565	1368	561	1257	524	924	399

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	1	0.0	46	--	--	--	--	--	--	--	--
3	8	0.4	47	--	--	--	--	--	--	--	--
4	23	2.0	47	--	--	--	--	--	--	--	--
5	46	6.3	49	79	32	77	31	52	22	--	--
6	69	13.5	52	179	73	175	72	143	61	42	20
7	81	21.7	55	303	124	299	123	265	111	158	71
8	75	26.3	58	384	158	381	157	352	147	262	114
9	54	23.8	61	357	147	355	146	336	140	278	119
10	29	15.6	62	237	98	236	97	228	95	199	85
11	11	7.2	63	110	45	110	45	106	44	97	41
12	3	2.3	63	34	14	34	14	33	14	31	13
13	1	0.5	63	8	3	8	3	8	3	7	3
	400	119.6	--	1691	694	1675	689	1524	637	1074	466

SITE INDEX 80 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	46	--	--	--	--	--	--	--	--
3	12	0.6	47	--	--	--	--	--	--	--	--
4	35	3.0	48	--	--	--	--	--	--	--	--
5	66	9.0	50	115	47	111	46	75	32	--	--
6	95	18.6	53	250	102	245	101	200	85	59	29
7	105	28.1	56	399	164	394	162	350	147	209	93
8	90	31.5	59	466	192	462	191	427	179	318	139
9	58	25.5	61	387	160	385	159	365	152	301	130
10	27	14.6	62	223	92	222	92	214	89	187	80
11	9	5.6	63	86	35	86	35	84	35	76	32
12	2	1.6	63	25	10	25	10	24	10	22	9
	500	138.2	--	1951	802	1930	795	1738	729	1172	512

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	3	0.1	46	--	--	--	--	--	--	--	--
3	18	0.9	47	--	--	--	--	--	--	--	--
4	49	4.3	48	--	--	--	--	--	--	--	--
5	90	12.2	50	159	65	153	63	104	45	--	--
6	123	24.1	54	330	135	323	133	264	112	77	38
7	128	34.3	57	495	204	489	202	433	183	259	116
8	101	35.2	60	528	218	523	217	484	204	360	158
9	58	25.5	62	389	160	387	160	366	153	303	131
10	23	12.5	62	192	79	191	79	184	77	161	69
11	6	4.0	63	61	25	61	25	59	24	54	23
12	1	0.9	63	13	5	13	5	13	5	12	5
	600	154.0	--	2166	892	2141	884	1908	803	1226	538

SITE INDEX 80 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	5	0.1	46	--	--	--	--	--	--	--	--
3	26	1.3	47	--	--	--	--	--	--	--	--
4	67	5.8	48	--	--	--	--	--	--	--	--
5	117	16.0	51	210	86	203	84	137	59	--	--
6	153	30.1	55	417	172	409	169	334	142	98	48
7	150	40.0	58	585	241	578	239	512	217	305	137
8	107	37.3	61	565	234	561	232	519	218	386	169
9	54	23.8	62	365	151	363	150	344	144	285	123
10	18	9.9	63	152	63	151	62	146	61	128	54
11	4	2.6	63	39	16	39	16	38	16	34	14
12	1	0.4	63	6	3	6	3	6	3	6	2
	700	167.2	--	2340	965	2310	956	2036	860	1241	549

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 800

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	7	0.1	46	--	--	--	--	--	--	--	--
3	35	1.7	47	--	--	--	--	--	--	--	--
4	87	7.6	49	--	--	--	--	--	--	--	--
5	148	20.2	52	269	110	260	108	176	76	--	--
6	184	36.2	55	510	210	500	207	408	174	119	59
7	167	44.7	59	663	274	655	272	581	246	346	156
8	108	37.7	61	576	238	571	237	528	223	393	173
9	47	20.9	62	322	133	320	133	304	127	251	108
10	13	7.2	63	111	46	111	46	107	44	94	40
11	2	1.6	63	25	10	25	10	24	10	22	9
	800	178.1	--	2476	1022	2441	1012	2127	901	1225	545

SITE INDEX 80 AGE 20 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	1	0.1	54	--	--	--	--	--	--	--	--
4	9	0.7	55	--	--	--	--	--	--	--	--
5	21	2.8	56	41	17	40	17	27	12	--	--
6	35	7.0	59	104	43	102	43	83	36	24	12
7	48	12.8	62	201	84	198	83	176	75	105	48
8	53	18.6	66	307	129	304	128	281	120	209	93
9	49	21.8	69	377	159	374	158	355	152	293	129
10	38	20.9	72	371	157	369	156	356	152	312	136
11	24	16.1	74	292	123	291	123	283	121	257	112
12	13	10.0	75	183	77	182	77	179	76	166	72
13	5	5.0	75	90	38	90	38	89	37	84	36
14	2	1.9	75	35	15	35	15	34	14	33	14
15	1	0.7	75	13	5	13	5	13	5	12	5
	300	118.4	--	2013	847	1999	843	1875	800	1495	657

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	3	0.1	54	--	--	--	--	--	--	--	--
4	14	1.3	55	--	--	--	--	--	--	--	--
5	33	4.5	56	65	27	63	26	43	19	--	--
6	53	10.4	59	158	66	155	65	127	55	37	19
7	69	18.3	63	293	123	289	122	256	110	153	70
8	73	25.3	67	426	179	422	178	391	168	291	130
9	64	28.1	70	492	208	489	207	463	198	383	169
10	46	25.0	73	449	190	447	189	430	184	377	165
11	27	17.7	74	323	137	322	136	313	134	285	124
12	13	10.0	75	182	77	182	77	178	76	165	71
13	5	4.4	75	80	33	79	33	78	33	74	32
14	2	1.9	75	34	14	34	14	33	14	32	14
	400	147.0	--	2501	1054	2482	1048	2312	990	1796	792

SITE INDEX 80 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	5	0.3	54	--	--	--	--	--	--	--	--
4	22	1.9	55	--	--	--	--	--	--	--	--
5	47	6.4	57	94	39	91	38	62	27	--	--
6	73	14.4	60	221	93	217	91	177	77	52	26
7	91	24.3	64	394	165	389	164	345	148	206	94
8	92	32.0	68	546	230	541	229	501	215	372	167
9	76	33.4	71	592	251	589	250	558	240	461	204
10	51	27.7	73	501	212	499	212	480	206	421	184
11	27	18.0	74	329	139	328	139	319	136	290	126
12	12	9.1	75	166	70	166	70	162	69	151	65
13	4	3.5	75	64	27	64	27	63	27	59	25
14	1	1.2	75	23	9	23	9	22	9	21	9
	500	172.1	--	2931	1236	2906	1229	2689	1154	2034	901

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	8	0.4	54	--	--	--	--	--	--	--	--
4	31	2.7	55	--	--	--	--	--	--	--	--
5	64	8.7	57	129	54	124	52	84	37	--	--
6	96	18.8	61	293	123	287	121	235	102	69	34
7	114	30.5	65	502	211	496	209	440	190	262	120
8	110	38.3	69	662	280	657	279	607	262	452	203
9	85	37.7	72	674	286	670	285	635	273	525	233
10	53	28.9	74	527	224	525	223	505	217	443	194
11	26	17.2	75	315	133	314	133	305	130	277	121
12	10	7.8	75	142	60	142	60	139	59	129	56
13	3	2.6	75	48	20	48	20	47	20	45	19
14	1	0.8	75	14	6	14	6	14	6	13	6
	600	194.2	--	3307	1397	3277	1388	3011	1295	2215	986

SITE INDEX 80 AGE 25 STEMS/ACRE 300

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	4	0.3	60	--	--	--	--	--	--	--	--
5	14	1.9	61	31	13	30	13	20	9	--	--
6	28	5.4	63	88	37	86	37	71	31	21	10
7	40	10.6	67	180	76	178	76	158	69	94	43
8	47	16.4	71	294	125	291	124	270	117	201	91
9	48	21.0	75	396	170	394	169	374	162	309	138
10	42	22.9	79	449	193	447	192	430	187	377	167
11	32	21.4	82	430	185	429	185	417	181	379	167
12	22	17.2	83	351	151	350	151	343	148	319	140
13	13	11.9	84	245	105	244	105	240	104	227	99
14	7	7.1	85	146	63	146	63	144	62	138	60
15	3	3.6	85	75	32	75	32	74	32	71	31
16	1	1.6	85	33	14	33	14	32	14	31	14
17	1	0.8	86	17	7	17	7	17	7	16	7
	300	142.1	--	2735	1171	2720	1167	2588	1122	2182	968

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 25 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	7	0.6	60	--	--	--	--	--	--	--	--
5	23	3.1	61	50	21	48	21	33	15	--	--
6	42	8.2	64	135	57	132	56	108	47	32	16
7	57	15.3	68	265	112	261	111	232	101	138	64
8	65	22.8	72	416	177	412	176	381	166	284	128
9	64	28.1	76	537	230	534	230	506	220	418	188
10	54	29.2	80	580	249	577	249	556	242	487	217
11	39	25.9	82	526	227	524	226	510	221	463	205
12	25	19.6	84	404	174	403	174	394	171	367	161
13	14	12.7	85	263	113	262	113	258	112	244	107
14	7	7.0	85	145	62	145	62	143	62	137	60
15	3	3.3	85	68	29	68	29	68	29	65	28
16	1	1.9	85	38	16	38	16	38	16	37	16
	400	177.8	--	3427	1469	3407	1463	3226	1401	2672	1190

SITE INDEX 80 AGE 25 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	11	1.0	60	--	--	--	--	--	--	--	--
5	33	4.5	62	73	31	70	30	48	21	--	--
6	58	11.3	65	188	80	185	79	151	66	44	22
7	76	20.4	69	358	153	354	151	314	137	187	87
8	84	29.4	73	544	233	539	231	499	218	371	169
9	79	34.8	77	675	290	672	289	637	278	526	236
10	64	34.7	81	696	300	693	299	667	290	584	260
11	44	29.3	83	599	258	597	258	580	252	527	234
12	27	20.9	84	433	186	432	186	422	183	393	173
13	14	12.7	85	263	113	263	113	258	112	244	107
14	6	6.5	85	135	58	135	58	133	57	127	55
15	2	2.8	85	58	25	58	25	58	25	56	24
16	1	1.4	85	29	12	29	12	28	12	28	12
	500	209.8	--	4051	1739	4026	1732	3794	1652	3087	1380

Continued

Table 27.--Weight yields per acre for loblolly pine in Soil Group A (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 30 STEMS/ACRE 300

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
5	7	1.0	65	17	7	16	7	11	5	--	--
6	21	4.1	66	70	30	69	29	56	25	16	8
7	33	8.9	70	158	67	156	67	138	61	83	38
8	41	14.4	74	271	116	269	116	249	109	185	84
9	44	19.5	79	386	167	384	166	364	159	301	136
10	42	22.8	83	473	205	471	204	453	198	397	178
11	36	23.5	87	505	220	503	219	489	215	444	199
12	28	21.7	89	477	208	476	208	466	204	434	193
13	20	18.1	91	403	175	402	175	395	173	374	166
14	13	13.6	92	306	133	305	133	301	132	288	127
15	8	9.3	93	210	91	210	91	207	90	200	88
16	4	5.8	93	131	57	131	57	130	56	126	55
17	2	3.3	94	74	32	74	32	74	32	72	31
18	1	1.7	94	38	17	38	17	38	17	37	16
19	1	1.3	94	29	13	29	13	29	12	28	12
	300	169.2	--	3549	1537	3534	1533	3401	1488	2986	1333

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)

SITE INDEX 60 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	19	--	--	--	--	--	--	--	--
3	10	0.5	19	--	--	--	--	--	--	--	--
4	24	2.1	20	--	--	--	--	--	--	--	--
5	44	6.0	21	31	11	30	11	20	7	--	--
6	64	12.6	22	69	24	68	24	56	20	16	7
7	76	20.4	24	120	42	118	42	105	38	62	24
8	73	25.4	26	158	56	157	56	145	53	108	41
9	55	24.4	27	158	56	157	56	149	54	123	46
10	32	17.5	28	116	41	116	41	111	40	97	36
11	14	9.2	28	61	22	61	22	59	21	54	20
12	4	3.4	29	22	8	22	8	22	8	20	7
13	1	1.0	29	6	2	6	2	6	2	6	2
	400	122.5	--	743	263	736	262	674	243	487	183

SITE INDEX 60 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	4	0.1	19	--	--	--	--	--	--	--	--
3	18	0.9	20	--	--	--	--	--	--	--	--
4	42	3.6	20	--	--	--	--	--	--	--	--
5	72	9.8	22	52	18	50	18	34	13	--	--
6	96	18.9	23	108	38	106	38	87	32	25	11
7	102	27.2	25	167	59	165	59	146	53	87	34
8	83	29.1	27	188	67	186	67	172	63	128	49
9	51	22.6	28	150	54	149	54	142	51	117	44
10	23	12.4	28	83	30	83	30	79	29	70	26
11	7	4.6	29	31	11	30	11	30	11	27	10
12	2	1.2	29	8	3	8	3	8	3	7	3
	500	130.4	--	787	280	778	278	698	254	462	175

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
1	1	0.0	19	--	--	--	--	--	--	--	--
2	8	0.2	19	--	--	--	--	--	--	--	--
3	31	1.5	20	--	--	--	--	--	--	--	--
4	67	5.9	21	--	--	--	--	--	--	--	--
5	108	14.7	22	81	29	78	28	53	20	--	--
6	131	25.7	24	153	55	150	54	123	45	36	15
7	120	32.2	26	205	73	202	73	180	66	107	42
8	81	28.3	28	188	67	186	67	172	63	128	49
9	38	17.0	28	114	41	114	41	108	39	89	33
10	12	6.6	29	44	16	44	16	42	15	37	14
11	3	1.8	29	12	4	12	4	11	4	10	4
	600	133.7	--	798	285	787	282	689	253	408	157

SITE INDEX 60 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
1	1	0.0	19	--	--	--	--	--	--	--	--
2	15	0.3	19	--	--	--	--	--	--	--	--
3	50	2.4	20	--	--	--	--	--	--	--	--
4	102	8.9	21	--	--	--	--	--	--	--	--
5	150	20.5	23	118	42	114	41	77	29	--	--
6	162	31.9	25	198	71	194	70	159	59	46	20
7	126	33.5	27	221	79	218	79	193	71	115	45
8	66	23.2	28	156	56	155	56	144	53	107	41
9	23	10.0	28	68	24	67	24	64	23	53	20
10	5	2.5	29	17	6	17	6	16	6	14	5
11	1	0.4	29	2	1	2	1	2	1	2	1
	700	133.6	--	780	280	768	277	655	242	337	132

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	1	0.0	29	--	--	--	--	--	--	--	--
4	9	0.8	29	--	--	--	--	--	--	--	--
5	28	3.9	30	29	11	28	10	19	7	--	--
6	57	11.2	32	88	33	87	33	71	27	21	9
7	83	22.3	35	191	72	188	71	167	64	100	41
8	91	31.7	38	294	112	292	111	270	104	201	81
9	72	31.9	40	313	120	311	119	295	115	244	97
10	40	21.8	42	221	85	220	84	212	82	185	74
11	15	9.6	43	99	38	98	38	95	37	87	34
12	4	3.0	43	30	12	30	12	29	11	27	11
	400	136.2	--	1265	481	1254	478	1158	448	864	347

SITE INDEX 60 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	3	0.1	29	--	--	--	--	--	--	--	--
4	18	1.6	29	--	--	--	--	--	--	--	--
5	51	7.0	30	54	20	52	20	35	14	--	--
6	94	18.4	33	151	57	148	56	121	47	35	16
7	121	32.3	36	290	110	287	109	254	99	152	63
8	110	38.5	40	373	143	370	142	342	133	254	103
9	68	30.2	42	306	118	304	117	288	112	238	96
10	27	14.8	43	152	58	151	58	145	56	127	51
11	6	4.2	43	43	16	43	16	42	16	38	15
12	1	0.7	43	7	3	7	3	7	3	6	2
	500	147.8	--	1375	525	1361	521	1234	481	851	346

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 15 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	6	0.3	29	--	--	--	--	--	--	--	--
4	33	2.9	29	--	--	--	--	--	--	--	--
5	85	11.6	31	91	34	88	33	60	24	--	--
6	139	27.4	34	235	89	230	88	188	74	55	25
7	155	41.4	38	389	149	384	148	341	134	203	85
8	114	39.7	41	398	153	394	152	365	143	271	111
9	52	22.9	42	236	91	234	91	222	87	183	74
10	13	7.3	43	76	29	75	29	73	28	64	25
11	2	1.3	43	13	5	13	5	13	5	11	5
	600	154.8	--	1437	550	1420	546	1261	494	788	324

SITE INDEX 60 AGE 15 STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	12	0.6	29	--	--	--	--	--	--	--	--
4	57	5.0	30	--	--	--	--	--	--	--	--
5	131	17.9	32	145	55	140	53	95	38	--	--
6	190	37.3	36	335	128	328	126	268	106	78	36
7	176	46.9	40	460	177	454	176	403	159	240	101
8	98	34.3	42	353	136	350	136	323	127	241	99
9	30	13.4	43	140	54	139	54	132	52	109	44
10	5	2.7	43	28	11	28	11	27	10	24	9
	700	158.2	--	1460	561	1439	555	1247	492	691	289

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	1	0.1	37	--	--	--	--	--	--	--	--
5	17	2.3	37	22	9	21	8	14	6	--	--
6	45	8.9	39	87	34	85	33	70	28	20	9
7	70	18.6	42	196	76	193	76	171	69	102	43
8	80	27.8	46	317	125	314	124	291	117	216	90
9	73	32.2	50	391	155	389	155	369	148	305	126
10	54	29.7	52	376	150	374	149	360	145	316	130
11	33	22.0	54	285	114	284	113	276	111	251	103
12	17	13.1	54	172	69	172	68	168	67	156	64
13	7	6.3	55	83	33	83	33	82	33	77	31
14	2	2.5	55	32	13	32	13	32	13	30	12
15	1	1.0	55	13	5	13	5	13	5	12	5
	400	164.5	--	1974	782	1961	778	1845	741	1486	615

SITE INDEX 60 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft²)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	4	0.3	37	--	--	--	--	--	--	--	--
5	33	4.6	37	43	17	42	16	28	12	--	--
6	74	14.5	40	146	57	143	56	117	47	34	16
7	102	27.1	44	297	117	293	116	260	105	155	66
8	105	36.5	48	433	172	429	171	397	160	295	124
9	84	37.3	51	468	187	465	186	441	179	365	152
10	54	29.7	53	384	154	383	153	368	149	323	134
11	28	18.5	54	242	97	242	97	235	95	213	88
12	11	9.0	55	119	47	118	47	116	46	108	44
13	4	3.4	55	45	18	45	18	44	18	42	17
14	1	1.3	55	16	7	16	7	16	6	15	6
	500	182.1	--	2193	871	2176	866	2022	816	1550	647

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 60 AGE 20 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	9	0.8	37	--	--	--	--	--	--	--	--
5	57	7.7	38	75	29	72	28	49	20	--	--
6	109	21.4	41	223	87	218	86	178	72	52	24
7	136	36.3	46	413	163	408	162	362	147	216	93
8	125	43.5	50	534	213	530	212	490	199	365	154
9	88	38.8	52	499	200	496	199	470	191	388	163
10	48	26.1	54	343	138	341	137	329	133	288	119
11	20	13.3	55	176	70	175	70	170	69	155	64
12	7	5.1	55	68	27	67	27	66	26	61	25
13	2	1.8	55	24	9	24	9	23	9	22	9
	600	194.8	--	2353	937	2332	931	2137	867	1547	651

SITE INDEX 60 AGE 20 STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	20	1.7	37	--	--	--	--	--	--	--	--
5	88	12.0	39	118	46	114	45	77	32	--	--
6	151	29.7	43	319	125	313	124	256	104	75	35
7	169	45.2	47	534	212	527	211	468	191	279	121
8	137	47.7	51	604	242	599	241	554	226	412	175
9	82	36.3	53	476	191	473	191	449	183	371	156
10	37	20.1	54	267	107	266	107	256	104	224	93
11	12	8.1	55	108	43	107	43	104	42	95	39
12	3	2.4	55	31	13	31	13	31	12	28	12
13	1	0.6	55	7	3	7	3	7	3	7	3
	700	203.9	--	2465	983	2438	976	2201	897	1491	634

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 400

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
2	2	0.0	23	--	--	--	--	--	--	--	--
3	10	0.5	23	--	--	--	--	--	--	--	--
4	24	2.1	24	--	--	--	--	--	--	--	--
5	44	6.0	25	37	13	36	13	24	9	--	--
6	64	12.6	27	83	30	81	29	66	25	19	8
7	76	20.4	28	142	51	140	51	124	46	74	29
8	73	25.4	30	186	68	185	68	171	64	127	49
9	55	24.4	32	185	68	184	68	175	65	144	55
10	32	17.5	33	136	50	135	50	130	48	114	43
11	14	9.2	33	71	26	71	26	69	26	63	24
12	4	3.4	33	26	10	26	10	26	9	24	9
13	1	1.0	33	7	3	7	3	7	3	7	3
	400	122.5	--	874	319	866	317	792	294	572	220

SITE INDEX 70 AGE 10 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
2	4	0.1	23	--	--	--	--	--	--	--	--
3	18	0.9	23	--	--	--	--	--	--	--	--
4	42	3.6	24	--	--	--	--	--	--	--	--
5	72	9.8	26	63	23	60	22	41	16	--	--
6	96	18.9	28	129	47	126	46	103	39	30	13
7	102	27.2	30	197	72	194	71	172	65	103	41
8	83	29.1	31	220	81	218	80	202	76	150	59
9	51	22.6	32	176	65	175	64	166	62	137	53
10	23	12.4	33	97	36	97	35	93	34	81	31
11	7	4.6	33	36	13	36	13	35	13	31	12
12	2	1.2	33	10	3	9	3	9	3	9	3
	500	130.4	--	926	339	915	336	820	307	541	211

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 10 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	23	--	--	--	--	--	--	--	--
2	8	0.2	23	--	--	--	--	--	--	--	--
3	31	1.5	24	--	--	--	--	--	--	--	--
4	67	5.9	25	--	--	--	--	--	--	--	--
5	108	14.7	26	97	35	93	34	63	24	--	--
6	131	25.7	29	181	66	178	65	145	55	42	19
7	120	32.2	31	241	89	238	88	211	80	126	50
8	81	28.3	32	220	81	218	81	202	76	150	59
9	38	17.0	33	134	49	133	49	126	47	104	40
10	12	6.6	33	52	19	52	19	50	18	43	17
11	3	1.8	33	14	5	14	5	13	5	12	5
	600	133.7	--	938	345	925	341	810	305	478	189

SITE INDEX 70 AGE 10 STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
1	1	0.0	23	--	--	--	--	--	--	--	--
2	15	0.3	23	--	--	--	--	--	--	--	--
3	50	2.4	24	--	--	--	--	--	--	--	--
4	102	8.9	25	--	--	--	--	--	--	--	--
5	150	20.5	27	140	51	135	50	91	35	--	--
6	162	31.9	30	234	86	229	85	187	71	55	24
7	126	33.5	31	259	96	256	95	227	86	135	55
8	66	23.2	33	183	68	181	67	168	63	125	49
9	23	10.0	33	79	29	79	29	74	28	62	24
10	5	2.5	33	20	7	20	7	19	7	17	6
11	1	0.4	33	3	1	3	1	3	1	2	1
	700	133.6	--	917	338	902	334	769	292	395	159

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 400

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	1	0.0	35	--	--	--	--	--	--	--	--
4	9	0.8	35	--	--	--	--	--	--	--	--
5	28	3.9	36	35	13	34	13	23	9	--	--
6	57	11.2	38	106	41	104	40	85	34	25	11
7	83	22.3	41	227	88	224	87	198	79	118	50
8	91	31.7	44	347	136	344	135	318	127	237	98
9	72	31.9	47	367	144	365	144	346	138	286	118
10	40	21.8	49	258	102	257	101	247	99	217	88
11	15	9.6	50	115	45	115	45	112	44	101	41
12	4	3.0	50	35	14	35	14	34	14	32	13
	400	136.2	--	1490	583	1477	579	1363	543	1016	419

SITE INDEX 70 AGE 15 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	3	0.1	35	--	--	--	--	--	--	--	--
4	18	1.6	35	--	--	--	--	--	--	--	--
5	51	7.0	36	65	25	62	24	42	17	--	--
6	94	18.4	39	180	70	177	69	144	58	42	20
7	121	32.3	43	343	134	339	133	301	120	179	76
8	110	38.5	46	438	172	434	172	402	161	299	125
9	68	30.2	48	358	141	356	141	337	135	278	115
10	27	14.8	49	177	70	176	70	170	68	149	61
11	6	4.2	50	50	20	50	20	49	19	44	18
12	1	0.7	50	8	3	8	3	8	3	7	3
	500	147.8	--	1619	635	1603	631	1452	582	999	417

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 15 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	6	0.3	35	--	--	--	--	--	--	--	--
4	33	2.9	35	--	--	--	--	--	--	--	--
5	85	11.6	37	110	42	106	41	72	29	--	--
6	139	27.4	41	279	109	274	107	223	90	65	31
7	155	41.4	45	459	181	453	179	402	162	240	103
8	114	39.7	48	466	185	462	184	428	172	318	134
9	52	22.9	49	275	109	274	109	260	104	215	89
10	13	7.3	50	88	35	88	35	85	34	74	30
11	2	1.3	50	15	6	15	6	15	6	13	5
	600	154.8	--	1693	666	1672	661	1483	598	925	392

SITE INDEX 70 AGE 15 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
3	12	0.6	35	--	--	--	--	--	--	--	--
4	57	5.0	36	--	--	--	--	--	--	--	--
5	131	17.9	38	174	68	168	66	113	46	--	--
6	190	37.3	42	396	156	388	153	317	129	93	44
7	176	46.9	46	540	214	534	212	473	192	282	122
8	98	34.3	49	412	164	409	163	378	153	282	119
9	30	13.4	50	163	65	162	65	154	62	127	53
10	5	2.7	50	33	13	33	13	31	13	28	11
	700	158.2	--	1719	679	1694	672	1467	595	811	348

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 400

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	1	0.1	44	--	--	--	--	--	--	--	--
5	17	2.3	44	27	11	26	10	17	7	--	--
6	45	8.9	46	104	42	102	41	84	35	24	12
7	70	18.6	50	233	94	230	93	204	84	122	53
8	80	27.8	54	375	152	372	151	344	142	256	110
9	73	32.2	58	461	188	458	187	434	180	359	153
10	54	29.7	61	441	181	439	180	423	175	370	157
11	33	22.0	62	334	137	332	136	323	134	294	124
12	17	13.1	63	201	82	201	82	196	81	183	76
13	7	6.3	64	97	40	97	40	95	39	90	37
14	2	2.5	64	38	15	38	15	37	15	35	15
15	1	1.0	64	15	6	15	6	15	6	14	6
	400	164.5	--	2325	947	2310	942	2172	898	1747	743

SITE INDEX 70 AGE 20 STEMS/ACRE 500

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	4	0.3	44	--	--	--	--	--	--	--	--
5	33	4.6	45	52	21	51	20	34	14	--	--
6	74	14.5	48	174	70	171	69	140	58	41	20
7	102	27.1	52	353	143	349	142	309	128	184	81
8	105	36.5	56	510	208	506	207	468	195	348	151
9	84	37.3	60	550	225	547	225	518	215	428	183
10	54	29.7	62	450	185	448	184	431	179	378	161
11	28	18.5	63	283	116	283	116	275	114	250	105
12	11	9.0	64	138	57	138	57	135	56	126	53
13	4	3.4	64	53	21	53	21	52	21	49	20
14	1	1.3	64	19	8	19	8	19	8	18	7
	500	182.1	--	2584	1055	2563	1049	2381	988	1822	782

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 70 AGE 20 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
4	9	0.8	44	--	--	--	--	--	--	--	--
5	57	7.7	45	90	36	87	35	59	25	--	--
6	109	21.4	49	266	107	261	106	213	89	62	30
7	136	36.3	54	489	199	483	197	429	179	256	113
8	125	43.5	58	629	258	624	256	577	241	429	187
9	88	38.8	61	585	241	581	240	551	230	455	196
10	48	26.1	63	401	165	399	165	384	160	337	144
11	20	13.3	63	205	84	205	84	199	82	181	76
12	7	5.1	64	79	32	79	32	77	32	72	30
13	2	1.8	64	28	11	28	11	27	11	26	11
	600	194.8	--	2772	1134	2746	1127	2515	1049	1817	787

SITE INDEX 70 AGE 20 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
4	20	1.7	44	--	--	--	--	--	--	--	--
5	88	12.0	46	142	57	137	56	93	39	--	--
6	151	29.7	50	380	154	373	152	304	128	89	43
7	169	45.2	55	631	258	623	256	552	232	329	147
8	137	47.7	59	709	292	703	290	650	273	484	212
9	82	36.3	62	557	230	554	229	525	220	434	187
10	37	20.1	63	312	129	311	129	299	125	262	112
11	12	8.1	64	126	52	126	52	122	51	111	47
12	3	2.4	64	37	15	37	15	36	15	33	14
13	1	0.6	64	9	4	9	4	9	4	8	3
	700	203.9	--	2903	1191	2871	1182	2590	1086	1751	765

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	2	0.0	27	--	--	--	--	--	--	--	--
3	10	0.5	27	--	--	--	--	--	--	--	--
4	24	2.1	28	--	--	--	--	--	--	--	--
5	44	6.0	29	44	16	42	16	29	11	--	--
6	64	12.6	31	96	36	94	35	77	30	23	10
7	76	20.4	33	164	61	162	60	143	55	86	35
8	73	25.4	35	215	80	213	80	197	75	146	58
9	55	24.4	36	213	80	211	79	200	76	165	65
10	32	17.5	37	155	58	155	58	149	56	130	51
11	14	9.2	37	82	31	81	30	79	30	72	28
12	4	3.4	38	30	11	30	11	29	11	27	10
13	1	1.0	38	8	3	8	3	8	3	8	3
	400	122.5	--	1006	376	997	374	912	347	657	259

SITE INDEX 80 AGE 10 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
2	4	0.1	27	--	--	--	--	--	--	--	--
3	18	0.9	27	--	--	--	--	--	--	--	--
4	42	3.6	28	--	--	--	--	--	--	--	--
5	72	9.8	30	73	27	71	26	48	19	--	--
6	96	18.9	32	149	56	146	55	119	46	35	16
7	102	27.2	34	227	85	224	84	199	76	119	48
8	83	29.1	36	253	95	251	95	232	89	173	69
9	51	22.6	37	201	76	200	75	190	72	157	62
10	23	12.4	37	111	42	110	42	106	40	93	36
11	7	4.6	38	41	15	41	15	39	15	36	14
12	2	1.2	38	11	4	11	4	11	4	10	4
	500	130.4	--	1066	400	1054	396	944	362	622	248

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 10 STEMS/ACRE 600

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	1	0.0	27	--	--	--	--	--	--	--	--
2	8	0.2	27	--	--	--	--	--	--	--	--
3	31	1.5	28	--	--	--	--	--	--	--	--
4	67	5.9	29	--	--	--	--	--	--	--	--
5	108	14.7	31	113	42	109	41	73	29	--	--
6	131	25.7	33	210	79	206	78	168	65	49	22
7	120	32.2	35	277	104	274	104	243	94	145	59
8	81	28.3	36	252	95	250	95	231	89	172	69
9	38	17.0	37	153	58	152	57	144	55	119	47
10	12	6.6	38	59	22	59	22	57	22	50	19
11	3	1.8	38	16	6	16	6	15	6	14	5
	600	133.7	--	1080	406	1065	402	932	359	548	222

SITE INDEX 80 AGE 10 STEMS/ACRE 700

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
1	1	0.0	27	--	--	--	--	--	--	--	--
2	15	0.3	27	--	--	--	--	--	--	--	--
3	50	2.4	28	--	--	--	--	--	--	--	--
4	102	8.9	29	--	--	--	--	--	--	--	--
5	150	20.5	32	163	61	157	59	106	42	--	--
6	162	31.9	34	270	102	264	100	216	84	63	29
7	126	33.5	36	297	112	293	111	260	101	155	64
8	66	23.2	37	209	79	208	79	192	74	143	57
9	23	10.0	38	90	34	90	34	85	33	70	28
10	5	2.5	38	23	8	22	8	22	8	19	7
11	1	0.4	38	3	1	3	1	3	1	3	1
	700	133.6	--	1055	398	1038	394	884	343	453	186

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 15 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
3	1	0.0	41	--	--	--	--	--	--	--	--
4	9	0.8	41	--	--	--	--	--	--	--	--
5	28	3.9	42	41	16	40	16	27	11	--	--
6	57	11.2	44	124	49	122	48	99	41	29	14
7	83	22.3	47	263	105	260	104	231	94	138	60
8	91	31.7	51	400	160	397	159	367	150	273	116
9	72	31.9	54	422	170	419	169	397	162	328	138
10	40	21.8	56	295	119	294	119	283	115	248	103
11	15	9.6	56	132	53	131	53	128	52	116	48
12	4	3.0	57	40	16	40	16	39	16	37	15
	400	136.2	--	1717	688	1703	684	1571	641	1168	494

SITE INDEX 80 AGE 15 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
						Merchantable weight to top--					
3	3	0.1	41	--	--	--	--	--	--	--	--
4	18	1.6	41	--	--	--	--	--	--	--	--
5	51	7.0	42	76	30	73	29	50	21	--	--
6	94	18.4	45	211	84	206	83	169	69	49	23
7	121	32.3	49	397	159	392	158	348	143	208	91
8	110	38.5	53	504	203	500	202	462	190	344	147
9	68	30.2	55	410	166	407	165	386	158	319	135
10	27	14.8	56	202	82	202	82	194	79	170	71
11	6	4.2	56	57	23	57	23	55	23	50	21
12	1	0.7	57	9	4	9	4	9	4	8	3
	500	147.8	--	1866	750	1847	745	1673	687	1148	491

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80   AGE 15   STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	6	0.3	41	--	--	--	--	--	--	--	--
4	33	2.9	41	--	--	--	--	--	--	--	--
5	85	11.6	43	129	51	124	50	84	35	--	--
6	139	27.4	47	325	130	318	128	260	108	76	36
7	155	41.4	51	529	213	522	212	463	192	276	122
8	114	39.7	54	535	217	530	216	491	203	365	157
9	52	22.9	56	315	128	313	127	297	122	245	104
10	13	7.3	56	101	41	101	41	97	40	85	36
11	2	1.3	57	17	7	17	7	17	7	15	6
	600	154.8	--	1951	787	1927	780	1708	706	1063	461

SITE INDEX 80   AGE 15   STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
3	12	0.6	41	--	--	--	--	--	--	--	--
4	57	5.0	42	--	--	--	--	--	--	--	--
5	131	17.9	44	204	81	197	79	133	56	--	--
6	190	37.3	49	459	185	450	182	368	153	108	52
7	176	46.9	53	621	252	614	250	544	226	324	144
8	98	34.3	55	472	192	468	191	433	180	322	139
9	30	13.4	56	187	76	186	75	176	72	145	62
10	5	2.7	57	37	15	37	15	36	15	31	13
	700	158.2	--	1981	801	1951	793	1690	702	931	409

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 400

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	1	0.1	52	--	--	--	--	--	--	--	--
5	17	2.3	52	31	13	30	13	21	9	--	--
6	45	8.9	54	123	50	120	50	98	42	29	14
7	70	18.6	58	272	112	269	111	238	101	142	64
8	80	27.8	62	435	181	431	180	399	169	297	131
9	73	32.2	66	530	222	527	221	500	212	413	180
10	54	29.7	69	506	212	504	212	485	206	425	184
11	33	22.0	71	382	160	381	160	370	157	336	145
12	17	13.1	72	230	96	229	96	225	95	209	89
13	7	6.3	72	111	46	111	46	109	46	103	44
14	2	2.5	72	43	18	43	18	42	18	41	17
15	1	1.0	72	17	7	17	7	17	7	16	7
	400	164.5	--	2680	1118	2662	1113	2503	1059	2010	876

SITE INDEX 80 AGE 20 STEMS/ACRE 500

D.b.h. (in)	Stems per acre (no.)	Basal area (ft^2)	Avg. ht. (ft)	Total wgt. green o.b.	Total wgt. dry i.b.	Merchantable weight to top-- 2 inches green o.b.	2 inches dry i.b.	4 inches green o.b.	4 inches dry i.b.	6 inches green o.b.	6 inches dry i.b.
4	4	0.3	52	--	--	--	--	--	--	--	--
5	33	4.6	52	62	25	60	25	40	17	--	--
6	74	14.5	55	204	84	200	83	164	70	48	24
7	102	27.1	60	410	170	405	169	359	153	214	97
8	105	36.5	64	589	246	584	245	541	230	402	178
9	84	37.3	68	632	265	628	264	595	254	492	216
10	54	29.7	70	516	217	513	216	494	210	433	188
11	28	18.5	72	324	136	323	136	314	133	286	123
12	11	9.0	72	158	66	158	66	155	65	144	62
13	4	3.4	72	60	25	60	25	59	25	56	24
14	1	1.3	72	22	9	22	9	22	9	21	9
	500	182.1	--	2978	1245	2954	1239	2743	1166	2095	921

Continued

Table 28.--Weight yields per acre for loblolly pine in Soil Group B (in hundreds of pounds)--Contd.

SITE INDEX 80 AGE 20 STEMS/ACRE 600

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	9	0.8	52	--	--	--	--	--	--	--	--
5	57	7.7	53	106	44	102	42	69	30	--	--
6	109	21.4	57	311	129	305	127	249	107	73	36
7	136	36.3	62	567	237	560	235	497	213	296	135
8	125	43.5	66	724	304	718	303	664	284	494	220
9	88	38.8	69	671	283	667	282	632	270	522	230
10	48	26.1	71	459	194	457	193	440	188	386	168
11	20	13.3	72	235	99	234	99	227	97	207	89
12	7	5.1	72	90	38	90	38	88	37	82	35
13	2	1.8	72	32	13	32	13	31	13	29	12
	600	194.8	--	3195	1339	3165	1331	2898	1238	2089	926

SITE INDEX 80 AGE 20 STEMS/ACRE 700

	Stems					Merchantable weight to top--					
	per	Basal	Avg.	Total wgt.		2 inches		4 inches		6 inches	
D.b.h.	acre	area	ht.	green	dry	green	dry	green	dry	green	dry
(in)	(no.)	(ft^2)	(ft)	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.	o.b.	i.b.
4	20	1.7	52	--	--	--	--	--	--	--	--
5	88	12.0	54	167	69	161	67	109	47	--	--
6	151	29.7	58	443	184	434	182	355	153	104	52
7	169	45.2	64	729	306	720	303	638	275	381	174
8	137	47.7	68	815	344	808	342	747	321	556	249
9	82	36.3	71	639	270	635	269	602	258	497	220
10	37	20.1	72	357	151	356	150	342	146	300	131
11	12	8.1	72	144	61	144	60	140	59	127	55
12	3	2.4	72	42	18	42	18	41	17	38	16
13	1	0.6	72	10	4	10	4	10	4	9	4
	700	203.9	--	3345	1406	3309	1395	2984	1281	2012	901

6. Survival Trends

The methodology used in section 5 to predict structure and current per acre yield of a stand with given age, site index, and number of surviving stems per acre can be used to estimate future stand structure and yield if an estimate of surviving number of trees per acre at the projection age can be obtained. A modified form of the nonlinear survival model developed by Clutter and Jones (1980) was fitted to the survival data collected on the remeasured plots described in section 2. The final equation is

$$N_2 = 100\left\{\left(\frac{N_1}{100}\right)^{\beta_1} + \left(\beta_2 + \frac{\beta_3}{S}\right) \times \left[\left(\frac{A_2}{10}\right)^{\beta_4} - \left(\frac{A_1}{10}\right)^{\beta_4}\right]\right\}^{\left(\frac{1}{\beta_1}\right)} \quad (29)$$

where:

A_1 = initial age
A_2 = projection age
N_1 = number of surviving stems per acre at age A_1
N_2 = predicted number of surviving stems per acre at age A_2
S = site index (age 25)
β_1 = -2.029625
β_2 = 0.00261778
β_3 = -0.0933325
β_4 = 3.683674

The above equation is based on data from 123 plots and explains 86.4 percent of the variability among the observed N_2 values.

To illustrate the use of equation (29), consider a site index 68 plantation that is currently 12 years old with 575 surviving stems per acre. An estimate of the number of surviving stems that will be present at age 25 is desired. Substituting into equation (29) and solving gives

$$N_2 = 100\left\{\left(\frac{575}{100}\right)^{\beta_1} + \left(\beta_2 + \frac{\beta_3}{68}\right) \times \left[\left(\frac{25}{10}\right)^{\beta_4} - \left(\frac{12}{10}\right)^{\beta_4}\right]\right\}^{\left(\frac{1}{\beta_1}\right)}$$

= 391 stems per acre.

If predictions of stand structure and yields at age 25 are needed, they can be obtained by techniques described in section 5 with plantation age set equal to 25, site index equal to 68, and stems per acre equal to 391.

Graphs of the survival relationships defined by equation (29) are shown in figure 4. These curves show that for any given combination of plantation age and initial number of trees per acre, subsequent mortality is positively correlated with site index. Previously published equations for predicting southern pine mortality do not include site index as a variable. However, the equation of Smalley and Bailey (1974) uses dominant height as a predictor. It may well be that competition mortality has been a minor component of total mortality in previously collected data sets for southern pine mortality and, as a result, the significance of site index as a predictor variable has not been detected. The data available for this analysis have generally higher average levels of both site index and stand density than the data used in previous comparable studies and could possibly be the reason for the significant effect of site index on mortality.

Table 29 shows stand volume development that incorporates mortality trends predicted by equation (29). For example, a site index 60, Soil Group A plantation with 600 stems per acre at age 10 is shown as having an age-20 volume of 2,637 cubic feet per acre. This figure was obtained by first solving equation (29) with A_1 = 10, A_2 = 20, N_1 = 600, and S = 60 to obtain N_2 = 495 and then using the techniques described in section 5 to calculate the age-20 yield.

Mean annual increment values have been calculated from yields shown in table 29 and are tabulated in table 30. These results show that, for example, a Soil Group A, site index 70 plantation with 600 stems per acre at age 10 would produce average annual growth rates of 160.1 cubic feet per acre over a 15-year rotation, 175.8 cubic feet per acre with a 20-year rotation, 172.5 cubic feet per acre per year during a 25-year rotation, and 159.9 cubic feet per acre with a 30-year rotation. Although these tabulations convey considerable information about the relationship between plantation age and mean annual increment, they

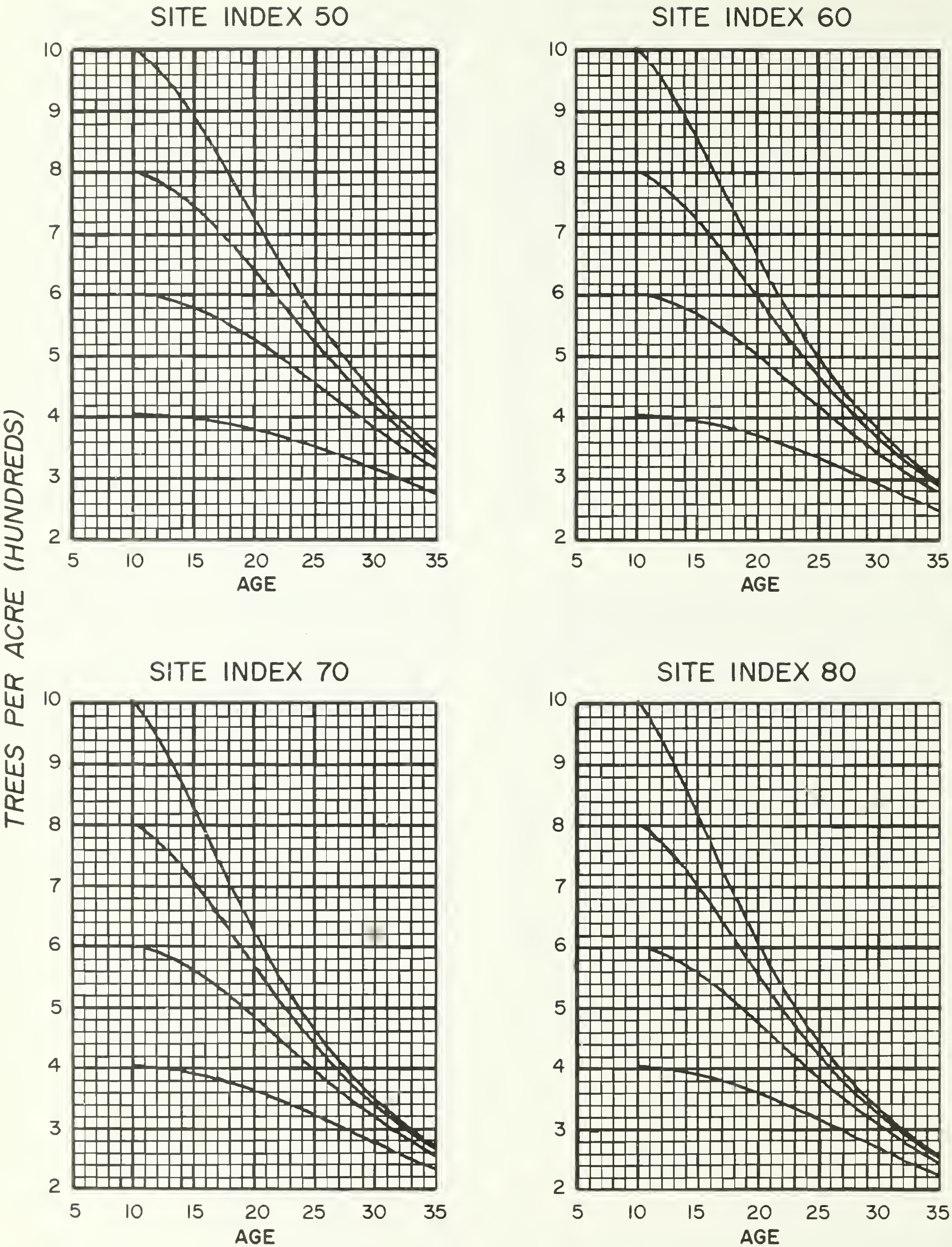

Figure 4.--Survival trends for various combinations of site index and number of trees per acre at age 10.

Table 29.--Projected volume yields (outside bark, 4-inch merchantable top) of stands with specified number of stems per acre at age 10 for Soil Groups A and B, by site index

Site index	Stems per acre at age 10	Age (years) 15	20	25	30
		- - - - - - Cubic feet per acre - - - - - -			
		SOIL GROUP A			
	400	879	1524	2170	2746
	600	935	1797	2575	3172
50	800	868	1926	2794	3386
	1000	738	1984	2918	3502
	400	1411	2194	2915	3496
	600	1632	2637	3431	3965
60	800	1691	2883	3705	4187
	1000	1656	3023	3859	4304
	400	1994	2900	3685	4273
	600	2401	3517	4314	4797
70	800	2602	3873	4641	5038
	1000	2678	4085	4823	5163
	400	2615	3631	4473	5067
	600	3226	4427	5216	5652
80	800	3581	4891	5596	5915
	1000	3774	5171	5806	6050
		SOIL GROUP B			
60	400	2114	3147	--	--
	600	2325	3605	--	--
	800	2309	3813	--	--
	400	2439	3605	--	--
70	600	2683	4115	--	--
	800	2676	4352	--	--
	400	2761	4060	--	--
80	600	3038	4624	--	--
	800	3039	4886	--	--

Table 30.--Mean annual increment (outside bark volume, 4-inch merchantable top) of stands with specified number of stems per acre at age 10 for Soil Groups A and B, by site index

Site index	Stems per acre at age 10	Age (years) 15	20	25	30
		- - - - - - - Cubic feet per acre - - - - - -			
SOIL GROUP A					
50	400	58.6	76.2	86.8	91.5
	600	62.4	89.8	103.0	105.7
	800	57.9	96.3	111.8	112.9
	1000	49.2	99.2	116.7	116.7
60	400	94.1	109.7	116.6	116.5
	600	108.8	131.8	137.2	132.2
	800	112.7	144.2	148.2	139.6
	1000	110.4	151.2	154.4	143.5
70	400	132.9	145.0	147.4	142.4
	600	160.1	175.8	172.5	159.9
	800	173.5	193.6	185.6	167.9
	1000	178.5	204.2	192.9	172.1
80	400	174.3	181.6	178.9	168.9
	600	215.1	221.4	208.6	188.4
	800	238.8	244.6	223.8	197.2
	1000	251.6	258.5	232.2	201.7
SOIL GROUP B					
60	400	141.0	157.3	--	--
	600	155.0	180.2	--	--
	800	153.9	190.7	--	--
70	400	162.6	180.2	--	--
	600	178.8	205.8	--	--
	800	178.4	217.6	--	--
80	400	184.0	203.0	--	--
	600	202.5	231.2	--	--
	800	202.6	244.3	--	--

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Table 31.--Age for maximum mean annual increment of various combinations of site index and number of trees per acre at age 10 for Soil Group A plantations

Site index	Trees per acre 400	600	800	1000
	- - - - - - - *Years*	- - - - - - -		
50	>30	29	28	27
60	28	24	23	23
70	24	21	20	20
80	21	19	18	18

do not provide a precise estimate of the age at which maximum mean annual increment occurs. The ages for maximum mean annual increment for various combinations of number of trees per acre at age 10 and site index have therefore been determined by making annual calculations. The results are given in table 31 for Soil Group A plantations. The table shows that for a site index 70 plantation with 600 trees per acre at age 10, maximum mean annual increment is achieved with a rotation length of 21 years. Calculations for Soil Group B indicate that maximum mean annual increment is still increasing at ages up to 20 years for all combinations of site index and number of trees per acre at age 10. Accurate prediction of mean annual increment for Soil Group B plantations older than age 20 is probably impossible because of the limitations of the available data.

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Appendix I

English to Metric Conversion Factors

1 inch = 2.540 centimeters

1 foot = 0.3048 meters

1 pound = 0.4536 kilograms

1 cubic foot = 0.02832 cubic meters

1 stem per acre = 2.471 stems per hectare

1 cubic foot per acre = 0.06997 cubic meters per hectare

1 pound per acre = 1.121 kilograms per hectare

1 square foot per acre = 0.2296 square meters per hectare

Appendix II

Computer Subprograms

This Appendix lists a set of FORTRAN subprograms designed to perform the calculations for all the equations previously presented. (Documentation of the operation of the subprograms is given in comment statements in the listing.) These subprograms can be logically divided into five groups:

1. <u>Subprograms used to calculate per acre volume or weight yields</u>. Estimates of per acre volume or weight yields are obtained by calling the subroutine SPYLDL. Subroutine PSPDS2 is called by SPYLDL, and the function subprogram CDF is called by PSPDS2.

2. <u>Subprograms used to calculate per tree volume or weight yields</u>. A number of function subprograms are included to calculate estimated per tree volumes and weights. These subprograms, by name and function, are as follows:

Subprogram	Function
VOLOBT	Calculates total stem outside bark volume
VOLIBT	Calculates total stem inside bark volume
VOLOBM	Calculates merchantable stem outside bark volume
VOLIBM	Calculates merchantable stem inside bark volume
GWTOT	Calculates total stem green weight (wood and bark)
GWMER	Calculates merchantable stem green weight (wood and bark)
DWTOT	Calculates total stem dry weight (wood only)
DWMER	Calculates merchantable stem dry weight (wood only)

3. <u>Subprograms used to evaluate taper relationships</u>. Four function subprograms are included for carrying out the computations involved in evaluating taper relationships. These subprograms, by name and function, are as follows:

Subprogram	Function
TFDOB	Calculates the outside bark diameter at a specified height above the ground
TFHTOB	Calculates the height above ground at which a specified outside bark diameter occurs
TFDIB	Calculates the inside bark diameter at a specified height above the ground

TFHTIB	Calculates the height above ground at which a specified inside bark diameter occurs

4. Subprograms used to calculate site index or average height of dominants and codominants. The subroutine SPLPSI can be used to calculate site index from age and average height of dominants and codominants. When site index is known, subroutine SPLPHD can be used to calculate the average height of dominants and codominants from site index and age.

5. Subprogram used to calculate predicted number of stems per acre. The subroutine KILLEM can be used to calculate predicted number of stems per acre. Required inputs to the subroutine are site index, current age, current number of stems per acre, and future age.

SUBROUTINE FOLLOWS:

```
      SUBROUTINE SPYLDL(A,S,D,UNIT,BARK,TOPD,GROUP,YIELD,FR,H,CLYLD)      L1983I
C                                                                          L1983I
C     THIS SUBROUTINE CALCULATES ESTIMATED PER ACRE YIELD                 L1983I
C     FOR A SITE PREPARED LOBLOLLY PINE PLANTATION OF AGE "A"             L1983I
C     SITE INDEX "S", AND "D" STEMS PER ACRE.  YIELD MAY BE               L1983I
C     VOLUMETRIC, GREEN WEIGHT, OR DRY WEIGHT DEPENDING ON                L1983I
C     THE LITERAL CODE ASSIGNED TO "UNIT".  THE ARGUMENT "BARK"           L1983I
C     CONTROLS WHETHER YIELDS ARE CALCULATED ON AN INSIDE-BARK            L1983I
C     OR OUTSIDE-BARK BASIS.  THE MERCHANTABILITY LIMIT USED              L1983I
C     IS CONTROLLED BY THE ARGUMENT "TOPD".  DETAILED DEFINITIONS         L1983I
C     FOR ALL ARGUMENTS INVOLVED IN THE CALLING SEQUENCE ARE GIVEN        L1983I
C     BELOW:                                                              L1983I
C             A = PLANTATION AGE                                          L1983I
C             S = SITE INDEX  (BASE AGE 25 YEARS)                         L1983I
C             D = NUMBER OF SURVIVING STEMS ACRE AT AGE "A"               L1983I
C          UNIT = AN INPUT SPECIFYING THE TYPE OF YIELD STATISTIC         L1983I
C                 DESIRED.  IF UNIT = 'VOL ', YIELD WILL BE VOLUMETRIC    L1983I
C                 IN CUBIC FEET;  IF UNIT = 'GWT ', YIELD WILL BE PER     L1983I
C                 ACRE GREEN WEIGHT IN HUNDREDS OF POUNDS;  IF            L1983I
C                 UNIT = 'DWT ', YIELD WILL BE PER ACRE DRY WEIGHT        L1983I
C                 IN HUNDREDS OF POUNDS.                                  L1983I
C          BARK = AN INPUT SPECIFYING WHETHER VOLUMETRIC YIELD            L1983I
C                 IS TO BE CALCULATED ON AN OUTSIDE-BARK OR INSIDE-       L1983I
C                 BARK BASIS.  IF BARK = 'OB  ', OUTSIDE-BARK VOLUMES     L1983I
C                 ARE CALCULATED;  IF BARK = 'IB  ', INSIDE-BARK          L1983I
C                 VOLUMES ARE CALCULATED.  THE CODE ASSIGNED TO           L1983I
C                 BARK HAS EFFECT ONLY WHEN UNIT = 'VOL '.  GREEN-        L1983I
C                 WEIGHT YIELDS ARE ALWAYS CALCULATED ON AN OUTSIDE-      L1983I
C                 BARK BASIS AND DRY-WEIGHT YIELDS ARE ALWAYS             L1983I
C                 COMPUTED ON AN INSIDE-BARK BASIS.                       L1983I
      CONTINUE                                                            L1983I
C          TOPD = OUTSIDE-BARK MERCHANTABLE TOP DIAMETER.  TOTAL-         L1983I
C                 STEM VOLUMES OR WEIGHTS ARE OBTAINED BY SETTING         L1983I
C                 TOPD = 0..  IF TOPD = 4., THE YIELD STATISTIC           L1983I
C                 COMPUTED WOULD BE MERCHANTABLE YIELD TO A 4"            L1983I
C                 TOP.  RECOMMENDED RANGE FOR THIS VARIABLE IS            L1983I
C                 6.0 >= TOPD >= 0.0.                                     L1983I
C         GROUP = AN INPUT IDENTIFYING THE SOIL GROUP FOR THE SITE        L1983I
C                 ON WHICH THE PLANTATION IS GROWING.                     L1983I
C                  GROUP = 2. IF THE SOIL SERIES IS BALLAHACK, TORHUNTA,  L1983I
C                             BAYBORO, BYARS,OR PANTEGO, OR IF THE SITE   L1983I
C                             IS A TYPICAL POCOSIN OR CAROLINA BAY, OR    L1983I
C                             IF THE A1 HORIZON IS MORE THAN 8 INCHES     L1983I
C                             THICK WITH 10 PERCENT OR MORE ORGANIC       L1983I
C                             MATTER.                                     L1983I
C                  GROUP = 1. FOR ALL OTHER CASES                         L1983I
      CONTINUE                                                            L1983I
C                                                                          L1983I
C                                                                          L1983I
C     DETAILED DEFINITIONS FOR ALL QUANTITIES RETURNED BY THE              L1983I
C     SUBROUTINE ARE GIVEN BELOW:                                         L1983I
C        YIELD = THE PER ACRE YIELD. VOLUME YIELDS ARE IN CUBIC FOOT      L1983I
C                AND WEIGHT YIELDS ARE IN HUNDREDS OF POUNDS.             L1983I
C           FR = A 20-ELEMENT ARRAY IN WHICH FR(I) IS THE NUMBER          L1983I
C                OF TREES/ACRE IN DBH CLASS "I".                          L1983I
C            H = A 20-ELEMENT ARRAY IN WHICH H(I) IS THE AVERAGE          L1983I
C                TOTAL HEIGHT FOR TREES IN DBH CLASS "I".                 L1983I
C        CLYLD = A 20-ELEMENT ARRAY IN WHICH CLYLD(I) IS THE PER          L1983I
```

```
C                 ACRE YIELD FOR TREES IN DBH CLASS "I". VOLUMETRIC      L1983I
C                 VALUES ARE IN CUBIC FEET AND WEIGHT                    L1983I
C                 VALUES ARE IN HUNDREDS OF POUNDS.                      L1983I
C                                                                        L1983I
C                                                                        L1983I
      REAL IB                                                            L1983I
      DIMENSION FR(20),H(20),DBH(20),TRYLD(20),CLYLD(20)                 L1983I
      DATA VOL,GWT,DWT,OB,IB/'VOL ','GWT ','DWT ','OB  ','IB  '/         L1983I
C                                                                        L1983I
      IEQN = 0                                                           L1983I
C                                                                        L1983I
      IF(UNIT.EQ.VOL.AND.BARK.EQ.OB)IEQN=1                               L1983I
      IF(UNIT.EQ.VOL.AND.BARK.EQ.IB)IEQN=2                               L1983I
      IF(UNIT.EQ.DWT)IEQN=3                                              L1983I
      IF(UNIT.EQ.GWT)IEQN=4                                              L1983I
C                                                                        L1983I
      IF(IEQN.GE.1.AND.IEQN.LE.4)GO TO 20                                L1983I
      WRITE(6,100)UNIT,BARK                                              L1983I
  100 FORMAT(1H1,'UNIT=',A4,' AND BARK=',A4,' IS INVALID COMBINATION OF  L1983I
     1ARGUMENTS TO SUBROUTINE SPYLDL.  EXECUTION TERMINATED.')           L1983I
      STOP                                                               L1983I
   20 CONTINUE                                                           L1983I
C                                                                        L1983I
      YIELD = 0.                                                         L1983I
      DO 25 I=1,20                                                       L1983I
      FR(I) = 0.                                                         L1983I
      H(I) = 0.                                                          L1983I
   25 CLYLD(I) = 0.                                                      L1983I
      IF(A.LT.10..OR.S.LT.20..OR.D.LT.25.)RETURN                         L1983I
      CALL PSPDS2(A,S,D,GROUP,FR,H,DBH,MINCL,MAXCL)                      L1983I
C                                                                        L1983I
      DO 10 I=MINCL,MAXCL                                                L1983I
      IF(I.LT.5)GO TO 10                                                 L1983I
      GO TO (1,2,3,4),IEQN                                               L1983I
C                                                                        L1983I
    1 TRYLD(I) = VOLOBM(DBH(I),H(I),TOPD)                                L1983I
      GO TO 5                                                            L1983I
C                                                                        L1983I
    2 TRYLD(I) = VOLIBM(DBH(I),H(I),TOPD)                                L1983I
      GO TO 5                                                            L1983I
C                                                                        L1983I
    3 TRYLD(I) = DWMER(DBH(I),H(I),TOPD)                                 L1983I
      GO TO 5                                                            L1983I
C                                                                        L1983I
    4 TRYLD(I) = GWMER (DBH(I),H(I),TOPD)                                L1983I
C                                                                        L1983I
    5 IF(TRYLD(I).LT.0.)TRYLD(I)=0.                                      L1983I
      CLYLD(I) = TRYLD(I)*FR(I)                                          L1983I
      YIELD = YIELD + CLYLD(I)                                           L1983I
      IF(UNIT.EQ.DWT.OR.UNIT.EQ.GWT)CLYLD(I) = CLYLD(I)/100.             L1983I
   10 CONTINUE                                                           L1983I
      IF(UNIT.EQ.DWT.OR.UNIT.EQ.GWT)YIELD=YIELD/100.                     L1983I
C                                                                        L1983I
      RETURN                                                             L1983I
      END                                                                L1983I
C                                                                        L1983I
C*********************************************************************** L1983I
      SUBROUTINE PSPDS2(A,S,D,GROUP,FR,H,DBH,MINCL,MAXCL)                L1983I
```

```
C     THIS SUBROUTINE CALCULATES THE PREDICTED STAND STRUCTURE            L1983I
C     FOR A SITE-PREPARED LOBLOLLY PINE PLANTATION OF KNOWN AGE,          L1983I
C     SITE INDEX, NUMBER OF STEMS PER ACRE AND SOIL GROUP.                L1983I
C     ARGUMENTS INVOLVED IN THE CALLING SEQUENCE ARE:                     L1983I
C             A = PLANTATION AGE.                                         L1983I
C             S = SITE INDEX (BASE AGE 25 YEARS).                         L1983I
C             D = NUMBER OF SURVIVING STEMS PER ACRE AT AGE "A".          L1983I
C         GROUP = AN INPUT IDENTIFYING THE SOIL GROUP FOR THE SITE        L1983I
C                 ON WHICH THE PLANTATION IS GROWING.  (FOR A COMPLETE    L1983I
C                 DEFINITION OF THIS VARIABLE, SEE SUBROUTINE SPYLDL.)    L1983I
C     VALUES RETURNED ARE:                                                L1983I
C            FR = A 20-ELEMENT ARRAY IN WHICH FR(I) IS THE NUMBER         L1983I
C                 OF TREES/ACRE IN DBH CLASS "I".                         L1983I
C             H = A 20-ELEMENT ARRAY IN WHICH H(I) IS THE AVERAGE         L1983I
C                 TOTAL HEIGHT FOR TREES IN CLASS "I".                    L1983I
C           DBH = A 20-ELEMENT ARRAY IN WHICH DBH(I) IS THE               L1983I
C                 MIDPOINT DBH VALUE FOR DBH CLASS "I".                   L1983I
C         MINCL = THE SMALLEST OCCUPIED DBH CLASS                         L1983I
C         MAXCL = THE LARGEST OCCUPIED DBH CLASS                          L1983I
C                                                                         L1983I
C                                                                         L1983I
      COMMON /WPARM/ALPHA,BETA,GAMMA                                      L1983I
      DIMENSION FR(20),H(20),DBH(20)                                      L1983I
C                                                                         L1983I
      CALL SPLPHD(A,S,GROUP,HDOM)                                         L1983I
      Z1=SQRT(A)                                                          L1983I
      Z2=ALOG(D)                                                          L1983I
      Z3=A/HDOM                                                           L1983I
      Z4=D/HDOM                                                           L1983I
      Z5=ALOG(A)                                                          L1983I
      IF(GROUP.EQ.2.)GO TO 40                                             L1983I
C                                                                         L1983I
C     CALCULATE WEIBULL PARAMETERS - ALPHA,BETA,GAMMA                     L1983I
C                                                                         L1983I
C                     SOIL GROUP 1                                        L1983I
C                                                                         L1983I
C                                                                         L1983I
      ALPHA=Z1*(0.2576*Z1-0.1073*Z2)                                      L1983I
      XBETA=2.2978-1.2111*Z3-0.0192*Z4                                    L1983I
      BETA=EXP(XBETA)                                                     L1983I
      XGAMMA=1.5518-0.0339*A +0.0714*Z5                                   L1983I
      GAMMA=EXP(XGAMMA)                                                   L1983I
      GO TO 50                                                            L1983I
C                                                                         L1983I
C                                                                         L1983I
C     CALCULATE WEIBULL PARAMETERS - ALPHA,BETA,GAMMA                     L1983I
C                                                                         L1983I
C                                                                         L1983I
C                     SOIL GROUP 2                                        L1983I
C                                                                         L1983I
C                                                                         L1983I
  40  ALPHA=Z1*(0.4912*Z1-0.2139*Z2)                                      L1983I
      XBETA=2.5829-0.0359*A-0.000672*D                                    L1983I
      BETA=EXP(XBETA)                                                     L1983I
      XGAMMA=5.0037-0.1495*A-22.3577/A                                    L1983I
      GAMMA=EXP(XGAMMA)                                                   L1983I
  50  CONTINUE                                                            L1983I
      IF(ALPHA.LT.0.)ALPHA=0.                                             L1983I
```

```
C                                                                       L1983I
C     INITIALIZE FR, H AND DBH ARRAYS                                   L1983I
C                                                                       L1983I
      DO 10 I=1,20                                                      L1983I
      DBH(I)=0.                                                         L1983I
      H(I)=0.                                                           L1983I
   10 FR(I)=0.                                                          L1983I
C                                                                       L1983I
C     TIME TO CALCULATE A DIAMETER DISTRIBUTION                         L1983I
C             HERE WE GO                                                L1983I
C                                                                       L1983I
      MINCL = ALPHA+.5                                                  L1983I
      IF(MINCL.LT.1)MINCL=1                                             L1983I
      DLOWER = ALPHA                                                    L1983I
      DUPPER = FLOAT(MINCL)+.5                                          L1983I
      DBH(MINCL)=.5*(DLOWER + DUPPER)                                   L1983I
      CUMF = CDF(DBH(MINCL))                                            L1983I
      X1=HDOM/A                                                         L1983I
      X2=ALOG(CUMF+1.0)                                                 L1983I
      H(MINCL) = HDOM*(.6046+0.0449*X1+(0.7385-0.0862*X1)*X2)           L1983I
      FR(MINCL) = (CDF(DUPPER) - CDF(DLOWER)) * D                       L1983I
      COUNT = FR(MINCL)                                                 L1983I
      IBEGIN = MINCL + 1                                                L1983I
      DO 20  I=IBEGIN,20                                                L1983I
      MAXCL=I                                                           L1983I
      DBH(I)=I                                                          L1983I
      DLOWER = DBH(I) - .5                                              L1983I
      DUPPER = DLOWER + 1.                                              L1983I
      CUMF = CDF(DBH(I))                                                L1983I
      X2=ALOG(CUMF+1.0)                                                 L1983I
      H(I)=HDOM*(0.6046+0.0449*X1+(0.7385-0.0862*X1)*X2)                L1983I
      FR(I) =(CDF(DUPPER) - CDF(DLOWER)) * D                            L1983I
      COUNT = COUNT + FR(I)                                             L1983I
      DIFF = D - COUNT                                                  L1983I
      IF(DIFF.GT..5.AND.I.LT.20)GO TO 20                                L1983I
      FR(I) = FR(I) + DIFF                                              L1983I
      GO TO 30                                                          L1983I
   20 CONTINUE                                                          L1983I
C                                                                       L1983I
   30 RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION CDF(DBH)                                                 L1983I
C                                                                       L1983I
C     THIS SUBPROGRAM CALCULATES THE WEIBULL CUMULATIVE                 L1983I
C     DISTRIBUTION FUNCTION VALUE ASSOCIATED WITH THE                   L1983I
C     DIAMETER VALUE "DBH"                                              L1983I
C                                                                       L1983I
         COMMON/WPARM/ALPHA,BETA,GAMMA                                  L1983I
C                                                                       L1983I
      IF(ALPHA.LT.0.)ALPHA=0.                                           L1983I
      IF(DBH.GT.ALPHA)GO TO 10                                          L1983I
      CDF = 0.                                                          L1983I
      RETURN                                                            L1983I
C                                                                       L1983I
   10 IF(BETA.LE.0.)BETA=.01                                            L1983I
```

```
      IF(GAMMA.LE.0.)GAMMA=.01                                          L1983I
      Q = (DBH-ALPHA)/BETA                                              L1983I
      Q1 = ALOG(Q)*GAMMA                                                L1983I
      IF(Q1.GT.174.) GO TO 20                                           L1983I
      Q2 = Q**GAMMA                                                     L1983I
      IF(Q2.GT.187.)GO TO 20                                            L1983I
      CDF = 1.-EXP(-Q2)                                                 L1983I
      RETURN                                                            L1983I
C                                                                       L1983I
C     AVOIDING POSSIBLE PROBLEMS FROM EXPONENT OUT OF RANGE             L1983I
C                                                                       L1983I
   20 CDF=1.                                                            L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C********************************************************************** L1983I
C********************************************************************** L1983I
C     INIVIDUAL TREE VOLUME AND WEIGHT EQUATIONS                        L1983I
C                                                                       L1983I
C     THE FOLLOWING SET OF FUNCTION SUBPROGRAMS                         L1983I
C     PREDICTS INDIVIDUAL TREE VOLUMES, GREEN WEIGHTS                   L1983I
C     (WITH BARK) AND DRY WEIGHTS (WITHOUT BARK) FOR                    L1983I
C     BOTH THE TOTAL STEM AND MERCHANTABLE STEM.  THE                   L1983I
C     EQUATIONS WERE DEVELOPED FROM DATA COLLECTED                      L1983I
C     IN SITE-PREPARED LOBLOLLY PINE PLANTATIONS IN THE                 L1983I
C     COASTAL PLAIN OF NORTH AND SOUTH CAROLINA, GEORGIA                L1983I
C     AND NORTH FLORIDA.                                                L1983I
C                                                                       L1983I
C     VARIABLES USED AS ARGUMENTS ARE:                                  L1983I
C         D = TREE DBH                                                  L1983I
C         H = TOTAL TREE HEIGHT                                         L1983I
C      TOPD = MERCHANTABLE-TOP DIAMETER (OUTSIDE BARK)                  L1983I
C                                                                       L1983I
C     THE SUBPROGRAMS AVAILABLE ARE:                                    L1983I
C        VOLOBT - RETURNS TOTAL OUTSIDE-BARK VOLUME                     L1983I
C                 WITH D AND H AS INPUTS                                L1983I
C        VOLIBT - RETURNS TOTAL INSIDE-BARK VOLUME                      L1983I
C                 WITH D AND H AS INPUTS                                L1983I
C        VOLOBM - RETURNS MERCHANTABLE OUTSIDE-BARK VOLUME              L1983I
C                 WITH D,H AND TOPD AS INPUTS                           L1983I
C        VOLIBM - RETURNS MERCHANTABLE INSIDE-BARK VOLUME               L1983I
C                 WITH D,H AND TOPD AS INPUTS                           L1983I
C         GWTOT - RETURNS TOTAL GREEN WEIGHT                            L1983I
C                 WITH D AND H AS INPUTS                                L1983I
C         GWMER - RETURNS MERCHANTABLE GREEN WEIGHT                     L1983I
C                 WITH D,H AND TOPD AS INPUTS                           L1983I
C         DWTOT - RETURNS TOTAL DRY WEIGHT                              L1983I
C                 WITH D AND H AS INPUTS                                L1983I
C         DWMER - RETURNS MERCHANTABLE DRY WEIGHT                       L1983I
C                 WITH D,H AND TOPD AS INPUTS                           L1983I
C                                                                       L1983I
C     ALL VOLUMES ARE EXPRESSED IN CUBIC FEET.                          L1983I
C     ALL WEIGHTS ARE EXPRESSED IN POUNDS.                              L1983I
C                                                                       L1983I
C********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION VOLOBT(D,H)                                              L1983I
      DATA B0,B1,B2/-5.5326,1.8945,0.9288/                              L1983I
```

```
      VOLOBT=EXP(B0+B1*ALOG(D)+B2*ALOG(H))                              L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION VOLIBT(D,H)                                              L1983I
      DATA B0,B1,B2/-6.5143,1.9229,1.1105/                              L1983I
      VOLIBT=EXP(B0+B1*ALOG(D)+B2*ALOG(H))                              L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION VOLOBM(D,H,TOPD)                                         L1983I
      DATA B1,B2,B3/0.4724,3.3559,3.1135/                               L1983I
      VOLOBM=VOLOBT(D,H)*(1.0-B1*(TOPD**B2/D**B3))                      L1983I
      IF(VOLOBM.LT.0.)VOLOBM=0.                                         L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION VOLIBM(D,H,TOPD)                                         L1983I
      DATA B1,B2,B3/0.5694,3.4304,3.2395/                               L1983I
      VOLIBM=VOLIBT(D,H)*(1.0-B1*(TOPD**B2/D**B3))                      L1983I
      IF(VOLIBM.LT.0.)VOLIBM=0.                                         L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION GWTOT(D,H)                                               L1983I
      DATA B0,B1,B2/-2.0153,1.9159,1.0481/                              L1983I
      GWTOT = EXP(B0+B1*ALOG(D)+B2*ALOG(H))                             L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION GWMER(D,H,TOPD)                                          L1983I
      DATA B1,B2,B3/0.4819,3.3208,3.0622/                               L1983I
      GWMER = GWTOT(D,H) * (1.0-B1*(TOPD**B2/D**B3))                    L1983I
      IF(GWMER.LT.0.)GWMER=0.                                           L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION DWTOT(D,H)                                               L1983I
      DATA B0,B1,B2/-3.5428,1.8721,1.2273/                              L1983I
      DWTOT=EXP(B0+B1*ALOG(D)+B2*ALOG(H))                               L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION DWMER(D,H,TOPD)                                          L1983I
```

```
      DATA B1,B2,B3/0.4868,3.5503,3.3322/                               L1983I
      DWMER=DWTOT(D,H)*(1.0-B1*(TOPD**B2/D**B3))                        L1983I
      IF(DWMER.LT.0.)DWMER=0.                                           L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      SUBROUTINE SPLPSI(A,HD,GROUP,SITE)                                L1983I
C                                                                       L1983I
C                                                                       L1983I
C     THIS SUBROUTINE CALCULATES SITE INDEX (BASE AGE 25)               L1983I
C     FROM PLANTATION AGE "A" AND AVERAGE HEIGHT OF DOMINANTS           L1983I
C     AND CODOMINANTS "HD".  A SEPARATE SITE INDEX EQUATION             L1983I
C     IS AVAILABLE FOR EACH SOIL GROUP.  THE SOIL                       L1983I
C     GROUP CLASSES ARE DEFINED IN SUBROUTINE "SPYLDL"                  L1983I
C                                                                       L1983I
      B1=-4.69839                                                       L1983I
      B2=-37.22042                                                      L1983I
      B3=-.676442                                                       L1983I
      IF(GROUP.EQ.1.)                                                   L1983I
     1  Y = B2/25. - B3 + (ALOG(HD)-B2/A+B3) * EXP(B1*(1./A- 1./25.))   L1983I
      IF(GROUP.EQ.1.) SITE=EXP(Y)                                       L1983I
      IF(GROUP.EQ.2.)                                                   L1983I
     1    SITE = HD * ((.74760/(1.0 - EXP(-.05507*A)))**1.4350)         L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      SUBROUTINE SPLPHD(A,SITE,GROUP,HD)                                L1983I
C                                                                       L1983I
C     THIS SUBROUTINE CALCULATES AVERAGE HEIGHT OF DOMINANTS            L1983I
C     AND CODOMINANTS FROM PLANTATION AGE "A" AND SITE INDEX            L1983I
C     "SITE" (BASE AGE 25).  A SEPARATE EQUATION IS USED FOR            L1983I
C     EACH OF THE TWO SOIL GROUPS.  DEFINITIONS OF THE SOIL             L1983I
C     GROUPS ARE GIVEN IN SUBROUTINE SPYLDL.                            L1983I
C                                                                       L1983I
      B1=-4.69839                                                       L1983I
      B2=-37.22042                                                      L1983I
      B3=-.676442                                                       L1983I
      IF(GROUP.EQ.1.)                                                   L1983I
     1  Y = B2/A - B3 + (ALOG(SITE)-B2/25.+B3)*EXP(-B1*(1./A-1./25.))   L1983I
      IF(GROUP.EQ.1.) HD=EXP(Y)                                         L1983I
      IF(GROUP.EQ.2.)                                                   L1983I
     1    HD = SITE * ((1.33760 * (1. - EXP(-.05507*A)))**1.4350)       L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION TFDOB(DBH,TOTHT,HTAG)                                    L1983I
C                                                                       L1983I
C     THIS FUNCTION RETURNS THE PREDICTED OUTSIDE-BARK DIAMETER         L1983I
```

```
C     AT A POINT "HTAG" FEET ABOVE THE GROUND FOR A TREE WITH A         L1983I
C     BREAST-HEIGHT DIAMETER OF "DBH" INCHES AND A TOTAL HEIGHT         L1983I
C     OF "TOTHT" FEET.                                                  L1983I
C                                                                       L1983I
C                                                                       L1983I
      DATA B1,B2,B3,B4/1.129318,.899034,-.685006,.737518/               L1983I
C                                                                       L1983I
      TFDOB = B1 * DBH**B2 * TOTHT**B3 * (TOTHT-HTAG)**B4               L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION TFHTOB(DBH,TOTHT,DOB)                                    L1983I
C                                                                       L1983I
C     THIS FUNCTION RETURNS THE PREDICTED HEIGHT ABOVE GROUND           L1983I
C     TO A POINT ON THE STEM WHERE THE OUTSIDE-BARK DIAMETER            L1983I
C     IS "DOB" INCHES FOR A TREE WITH A BREAST-HEIGHT DIAMETER          L1983I
C     OF "DBH" INCHES AND A TOTAL HEIGHT OF "TOTHT" FEET.               L1983I
C                                                                       L1983I
C                                                                       L1983I
      DATA B1,B2,B3,B4/.84798,-1.2190,.9288,1.3559/                     L1983I
C                                                                       L1983I
      TFHTOB = TOTHT - (B1 * DBH**B2 * TOTHT**B3 * DOB**B4)             L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION TFDIB(DBH,TOTHT,HTAG)                                    L1983I
C                                                                       L1983I
C     THIS FUNCTION RETURNS THE PREDICTED INSIDE-BARK DIAMETER          L1983I
C     AT A POINT "HTAG" FEET ABOVE THE GROUND FOR A TREE WITH A         L1983I
C     BREAST-HEIGHT DIAMETER OF "DBH" INCHES AND A TOTAL HEIGHT         L1983I
C     OF "TOTHT" FEET.                                                  L1983I
C                                                                       L1983I
C                                                                       L1983I
      DATA B1,B2,B3,B4/.770783,.883723,-.619672,.764991/                L1983I
C                                                                       L1983I
      TFDIB = B1 * DBH**B2 * TOTHT**B3 * (TOTHT-HTAG)**B4               L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      FUNCTION TFHTIB(DBH,TOTHT,DIB)                                    L1983I
C                                                                       L1983I
C     THIS FUNCTION RETURNS THE PREDICTED HEIGHT ABOVE GROUND           L1983I
C     TO A POINT ON THE STEM WHERE THE INSIDE-BARK DIAMETER             L1983I
C     IS "DIB" INCHES FOR A TREE WITH A BREAST-HEIGHT DIAMETER          L1983I
C     OF "DBH" INCHES AND A TOTAL HEIGHT OF "TOTHT" FEET.               L1983I
C                                                                       L1983I
C                                                                       L1983I
      DATA B1,B2,B3,B4/1.405410,-1.155207,.810039,1.307206/             L1983I
C                                                                       L1983I
```

```
      TFHTIB = TOTHT - (B1 * DBH**B2 * TOTHT**B3 * DIB**B4)             L1983I
C                                                                       L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C                                                                       L1983I
      SUBROUTINE KILLEM(S,A1,A2,T1,T2)                                  L1983I
C                                                                       L1983I
C         S = SITE INDEX BASE AGE 25                                    L1983I
C        A1 = INITIAL AGE                                               L1983I
C        A2 = ENDING AGE                                                L1983I
C        T1 = NUMBER OF TREES PER ACRE AT AGE A1                        L1983I
C        T2 = NUMBER OF TREES PER ACRE AT AGE A2                        L1983I
C                                                                       L1983I
      DATA B1,B2,B3,B4/-2.029625,.00261778,3.683674,-.0933325/          L1983I
C                                                                       L1983I
      T2=100.*((T1/100.)**B1+(B2+B4/S)*((A2/10.)**B3-(A1/10.)**B3))     L1983I
     1              **(1./B1)                                           L1983I
      RETURN                                                            L1983I
      END                                                               L1983I
C                                                                       L1983I
C*********************************************************************** L1983I
C*********************************************************************** L1983I
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Clutter, Jerome L.; Harms, William R.; Brister, Graham, H.; Reney, John W.
Stand structure and yields of site-prepared loblolly pine plantations in the lower coastal plain of the Carolinas, Georgia, and north Florida. Gen. Tech. Rep. SE-27. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 173 pp.

Equations and tables are presented for estimating total and merchantable volumes and weights of loblolly pine planted on prepared sites in the Lower Atlantic Coastal Plain. The equation system can be used to predict current and projected yields in cubic feet and green and dry weights.

KEYWORDS: Pinus taeda, taper equations, volume equations, forest management in Southeastern States.

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The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Wood Residue Distribution Simulator (WORDS)

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Wood Residue Distribution Simulator (WORDS)

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ABSTRACT

Successful development of woody biomass for energy will depend on the distribution of local supply and demand within subregions, rather than on the total inventory of residues. The Wood Residue Distribution Simulator (WORDS) attempts to find a least-cost allocation of residues from local sources of supply to local sources of demand, given the cost of the materials, their distribution, and the distribution of demand. The results are useful in evaluating the feasibility of developing wood energy either for a subregion in general or for specific locales. This paper describes WORDS and gives an example of its application to mill residues in the State of Georgia.

Keywords: Energy, supply, demand, Georgia.

Introduction

Interest in the development of wood energy remains high in the Southeast. Some States in the region maintain ongoing programs to promote the use of noncommercial forest biomass for energy production. A substantial quantity of mill residues is generated, and there is a growing capability for recovering poor-quality material that previously has remained in the woods. Hence, residues for energy application are expected to be available for the long term with forest residues replacing mill residues as the latter decline in availability.

Much of the promotion to date has been based on the total inventory of potential wood fuels over fairly large geographical areas. Such totals are of limited value to the prospective user because they indicate only in a general way whether more precise assessments are justified. Successful development of many resources depends upon the distribution of local supply and demand within subregions. This is especially true of woody biomass used for energy because of its relatively low per unit heating value.

Our objective was to develop and evaluate methods for estimating the effective supply of wood residue fuels over a subregion given the cost of such materials, their distribution, and the distribution of the demand for them. The resulting Wood Residue Distribution Simulator (WORDS) attempts to find a least-cost wood residue allocation from local sources of supply to local points of demand. Simulation output may be used as a basis for evaluating whether or not wood residue is a viable energy source for either the subregion as a whole or for specific locales within the subregion. This paper describes the WORDS program and gives an example and evaluation of its use, with the State of Georgia as a pilot area.

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The Simulator

Two versions of WORDS have been developed, one for use in batch mode, the other for interactive mode on a computer TSO terminal. Both versions have three distinct segments. The first segment summarizes uncommitted wood residues and calculates average costs and energy values for those residues. The second computes cost-effective shipping distances as a function of a constant wood energy value, a schedule of shipping costs, and a variable wood residue purchase price. This segment also calculates the potential cost-effective supply available to each demand source. The third segment derives the allocation of wood residues from the sources of supply to the sources of demand, assuming that the demand sources compete for supply pools common to them.

Limitations on WORDS are inherent primarily in the dimensions of arrays. These can be readily altered to increase the simulator's capacity. "Supply unit" and "demand unit" are the terms used to denote locations from which and to which residues might be shipped. WORDS can accommodate up to 160 units for both supply and demand. Because a subregion may have many more actual supply and demand sources, it may be necessary to aggregate sources so that the total units of each is 160 or less. Thus, a particular demand or supply unit might be a composite of several supply or demand sources. To calculate transportation distances, the weighted geographical center of the several sources would be the ideal location of the aggregate unit. In practice, however, it may be necessary to use some other location, such as city centers or county seats, so that transportation distance values can be derived at reasonable cost.

"Wood residues" denotes any of a number of similar materials, usually with different heating characteristics and different costs. WORDS can allocate any combination of residues up to eight. Data on each individual residue are inputs to the simulator, and the program calculates aggregate values for the user-specified combination.

A "cost-effective" wood fuel is defined as having a lower delivered cost per unit energy than an alternate energy source. We wish to emphasize strongly that an accurate estimate of the feasibility of using wood residues for energy must incorporate other costs in addition to the delivered cost of fuel. For example, storage and handling costs are inherently greater because wood residues are bulkier than fossil fuels. Some measure of conversion costs (such as capital cost amortized over the life of the wood-fueled system) must also be considered. Also, wood-fueled systems are more expensive to maintain than gas- or oil-fired systems.[1] Costs such as these must be included when estimating the overall feasibility of wood residues as an energy source. Currently, WORDS does not incorporate these costs, but it has been structured so that they can be easily added.

The three simulator segments are in the form of three computer programs, as follows:

Residue Summary Program

Because residue types vary in purchase price and energy value, it is important to be able to evaluate each type separately and in combination with others.

A description of each supply unit's wood residue inventory is required. This description consists of up to eight categories of wood residues (such as

[1]Karchesy, Joseph; Koch, Peter. Energy production from hardwoods growing on southern pine sites. Gen. Tech. Rep. SO-24. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1979. 59 p.

hardwood bark, softwood chips, etc.), the quantity available in each category, the energy value of each type of residue in millions of Btu's per ton, and the cost of each residue type in dollars per ton. After the user specifies some desired combination of residue types, the program calculates, for each supply source, the total residue available, the average price of the residue, and the average heating value of the residue. These values are printed out in a report and stored in an external file for use in subsequent segments.

The program also calculates the maximum distance the given combination of residues can be shipped, with cost-effectiveness as a constraint. First, the user must develop a subroutine which, given a transport mileage, will return the cost of shipping 1 ton of residues that number of miles. The delivered cost of some alternate energy source (the "break-even" cost) must also be specified. By using the systemwide average heating value of residues, the program creates a table of the maximum cost-effective residue shipping distances as a function of purchase price, ranging from user-supplied minimum to maximum in 50-cent increments. Because shipping costs are likely to be on a graduated scale, the computations are performed iteratively. For each price increment, delivered residue costs (in dollars per million Btu's) are calculated for transportation distance increments until the cost exceeds some user-supplied alternate fuel delivered cost. The last distance used before the break-even cost is exceeded is considered the maximum cost-effective shipping distance for that particular residue cost. To give the user some reference values, both the average systemwide cost of residue and the average systemwide unit Btu content of the residue are reported.

Potential Supply Availability Program

The second segment uses calculations from the first segment to determine the supply of wood residue potentially available to each demand unit, with cost-effectiveness as a constraint and competition among demand units for common supply pools ignored.

With demand unit-supply unit distances and the transportation cost function, the program calculates a per million Btu transportation cost between every demand unit and every supply unit. It adds to this the purchase price of the residue at the supply unit, then compares that cost to the break-even cost at the demand source; every transfer that results in a cost lower than break-even is designated as cost-effective. The break-even cost may be different for each demand unit because a unique alternate fuel cost may be specified for each demand unit.

The program sums the total cost-effective supply for each demand source and prints out this sum as the supply potentially available to the demand source. At the discretion of the user, every cost-effective supply-demand transfer can be reported as well. The program also sums all supply and demand in the system, compares the two, and reports whether or not a deficit exists. Finally, supply and demand files are created for inputs to the Residue Allocation Program.

Residue Allocation Program

This program is adapted from a recreation distribution simulation model developed by Dress and Devine[2] and allocates wood residues from supply units to demand units, all of which are competing

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[2]Dress, Peter E.; Devine, Hugh A., Jr. A simulation model for the estimation of unmet recreation facilities demand. Georgia Comprehensive Recreation Plan (GORP). Atlanta, GA: Georgia Department of Natural Resources; unpublished paper on file; 1978.

for the supply. The object is to approximate a least-cost allocation through a simulation procedure. Although linear programming could be used to find the optimal (i.e., the absolute least-cost) allocation, linear programming is expensive for large supply-demand systems. The simulation procedure approximates the optimal solution at a fraction of the cost. Dress and Devine[3] provide extensive documentation on the basic model, so our discussion is limited to its application to wood residue allocation. An optimal systemwide allocation is, in general, the one that satisfies as much demand as possible while minimizing the cost of doing so. In standard optimization terminology, our problem is to minimize total costs of allocating wood residues, subject to the constraints that either all demand is satisfied, or all supply is used, or both.

In the wood residue model each supply-demand transfer is assigned to a preference class, based on the delivered cost of fuel for the transfer. The user specifies the number of preference classes to be assigned and the cost range for each class. The program computes the purchase price plus transport cost for every potential supply-demand transfer and, based on the class boundaries, assigns each transfer to a preference class. Preference class 1 (the highest) will contain all the least expensive transfers; preference class 2, the next least expensive; and so forth.

Allocation is made in increments, the size of which are specified by the user. In general, smaller increments provide closer-to-optimal solutions but at a higher cost in computer time. The program allocates an increment of supply to a demand unit from every supply unit in the demand unit's preference class 1. It then proceeds to another demand unit, repeating the procedure. When all demand units have received their first increment allocations, the program returns to the first demand unit to allocate the second increment. This iterative process continues until all possible allocations in preference class 1 have been made. Normally this will occur either when demands have been satisfied or supplies exhausted along class 1 supply-demand transfer routes. If, after preference class 1 allocations are made, uncommitted supplies or unsatisfied demands still exist in the system, the program proceeds to repeat the above procedure for each successive preference class until all supply is allocated or all demand is satisfied. Allocating by preference class sequence results in a relatively low-cost overall allocation, because the lowest cost allocations (as a group) are made before more expensive allocations. Allocating within preference classes by increments simulates competition, because the supply is distributed, bit by bit, among demand units in the same preference class. When a supply source is exhausted or a demand source satisfied, no more allocations involving those units are made, although the procedure continues for the other units.

Inherent in this type of simulation is the fact that the quantity allocated to a given demand unit depends on the order of that demand unit in the sequence. If supply within a preference class is exhausted between the first increment allocation in a given iteration and the last, those demand units receiving the allocations first in the iteration will receive a larger supply at the lower cost. This is why a simulation will not necessarily result in the optimum allocation ensured by a linear program, which essentially makes simultaneous allocations to all demand units in the propor-

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[3]Dress, Peter E.; Devine, Hugh A., Jr. Decription of procedures, concepts and computation software for the estimation of unmet recreational demands. Georgia Comprehensive Recreation Plan (GORP). Atlanta, GA: Georgia Department of Natural Resources; unpublished paper on file; 1978.

tions that result in least cost. To reduce this effect, the demand units are randomly reordered before allocations within each preference class, eliminating a consistent automatic bias.

Finally, reports are generated by the program. The quantity of residue allocated from every supply unit to every demand unit as well as a list of the preference class assignment for each supply-demand transfer are produced as tables. Another report shows the satisfied and unsatisfied demand of each demand unit as well as the allocated and unallocated inventory of each supply unit.

A WORDS Example

Data from 1980 were used to test WORDS. The residue type consisted of unused mill residues in the State of Georgia. The residue production figures were from a survey conducted periodically by the Georgia Forestry Commission. Counties were used as supply units, with county seats taken as transportation nodes. Because of the confidential nature of these supply data, the county supply codes were randomized and reports listed only code numbers rather than county names. Supplies were aggregated by county and comprised eight residue types--softwood bark, hardwood bark, softwood shavings, hardwood shavings, softwood chips, hardwood chips, softwood dust, and hardwood dust.

For approximate energy value calculations, the residues were classified as either hardwoods or softwoods and as either bark or other wood fibers. Potential heating values were calculated by correcting for moisture content as given by Taras and Clark[4] and by estimating available heat according to Karchesy and Koch.[5] While burning efficiencies vary with equipment, a 70 percent efficiency was used to represent woodfired systems in general. The resulting available energy values were:

Residues	Million Btu/green ton
Softwood bark	7.482
Hardwood bark	6.056
Other softwood	5.789
Other hardwood	5.960

No explicit estimates of demand were available, so we formulated a hypothetical situation to represent a "real-world" problem. The assumption was that all nonelectrically heated public schools were to be converted to wood-fired heating systems. Estimates of countywide demand for each county were based on average annual heating energy use per student in three climatically stratified zones.

A schedule of approximate shipping rates was derived from confidential industry sources in the State:

Miles	Dollars/ton-mile
0- 40	0.245
41- 60	.205
61- 80	.195
81-100	.185
100+	.170

The following average residue prices were derived, again, from several confi-

[4]Taras, Michael A.; Clark, Alexander, III. Aboveground biomass of loblolly pine in a natural, uneven-aged sawtimber stand in central Alabama. Tappi 58(2): 103-105; 1975.

[5]See footnote 1.

dential industry sources in the State:

Residue	Dollars/ton
Softwood and hardwood bark	5.50
Softwood chips	18.00
Hardwood chips	11.00
Softwood and hardwood dust	5.50
Softwood and hardwood shavings	11.00

Model Parameters

The following parameters were used for the example solution:

- Minimum and maximum wood residue purchase prices for calculating cost-effective shipping distances were $5 and $15 per ton, respectively.
- Three preference classes were used for supply-demand transfers; class 1, from $0 to $20; class 2, from $20.01 to $35; class 3, from $35.01 to $100 per delivered ton of residue.
- The allocation increment was 500 tons, with the maximum number of iterations set at 100. This would permit 50,000 (100x50) tons of residue to be shipped from any supply unit or to any demand unit in a given preference class. The object was to limit iterations but to base the limitations on a sufficiently large quantity so that either supply would be exhausted or demand met within a preference class before the maximum number of iterations was reached.

Results and Discussion

Although the problem addressed was hypothetical, the data enabled us to draw some useful conclusions about both the simulator's potential use and the development of wood residue as an energy source.

Cost-effective shipping distances for wood residues. With an inflated 1980 natural gas price of $0.48 per therm (100,000 Btu) and an assumed efficiency of 80 percent for gas-fired equipment, the estimated alternate fuel cost was about $6 per million Btu. For our data set, this resulted in cost-effective shipping mileages ranging from 137 miles at a residue price of $15 per ton to 196 miles at a residue purchase price of $5 per ton. As a general reference, the weighted cost of all residues in the State at that time was $6.66 per ton.

While transportation costs and wood residue prices are likely to increase, these will be offset at least partially by higher alternate fuel costs. The implication is that over the near term, mill residues could be a feasible source of energy even at transfer distances as great as 100 miles.

Residue availability. Wood residues, particularly mill residues, will become scarcer as the demand for less expensive energy increases. The large amount of residue existing in Georgia in 1980 suggests, however, that it may be several years before demand exceeds supply. By using natural gas as the alternate fuel source for all Georgia counties, the WORDS solution indicated that every county in the State has at least 47 other counties (out of a possible 158) from which it could potentially draw wood residue under the cost-effective constraint.

Under competition among counties, WORDS still indicated that, for the hypothetical problem, the total demand could be satisfied over the entire system and at a better than break-even cost. No county would have to pay more than an average of $4.50 per million Btu, and over 90 percent of the counties could obtain their residues at a delivered cost of under $3 per million Btu.

The model. WORDS appears to be a useful and inexpensive tool to aid in assessing the feasibility of large-scale use of wood residues for energy. Model parameters are easy to alter, hence sensitivity analyses to evaluate the effects of any changes in price or in the residue mix are easily made. The model is versatile enough for large or small residue supply-demand systems and with only minor changes can be adapted to other supply-demand systems as well.

Eza, Douglas A.; McMinn, James W.; Dress, Peter E.
Wood residue distribution simulator (WORDS). Gen. Tech. Rep. SE-28. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 6 pp.

Successful development of woody biomass for energy will depend on the distribution of local supply and demand within subregions, rather than on the total inventory of residues. The Wood Residue Distribution Simulator (WORDS) attempts to find a least-cost allocation of residues from local sources of supply to local sources of demand, given the cost of the materials, their distribution, and the distribution of demand. The results are useful in evaluating the feasibility of developing wood energy either for a subregion in general or for specific locales. This paper describes WORDS and gives an example of its application to mill residues in the State of Georgia.

KEYWORDS: Energy, supply, demand, Georgia.

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KEYWORDS: Energy, supply, demand, Georgia.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

General Technical Reports SE-29 and
SE-30 are available on microfiche
which is located in cabinets on third
floor behind the information desk.

United States
Department of
Agriculture

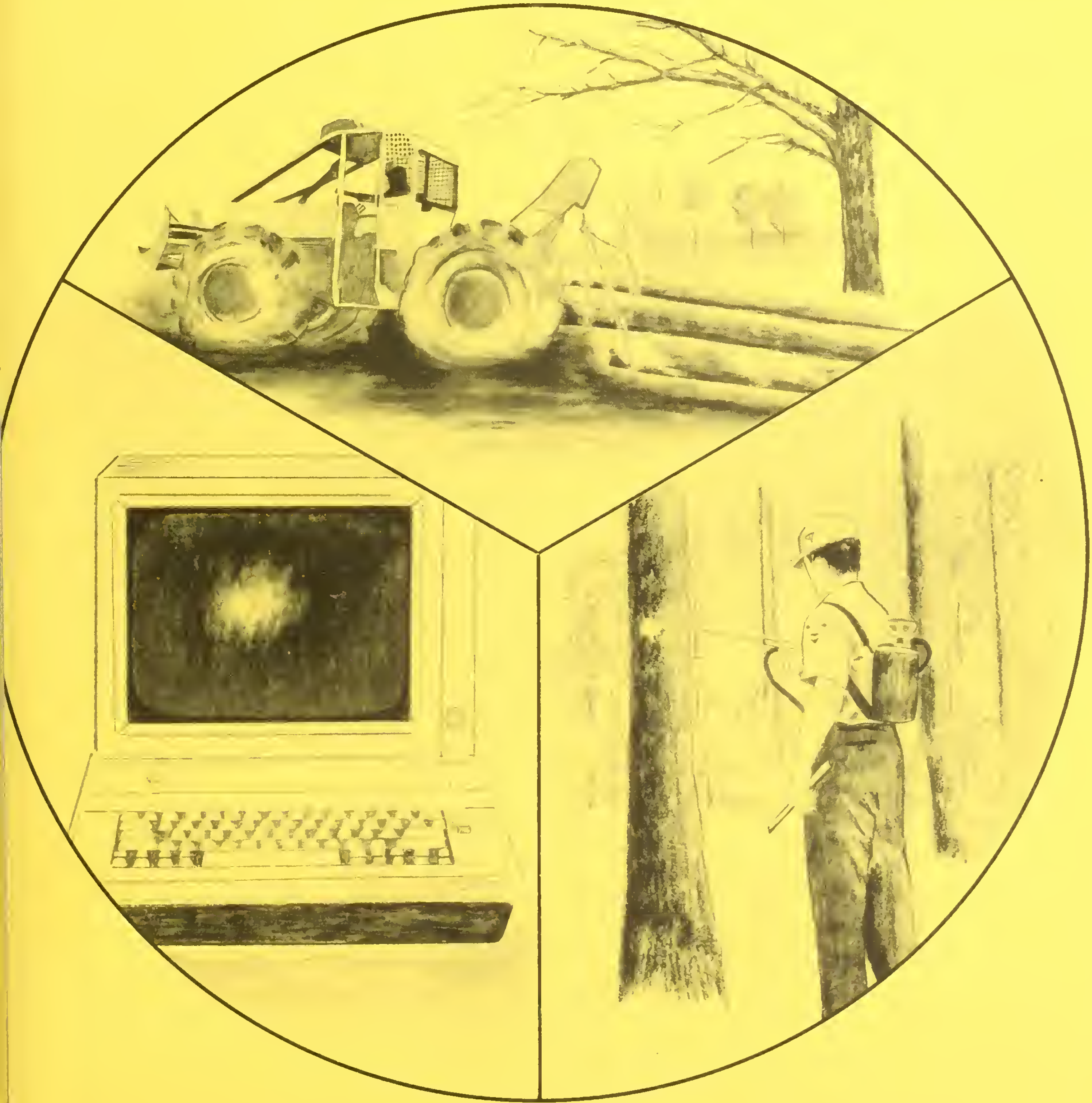
Forest Service

Southeastern Forest
Experiment Station

General Technical Report SE-31

User's Manual for Total-Tree Multiproduct Cruise Program

Alexander Clark III, Thomas M. Burgan,
Richard C. Field, and Peter E. Dress



February 1985

Southeastern Forest Experiment Station
200 Weaver Blvd.
Asheville, NC 28804

United States Department of Agriculture

Forest Service

Suite 330, Jackson Mall Office Center
300 Woodrow Wilson Ave., Jackson, Ms. 39213

1630

August 1, 1985

Forestry School Deans/University Librarians

Dear Dean/Librarian:

The enclosed literature describes the new Total Tree Multiproduct Cruise Program. The TTMPCP is considered to be the state of the art in determining biomass weights and volumes from standard timber cruise data.

Information on how to obtain the mainframe, or microcomputer version is provided in the enclosed summary.

Sincerely,

A. B. CURTIS, JR.
WOOD RESUDIE UTILIZATION SPECIALIST

Enclosure

SUMMARY

TOTAL-TREE MULTIPRODUCT CRUISE PROGRAM

BY

Alexander Clark III, Research Scientist
Utilization of Southern Timber

Thomas M. Burgan, Graduate Research Assistant
University of Georgia

Richard C. Field, Operations Research Analyst
Economic Returns from Forestry Investments

AND

Peter E. Dress, Professor
University of Georgia

July 1985

UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

Southeastern Forest Experiment Station

Forestry Sciences Laboratory

Carlton Street, Athens, Georgia 30602

The Total-Tree Multiproduct Cruise Program[1] is a user friendly interactive program estimating the weights and volumes of various tree products given data from a standard er cruise. The program accepts cruise summary-tree counts and produces tables of ht in tons and volume in board feet, cunits, and cords for total trees, saw logs, ogs, chipping logs, pulpwood, and hardwood crown firewood on a per-acre basis or by ing areas and tract totals. The program contains weight and volume equations for tree ies in the Coastal Plain, Piedmont, and Southern Appalachian Mountain physiographic ons of Southern United States.

The user answers prompted questions concerning information identifying the tract and tain characteristics of the cruise. The program will accept data from fixed-area plot, nt sample, strip, and 100 percent cruises. Commercially important species can be lied individually or by species groups (hard hardwood, soft hardwood). Southern pine t be identified as natural stands or plantations. The tally for a maximum of six cies or species groups can be entered for each cutting area. The program will accommodate es 1 to 30 inches d.b.h. and 10 to 140 feet in height. Tree counts may be entered by or 2-inch d.b.h. classes and by total height or height to 4-inch d.o.b. top in 5- or foot intervals. Sawtimber-size trees may be tallied by d.b.h. and saw-log merchantable ght in logs.

The user may specify the pound-per-cord equivalents to be used to estimate cord umes and the board-foot rule and form class to be used to estimate board-foot volumes. user can also enter increment core annual growth data or use stored average annual wth increment values to obtain projected stand volumes for up to 5 years in the future. user can specify the units (tons, cords, or cunits) for expressing stand components.

Output consists of four tables--a table showing board-foot volume by d.b.h. class for h species (table 1), a table showing total tree and tree component biomass in tons, ds, and cunits by d.b.h. class (table 2), and a summary table showing total stand and nd component products for each species (table 3). Table 3 is also printed to display user-requested estimation of future yields. The fourth table (table 4) shows projected ual growth by stand component and species.

The mainframe version of the program with options described is operational on the CDC ER 750 and IBM 370 at the University of Georgia Computer Center. The code for the nframe version is written in Fortran V and is available from the Utilization of Southern ber Research Work Unit, Southeastern Forest Experiment Station, Forestry Sciences Labora- y, Athens, Georgia.

The microcomputer version is written in UCSD PASCAL for operation on IBM-PC micro- puters that use the p-System (C2.A) operating system copyrighted by Network Consulting . The program requires two disk drives and 256 K ram. The microcomputer version is tributed on two 5-1/4 inch double sided, double density floppy disks. The program disk tains NCI's p-System operating system and the compiled PASCAL code for the TTMP Cruise gram. The second disk is the work disk and contains the species weight and volume ation coefficients and is used to store cruise data output for printing. A turnkey rocomputer version of the program is available through Forest Resources Systems Institute RS). A fee of $35 for members of FORS and $50 for nonmembers is charged for the gram to cover the cost of NCI's copyright on the operating system and the two floppy ks. To obtain the microcomputer version send a check or money order to:

Forest Resources Systems Institute
Courtview Towers, Suite 24
201 N. Pine Street
Florence, AL 35630

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[1] ogram developed with cooperative funding from the Georgia Forestry Commission and in peration with the School of Forest Resources, University of Georgia.

TABLE 1

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

WNER - JOHN DOE
SS - MAIN ST ATHEND GA 30602
LOC. - GREEN CO
1 - PINE-HWD STAND
TER - SMITH
SS - ATHENS GA

CASE NO. - 16A
DISTRICT NO. - 14
TOTAL TRACT(AC) - 80.00
AREA 1 ACREAGE - 40.00
PHONE - 404-546-2441
DATE - 84/02/10.

ABLE 1B--PREDICTED SCRIBNER GROSS SAWLOG BD.FT. VOLUME BY DBH CLASSES.
CURRENT ESTIMATES - YIELD PER ACRE

AVERAGE HEIGHT			EST. NO. OF TREES			SAWLOG VOLUME-SCRIBNER,FC /1/			
-----(LOGS)-----			-------(NUMBER)---------			-----(THOUSAND BOARD FEET)----			
INE	HHWD	SHWD	PINE	HHWD	SHWD	PINE	HHWD	SHWD	ALL SPECIES
.1	0.0	0.0	20.2	0.0	0.0	.9	0.0	0.0	.9
.4	1.7	2.0	11.5	3.5	3.2	1.0	.2	.2	1.4
.1	1.8	2.2	6.3	3.3	3.7	.7	.3	.5	1.5
.4	2.0	2.2	4.1	.7	1.6	.7	.1	.3	1.1
.2	2.0	3.0	.8	.4	.3	.2	.1	.1	.4
.2	0.0	0.0	1.1	0.0	0.0	.3	0.0	0.0	.3
ES			44.1	7.9	8.8	3.8	.8	1.0	5.7

ORM CLASS: PINE= 78.; SOFT HWD= 78.; HARD HWD= 78.

TABLE 2

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

NER - JOHN DOE
S - MAIN ST ATHEND GA 30602
LOC. - GREEN CO
- PINE-HWD STAND
ER - SMITH
S - ATHENS GA

CASE NO. - 16A
DISTRICT NO. - 14
TOTAL TRACT(AC) - 80.00
AREA 1 ACREAGE - 40.00
PHONE - 404-546-2441
DATE - 84/02/10.

TABLE 2C--PREDICTED TOTAL TREE AND COMPONENT BIOMASS BY DBH CLASSES.
CURRENT ESTIMATE - YIELD PER ACRE

AVERAGE HEIGHT	EST. TREES	TOTAL TREE	STEM TO PULP TOP /1/	SAWLOGS	STEM PULPWOOD	FIREWOOD >= 4 IN.
FT.&LOGS)	(NO.)	--------CUNITS--------				
		PINE --SAPLINGS--				
0.0	35.0	.1				
0.0	30.0	.4				
		--PULPWOOD--				
23.7	38.2	1.4	1.0		1.0	
31.5	19.3	1.5	1.3		1.3	
		--PULPWOOD--				
40.0	1.0	.2	.2		.2	0.0
50.0	.4	.1	.1		.1	0.0
		--SAWTIMBER--				
2.1	20.2	3.4	2.7	2.4	.4	0.0
2.4	11.5	2.9	2.3	2.0	.3	0.0
2.1	6.3	1.9	1.6	1.3	.3	0.0
2.4	4.1	1.7	1.4	1.3	.2	0.0
2.2	.8	.4	.3	.3	.1	0.0
2.2	1.1	.6	.6	.5	.1	0.0
ES	167.9	14.5	11.5	7.7	3.8	0.0

M PULPWOOD TOP:
LPWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
WTIMBER - 4-IN. FOR PINE; 5-IN. FOR HHWD; 4-IN. FOR SHWD.

TABLE 3

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

R -	JOHN DOE	CASE NO. - 16A	
-	MAIN ST ATHEND GA 30602	DISTRICT NO. -	14
C. -	GREEN CO	TOTAL TRACT(AC) -	80.00
-	PINE-HWD STAND	AREA 1 ACREAGE -	40.00
R -	SMITH	PHONE - 404-546-2441	
-	ATHENS GA	DATE - 84/02/10.	

-SUMMARY OF PREDICTED TOTAL TREE AND TREE COMPONENT WEIGHT AND VOLUME.
CURRENT ESTIMATES - YIELD PER ACRE

NT	PINE	HARD-HWD	SOFT-HWD	ALL TREES
	GREEN TONS OF WOOD AND BARK			
EE(ALL)	50.2	21.0	18.0	89.2
(< 5 IN.)	1.7	1.2	1.1	4.0
EE(>= 5 IN.)	48.5	19.8	16.9	85.2
PULPWOOD TOP /1/	39.7	14.3	13.9	67.7
AWLOGS /2/	26.6	6.1	7.1	39.9
LL SAWLOGS /3/	18.4	0.0	0.0	18.4
LOGS /4/	8.2	0.0	0.0	8.2
OOD (ALL)	13.1	8.1	6.6	27.8
PWOOD TREES	8.5	5.8	4.3	18.7
TIMBER TOPS	4.6	2.3	2.3	9.2
OWN	8.8	5.5	3.2	17.5
FIREWOOD>=4IN	0.0	.8	.3	1.1
	CORDS OF WOOD AND BARK /5/			
EE(ALL)	18.8	7.3	6.3	32.3
(< 5 IN.)	.6	.4	.4	1.4
EE(>= 5 IN.)	18.1	6.9	5.9	30.9
PULPWOOD TOP /1/	14.9	5.0	4.9	24.6
AWLOGS /2/	9.9	2.1	2.5	14.6
LL SAWLOGS /3/	6.9	0.0	0.0	6.9
LOGS /4/	3.1	0.0	0.0	3.1
OOD (ALL)	4.9	2.8	2.3	10.0
PWOOD TREES	3.2	2.0	1.5	6.7
TIMBER TOPS	1.7	.8	.8	3.3
OWN	3.3	1.9	1.1	6.3
FIREWOOD>=4IN	0.0	.3	.1	.4
	VOLUME OF WOOD (CUNITS)			
EE(ALL)	14.5	5.2	5.0	24.7
(< 5 IN.)	.5	.3	.3	1.1
EE(>= 5 IN.)	14.0	4.9	4.7	23.[illegible]
PULPWOOD TOP /1/	11.5	3.7	3.9	19.1
AWLOGS /2/	7.7	1.6	2.1	11.[illegible]
LL SAWLOGS /3/	5.4	0.0	0.0	5.4
LOGS /4/	2.3	0.0	0.0	2.3
OOD (ALL)	3.8	2.1	1.9	7.7
PWOOD TREES	2.5	1.5	1.2	5.2
TIMBER TOPS	1.2	.6	.6	2.5
OWN	2.5	1.2	.8	4.6
FIREWOOD>=4IN	0.0	.2	.1	.3

PULPWOOD TOP:
PWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD: 4-IN. FOR SHWD.
TIMBER - 4-IN. FOR PINE; 5-IN. FOR HHWD: 4-IN. FOR SHWD.
OG MERCHANTABILITY: 7-IN. FOR PINE W/ MIN DBH 9-IN., 9-IN. FOR
WOODS OR THRU LOG GRADE NO. 3 MERCHANTABILITY W/ MIN DBH 11-IN.
L SAWLOGS - MIN 8 FT. W/ MIN 7-IN. DOB SMALL END.
OGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END,
MIN DBH - 14.0.
DS PER CORD: PINE=5350. HHWD=5750. SHWD=5750.

(Continued)

TABLE 3 (Continued)

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

R - JOHN DOE	CASE NO. - 16A
- MAIN ST ATHEND GA 30602	DISTRICT NO. - 14
C. - GREEN CO	TOTAL TRACT(AC) - 80.00
. PINE-HWD STAND	AREA 1 ACREAGE - 40.00
F - SMITH	PHONE - 404-546-2441
- ATHENS GA	DATE - 84/02/10.

-SUMMARY OF PREDICTED TOTAL TREE AND TREE COMPONENT WEIGHT AND VOLUME.
CURRENT ESTIMATES - YIELD PER ACRE

NT	PINE	HARD-HWD	SOFT-HWD	ALL TREES
	SAWLOG BOARD-FOOT VOLUME---(MBF)/1/			
OGS				
F	2.4	.5	.7	3.6
RNER	3.8	.8	1.0	5.7
WLOGS				
E	1.4	0.0	0.0	1.4
BNER	2.4	0.0	0.0	2.4
S				
E	1.1	0.0	0.0	1.1
BNER	1.5	0.0	0.0	1.5
	BASAL AREA PER ACRE (SQ.FT.)			
TREES	3	1	1	5
D TREES	15	7	7	29
EP TREES	36	7	9	52
ES	54	15	17	86

M CLASS: PINE= 78.; SOFT HWD= 78. HARD HWD= 78.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

OWFR - JOHN DOE
ES - MAIN ST ATHEND GA 30602
T OC. - GREEN CO
1- PINE-HWD STAND
STR - SMITH
ES - ATHENS GA

CASE NO. - 16A
DISTRICT NO. - 14
TOTAL TRACT(AC) - 80.00
AREA 1 ACREAGE - 40.00
PHONE - 404-546-2441
DATE - 84/02/10.

TABLE 4.--BASIC INVENTORY AND PROJECTED ANNUAL GROWTH

TAD POIENT	PRESENT VOLUME PER ACRE	PRESENT GROWTH PER ACRE PER YEAR	TOTAL ANNUAL GROWTH PER AREA	PERCENT ANNUAL CHANGE PER ACRE
AREA 1-- 40.00 ACRES-PINE-HWD STAND				
PINE				
L SAWLOGS (MBF SCRIB)	3.8	.189	7.57	4.92
SALL SAWLOGS (MBF)/1/	2.4	.107	4.28	4.53
PLYLOGS (MBF)/2/	1.5	.082	3.29	5.55
E TO PULP TOP (CORDS)	14.8	.587	23.47	3.96
ULWOOD (CORDS)	4.9	.172	6.88	3.52
OTL TREE CHIPS (TONS)	50.2	1.620	64.81	3.23
HAD-HWD				
L SAWLOGS (MBF DOYLE)	.5	.025	1.01	4.92
E TO PULP TOP (CORDS)	5.0	.157	6.30	3.17
ULWOOD (CORDS)	2.8	.084	3.37	2.98
OTL TREE CHIPS (TONS)	21.0	.613	24.51	2.92
SOT-HWD				
L SAWLOGS (MBF DOYLE)	.7	.037	1.50	5.47
E TO PULP TOP (CORDS)	4.8	.146	5.84	3.05
ULWOOD (CORDS)	2.3	.054	2.15	2.33
OTL TREE CHIPS (TONS)	18.0	.507	20.26	2.81
SPECIES				
L SAWLOGS (MBF)				
SAWLOGS (DOYLE)	1.2	.063	2.51	5.24
SAWLOGS (SCRIB)	3.8	.189	7.57	4.92
EM TO PULP TOP (CORDS)	24.6	.890	35.61	3.62
ULPWOOD (CORDS)	10.0	.310	12.40	3.09
OTAL TREE CHIPS (TONS)	89.2	2.740	109.58	3.07

MALL SAWLOGS - MIN 8 FT. W/ MIN 7-IN. DOB SMALL END.
LYLOGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END,
MIN DBH - 14.0.

E: NEGATIVE REFLECTS MOVEMENT OF MATERIAL INTO LARGER SIZE COMPONENT.
GROWTH ASSUMES APPROX. 1% ANNUAL MORTALITY.

User's Manual for Total-Tree Multiproduct Cruise Program

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Research Wood Scientist
Utilization of Southern Timber
Forestry Sciences Laboratory
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User's Manual for Total-Tree Multiproduct

Cruise Program

ABSTRACT

The Total-Tree Multiproduct Cruise Program is a user-friendly, interactive computer program that uses standard tree-cruise data to estimate the weight and volume of the total tree, saw logs, plylogs, chipping logs, pulpwood, crown firewood, and logging residue in timber stands. Input is cumulative cruise data for tree counts by d.b.h. alone or by d.b.h. class and total height, height to 4-inch top, or saw-log merchantable height for individual species or species groups. Output is in tables: (1) board-foot volume by d.b.h., (2) total-tree and tree-component biomass by d.b.h. class, (3) a summary table, and (4) projected annual growth by stand component and species. Output can be expressed in tons, cords, cunits, or board feet per acre, or by cutting units and tract totals. The program is written in FORTRAN V for a mainframe and in PASCAL for the IBM-PC microcomputer. This manual describes the program and how to enter cruise data to obtain desired output for both the mainframe and microcomputer versions.

Keywords: Computer program, inventory, biomass, tree weight, tree volume.

Introduction

Timber utilization practices are rapidly changing. The southern pines are now tree-length logged and marketed for veneer, saw logs, and pulpwood by weight rather than measured by scale stick to determine board feet or cords. Poor-quality hardwoods are now harvested for total-tree fuel chips, and logging residue from sawtimber hardwoods is marketed for firewood. To stay abreast of the changing utilization practices, to save time, and to reduce cruise computation errors, foresters need a versatile, easy-to-use procedure for automatically estimating the weight and volume of the total tree and its components (saw logs, plylogs, chipping logs, pulpwood, firewood). The Total-Tree Multiproduct (TTMP) Cruise Program meets this need.

TTMP Cruise Program is a computer program designed for general forestry application. It accepts cumulative cruise data collected by standard timber cruise procedures. It provides per acre or per area estimates of total-tree and tree-component biomass and product yields for trees 1-inch d.b.h. and larger. Area estimates can be summarized by cutting units within a tract. The output estimates can be expressed in tons, cords, or cunits, and in board feet by using the Doyle, Scribner, or International 1/4-inch board-foot rules for saw-log volumes.

This manual is a guide to the user of the TTMP Cruise Program and will assist in the interpretation of biomass and product estimates it provides. The manual also explains the program's capabilities, how it is designed, and how it calculates forest biomass and product estimates.

The mainframe version is written in Fortran V and is designed to be accessed from remote terminals. The use of standard language syntax simplifies the conversion of this program for running on other systems supporting FORTRAN V. It is currently operational on a CDC CYBER 750 and an IBM 370. The microcomputer version is written in UCSD PASCAL for operation on IBM-PC and IBM compatible microcomputers that use the p-System (C2.A) operating systems developed by Network Consulting, Inc. (NCI).[1] It is a turnkey program and requires two disk drives and a minimum of 256K RAM storage. The program was developed by the Utilization of Southern Timber Research Work Unit, USDA Forest Service, Southeastern Forest Experiment Station, in cooperation with the Georgia Forestry Commission and the University of Georgia's School of Forest Resources. For information on obtaining either version, write to the Southeastern Forest Experiment Station, 200 Weaver Boulevard, Asheville, NC 28804.

The program is designed for use by foresters or clerical personnel with little or no previous computer experience. The program prompts the user to enter information describing the cruise and the necessary tree counts. Data entry in the microcomputer version is interactive, fast, menu-driven, and self-explanatory. Special features are included that minimize the number of user key strokes per run. Data can be quickly entered and edited. The interactive procedure of the mainframe is self-explanatory and easily correctable. The same input data is requried for both versions and the output is identical.

The first version of the TTMP Cruise Program, called Total Biomass Cruise Program (Clark and Field 1981), has been operational for 3 years. The program has been used by the Georgia Forestry Commission to analyze more than 300 cruises. Other States, industries, consultants, and the USDA Forest Service have used it experimentally and support its increased availability.

Program Design

The TTMP Cruise Program uses tree data commonly measured in standard cruise procedures to estimate not only conventional forest products but total-tree and residual biomass.

Tree Size Classes

Trees must be separated into three size classes for input, analysis, and output:

Saplings--trees 1.0 to 4.9 inches d.b.h.

Pulpwood--or roundwood trees $\geq$ 5.0 inches d.b.h.

Sawtimber--trees $\geq$ 9.0 inches d.b.h. for pine and trees $\geq$ 11.0 inches d.b.h. for hardwoods containing a minimum of one 16-foot number 3 saw log

The mainframe version requires that pulpwood trees be entered in two tree size classes:

Pulpwood--or roundwood trees 5.0 to 8.9 inches d.b.h. for pine and 5.0 to 10.9 inches d.b.h. for hardwoods

Large pulpwood--or roundwood trees $\geq$ 9.0 inches for pine and trees $\geq$ 11.0 inches for hardwoods

Tree Dimensions Measured

During a cruise, the user can choose among various combinations of tree d.b.h. and height for measurements. Trees can also be tallied by d.b.h. alone, but this will produce less-precise summaries. The following combinations of tree dimensions and their range by tree size class can be accepted by the program. D.b.h. can be tallied at intervals of 1 or 2 inches up to 30 inches:

Tree dimension combinations	Size class and tally interval
	SAPLINGS
d.b.h.	1.0 to 4.0 inches
d.b.h and tree total height	10 to 90 ft in height at 5- or 10-ft intervals
	PULPWOOD AND LARGE PULPWOOD
d.b.h.	$\geq$ 5.0 inches
d.b.h. and tree total height	10 to 140 ft in height at 10-ft intervals or 20 to 100 ft in height at 5-ft intervals
d.b.h. and height to a 4-in d.o.b. top	10 to 140 ft in height at 10-ft intervals or 5 to 85 ft in height at 5-ft intervals
	SAWTIMBER
d.b.h.	$\geq$ 9.0 inches for pine $\geq$ 11.0 inches for hardwoods
d.b.h. and tree total height	10 to 140 ft in height at 10-ft intervals or 30 to 110 ft in height at 5-ft intervals
d.b.h. and height to a 4-in d.o.b. top	10 to 140 ft in height at 10-ft intervals or 20 to 100 ft in height at 5-ft intervals
d.b.h. and saw-log merchantable height	1.0 to 6.0 (16.3 ft) logs in height at half-log intervals

The selected d.b.h. and heights measured should be based on the type of timber cruised and objective of the cruise. When cruising pines, d.b.h. in combination with total height or height to a 4-inch d.o.b. top will give good estimates of the total tree, stem to pulp top, and stem to a fixed saw-log top of 7 inches. D.b.h. and saw-log merchantable height will give good estimates of the stem to a saw-log variable top. When cruising hardwoods by hard hardwood and soft hardwood groups, d.b.h. and total heights or height to a 4-inch top will also give good estimates of the total tree, stem to 4-inch top. These measurement combinations, however, can result in less-accurate estimates of the merchantable saw-log stem since these measurement combinations estimate to a fixed top of 9 inches d.o.b. and not a variable saw-log top. To obtain the best estimate of the saw-log merchantable stem, hardwoods should be tallied by d.b.h. and saw-log merchantable height.

Types of Cruises

The program has the capability of analyzing cruise data collected according to the following specifications:

1. Fixed-area plot--for any specified circular plot size,
2. Point sample--by using a prism with any specified prism factor,
3. Strip cruise--given width and total length of strip or percent of tract cruised and tract acreage,
4. 100 percent tree tally.

All trees $\geq$ 1.0 inch d.b.h. can be tallied by the same cruise procedure, or saplings (1.0 to 4.9 inches d.b.h.) can be tallied by using a different cruise procedure than that used for trees $\geq$ 5.0 inches d.b.h.

Species Tallied

The program contains weight and volume equations for the 10 most important species or species groups for each of the three main physiographic regions of the South--Gulf and Atlantic Coastal Plains, Piedmont, and Southern Appalachian Mountains. Thus the user can select weight and volume prediction equations developed for a general geographic area to expand specific-area cruise data to forest stand biomass estimates. Equations are stored in the program for the following species or species group. Also shown are the location, number, and d.b.h. range of the trees sampled to develop the species weight and volume equations used in the program.

Species name	Species sampled	Locations sampled	Trees sampled	D.b.h. range
			(No.)	(Inch)
	COASTAL PLAIN REGION			
PINE	Natural loblolly, slash, longleaf combined	Alabama, Georgia, South Carolina	1285	1-24
HARD-HARDWOODS	Hard hardwood species--white oak, water oak, laurel oak, hickory spp. combined	Coastal Plain of South and Southeast	303	1-20
SOFT-HARDWOODS	Soft hardwood species--sweetgum, blackgum, red maple, water tupelo, green ash, yellow-poplar combined	Coastal Plain of South and Southeast	842	1-20
OAK SPECIES	White oak, water oak, laurel oak combined	Coastal Plain of South and Southeast	138	1-20
LIVE OAK	Live oak	Northwest Florida	28	5-20
SWEETGUM	Sweetgum	Coastal Plain of South and Southeast	313	1-20
PINE2	Same as PINE--allows user to tally pine in two classes, sawtimber or poles	Alabama, Georgia, South Carolina	1285	1-24
SAND PINE	Sand pine	Northwest Florida	36	4-14
PLANTATION PINE	Plantation slash pine	Georgia	139	2-12
CYPRESS	Pond cypress	Central Florida	58	5-18

Species name	Species sampled	Locations sampled	Trees sampled	D.b.h rang
			(No.)	(Inch)
		PIEDMONT REGION		
PINE	Natural loblolly and shortleaf combined	Alabama, Georgia, South Carolina	1006	1-20
HARD-HARDWOOD	Hard hardwood species--southern red, scarlet, white oaks, and hickory combined	Georgia, Tennessee, South and North Carolina	189	1-20
SOFT-HARDWOOD	Soft hardwood species--yellow-poplar, red maple, sweetgum, green ash, sycamore combined	Georgia, South and North Carolina	126	1-20
WHITE OAK	White oak	Georgia, South and North Carolina	63	1 -20
RED OAK	Southern red oak, scarlet oak combined	Georgia, Tennessee, South and North Carolina	98	1-22
SWEETGUM	Sweetgum	Georgia, South and North Carolina	61	1-20
PINE2	Same as PINE--allows user to tally pine in two classes, sawtimber or poles	Alabama, Georgia, South Carolina	1006	1-20
VIRGINIA PINE	Virginia pine	Georgia	25	6-14
PLANTATION PINE	Plantation lolbolly pine	Alabama, Georgia, South Carolina	434	2-12
YELLOW-POPLAR	Yellow-poplar	Georgia, South and North Carolina	65	1-20
		SOUTHERN APPALACHIAN MOUNTAIN REIGON		
PINE	Natural loblolly and shortleaf combined	Alabama, Georgia, South Carolina	1006	1-20
HARD-HARDWOOD	Hard hardwood species--Northern red, white, chestnut, black, and scarlet oaks, hickory, black locust, sweet birch combined	Georgia, North Carolina	269	1-24

Species name	Species sampled	Locations sampled	Trees sampled	D.b.h. range
			(No.)	(Inch)
SOFT-HARDWOOD	Soft hardwood species--yellow-poplar, red maple, basswood, blackgum combined	Georgia, North Carolina	113	1-24
WHITE OAK	White oak	North Carolina	28	5-22
RED OAK	Northern red oak	North Carolina	71	5-24
YELLOW-POPLAR	Yellow-poplar	North Carolina	65	5-28
WHITE PINE	White pine	Georgia	36	1-24
VIRGINIA PINE	Virginia pine	Georgia	25	1-14
RED MAPLE	Red maple	North Carolina	36	5-16
HICKORY	Hickory spp.	Georgia, North Carolina	54	5-22

A maximum of six species or species groups can be entered for each area or cutting unit and a total of nine different species groups can be summarized for a total tract. The PINE2 species group is included to allow foresters to tally pine timber in two classes--sawtimber for lumber and veneer, and pole-grade trees for utility poles and pilings or to tally cut-and-leave trees.

Component Weight and Volume Estimates

Total-tree and tree-component weight and volume equations for estimating the green weight of wood and bark in pounds, and volume of wood in cubic feet, are stored in the program by region, species, tree size class, dimension measured, and tree component. The equations used in the TTMP Cruise Program were developed from biomass data collected across the South by the Utilization of Southern Timber Research Work Unit (fig. 1) in cooperation with the forest industries, Region 8 of the USDA Forest Service, North Carolina State Hardwood Research Cooperative, Georgia Forestry Commission, and Tennessee Valley Authority. These equations are available upon request from the authors, Utilization of Southern Timber Research Work Unit, Forestry Sciences Laboratory, Carlton Street, Athens, GA 30602.

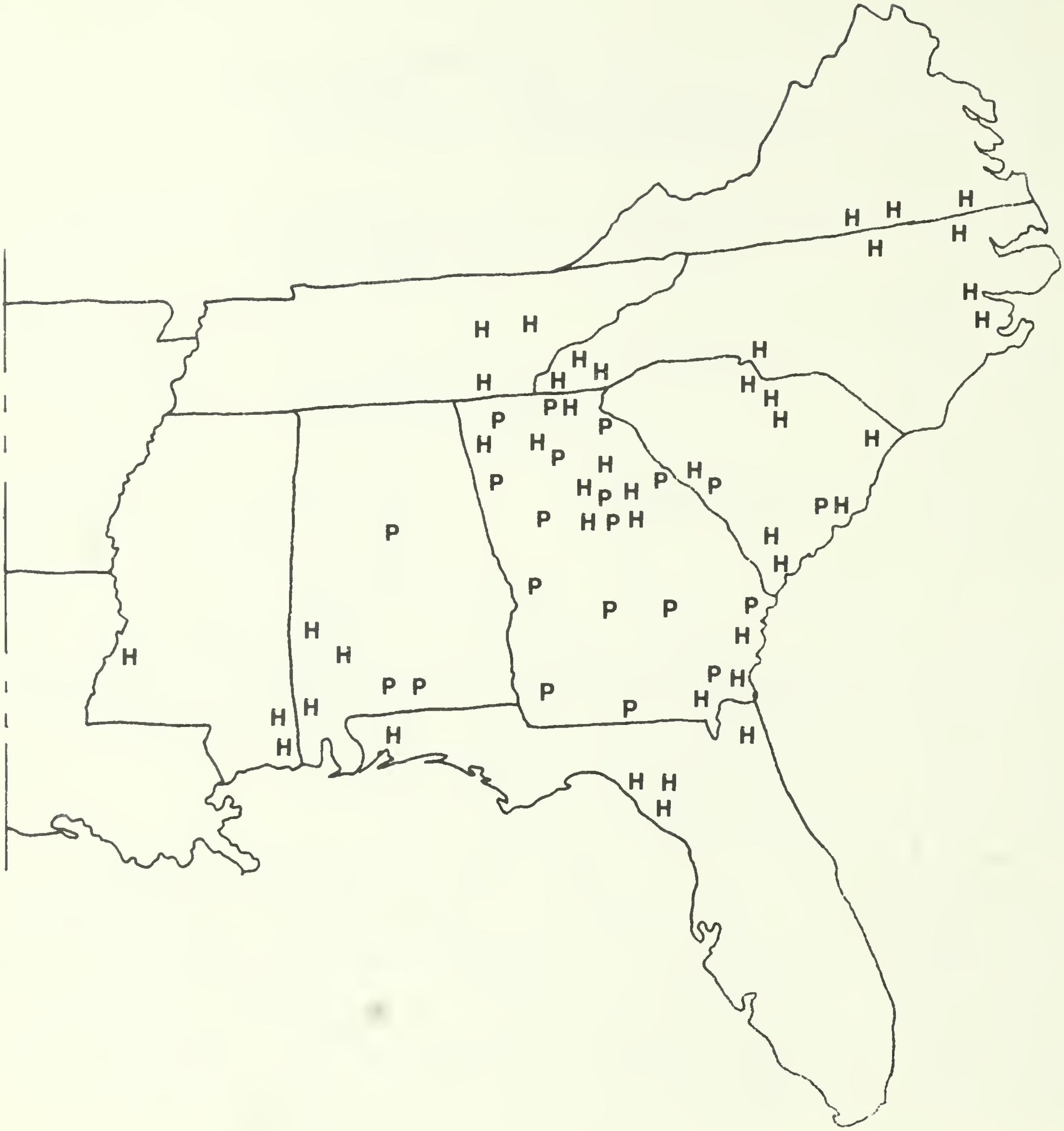

Figure 1.--Locations of stands where natural pine (P) and hardwood (H) trees were sampled for regional species equations.

The program prompts the user for the information needed to select the appropriate equations which are used with the tree-frequency counts to estimate total-tree and tree-component weights and volumes. Estimated weight in pounds and volume in cubic feet are converted to tons and cunits, respectively.

Total-tree and tree-component estimates in cords are calculated from the estimated weight of wood and bark to simulate one of the measurements used in selling wood. The following weight of wood and bark per cord equivalents are stored in the program:

Geographic region and species group	Cord equivalent (Pounds)
Coastal Plain	
Pine	5600
Hard hardwood	5700
Soft hardwood	5700
Piedmont	
Pine	5350
Hard hardwood	5700
Soft hardwood	5700
Appalachian Mountains	
Pine	5350
Hard hardwood	5800
Soft hardwood	5800

The pounds per cord equivalents are the same for hard hardwood and soft hardwood because soft and hard hardwoods are generally mixed when weighed at the woodyard. Users may enter their own factors for any of the species groups.

The user may specify the pulpwood d.o.b. top to be used for pine, hard hardwoods, and soft hardwoods in the analysis. This option allows the program to estimate more accurately the actual volumes to be harvested and what will be left as logging residue. The user may also request that the saw-log merchantable stem of natural southern pine be separated into small saw logs and into logs of suitable size for processing into veneer (plylogs). To do so, the user either specifies the minimum d.b.h. tree from which plylogs can be cut and the minimum top d.o.b. to which plylogs can be bucked or allows the program to use the default values of 13 inches d.b.h. and 10 inches d.o.b. top.

Upon request, the program will separate the stem of plantation pine into chipping logs and upper stem pulpwood. The user specifies a minimum d.o.b. top to which chipping logs can be cut and the minimum d.b.h. tree from which chipping logs can be processed or can use the default values of 8 inches d.b.h. and 6 inches d.o.b.

Board-foot volumes are estimated with equations developed from Mesavage and Girard (1956) volume tables (Appendix A). The user can specify the log rule (Doyle, Scribner, or International 1/4-inch) and form class to be used for estimating pine, hard hardwood, and soft hardwood board-foot volumes. No board-foot estimates are made unless d.b.h. and height (total height, height to 4-inch d.o.b. top, or saw-log merchantable height) are entered.

Growth Projection

The estimated weight and volume of a stand and its components can be projected for up to 5 years into the future. The user can input growth measurements or use growth values stored in the program. The growth measurements entered by the user consist of the previous 5 years' radial growth (excluding bark) and tree d.b.h. The user can enter the measurements for trees in both the pulpwood and the sawtimber-size classes for pine. The stored growth values consist of equations with d.b.h. used as the independent variable for predicting the radial growth of a tree. These equations were developed for pine, other softwoods, hard hardwood, and soft hardwoods by the three physiographic regions from forest inventory data collected in the Southeast by the Forest Inventory and Analysis Research Work Unit (FIA), Southeastern Forest Experiment Station, Asheville, NC (Joe P. McClure, Project Leader; pers. commun., 1983). Since default radial growth values used in the program are regional averages, users should enter radial growth measurements for the trees cruised to obtain more accurate growth projections.

Growth projections are made by using the stand table projection method (Avery 1967:233-235). This method assumes that trees in each diameter class are evenly distributed throughout the class and that each tree will grow at the average rate for that class. It also assumes that bark thickness does not change during the 5-year period. In addition to projecting growth in d.b.h., height projections are also made by using equations developed by FIA (Joe P. McClure, Pers. commun., 1983). Height growth equations are stored in the program for pine, other softwoods, hard hardwoods, and soft hardwoods for each of the three physiographic regions.

Mortality is then automatically subtracted from the projections by applying factors, based on FIA data, to the tree counts by d.b.h. class:

Tree d.b.h. class (Inches)	Annual mortality rate(%)	
	(Softwoods)	(Hardwoods)
≤ 6	1.9	1.1
$> 6 - < 22$	0.7	0.8
≥ 22	1.1	1.4

Projected tree and component weights and volumes are estimated by using the appropriate equations applied to the projected tree counts and d.b.h. and height values.

Data Input

Cruise data collected for a 40-acre pine-hardwood tract in the Coastal Plain will be used as an example in this manual. Trees 1.0 inch d.b.h. and larger were tallied in 2-inch classes with a 10-factor prism at 40 points in the tract. Default radial growth values were used to estimate growth. Exhibits 1 and 2 are examples of the completed field forms for recording cruise information and cumulative tree counts, by d.b.h. and height classes. Samples of blank forms are included at the end of the manual; however, conventional cruise tally cards can be used to record cruise data.

Exhibit 1. - - TOTAL TREE MULTI PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. 14 Case No. 16 A. Landowner John Doe Address Main St. Athens, Ga. 3060
Geographic Region 4 Acreage in Tract 40 No. Areas in Tract ____ Tract Location Green Co
Forester Smith Address Athens, Ga. Phone 404-546-2441
Area No. 1 Area Acreage 40 Type Cruise Point No. Plots 40 Planted or Natural Natural
Area Identification Pine-Hardwood Species Pine Date 4/5/84

PLOT NO.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

DBH	SAPLING COUNT	DBH	SAPLING COUNT
2	6	4	18

PULPWOOD--HEIGHT TO 4-INCH TOP (FEET)

DBH	10	20	30	40	50	60	70	80	90
6	4	11	12						
8		6	17	27	8				
12				2	1				
16					2				

SAWTIMBER--SAW-LOG MERCHANTABLE HEIGHT (LOGS)

DBH	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
10	5	20	20	1					
12	2	16	25	8					
14		16	12						
16		2	15	14					
18		1	2	3	1				
20		1	4	4	1				

Exhibit 2. - - TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. 14 Case No. 16 A Landowner John Doe Address Main St. Athens, Ga. 30605
Geographic Region 4 Acreage in Tract 40 No. Areas in Tract ____ Tract Location Green Co.
Forester Smith Address Athens, Ga. Phone 404-546-2441
Area No. 1 Area Acreage 40 Type Cruise Point No. Plots 40 Planted or Natural Natural
Area Identification Pine-Hardwood Species Hard + Soft Hardwood Date 4/5/84

	Hard Hardwood				Soft Hardwood			
PLOT NO.	DBH	COUNT	DBH	COUNT	DBH	COUNT	DBH	COUNT
	2	3	4	14	2	9	4	12

PLOT NO.: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

PULPWOOD--HEIGHT TO 4-INCH TOP (FEET)

DBH	Hard 10	Hard 20	Hard 30	Hard 40	Hard 50	Hard 60	Hard 70	Hard 80	Soft 10	Soft 20	Soft 30	Soft 40	Soft 50	Soft 60	Soft 70	Soft 80
6	2	4	2						1	5	2					
8		4	6	5						6	8	1				
10				1												
14					2											

SAWTIMBER--SAW-LOG MERCHANTABLE HEIGHT (LOGS)

DBH	Hard 1.0	Hard 1.5	Hard 2.0	Hard 2.5	Hard 3.0	Hard 3.5	Hard 4.0	Hard 4.5	Soft 1.0	Soft 1.5	Soft 2.0	Soft 2.5	Soft 3.0	Soft 3.5	Soft 4.0	Soft 4.5
12		5									8					
14		6	10								8	10	4			
16			4									4				
18			2													
20																
22																

Microcomputer Example

The microcomputer version is distributed on two 5-1/4-inch double-sided, double-density floppy disks. The program disk contains NCI's p-System operating system and the compiled PASCAL code for the TTMP Cruise Program. The second disk is the work disk and contains the species weight and volume equation coefficients and is used to store cruise data output for printing.

To run the micro version, place program disk in drive A and the work disk in drive B and "boot-up" the computer. After the NCI copyright message, the introduction describing TTMPCP will appear on the screen as shown below:

```
$$$$$   $$$$$   $   $   $$$$$   $$$$$   $$$$$
  $       $     $$ $$   $   $   $   $   $   $
  $       $     $ $ $   $$$$$   $       $$$$$
  $       $     $   $   $       $   $   $
  $       $     $   $   $       $$$$$   $

The Total Tree Multi-Product Cruise Program is designed to estimate
total tree, saw log, pulpwood, and firewood weight and volume of
forest stands from standing tree cruise data.  TTMPCP was developed
by the USDA Forest Service Southeastern Forest Experiment Station
in cooperation with the Georgia Forestry Commission and the Univer-
sity of Georgia School of Forest Resources.

                                             Version 1A - 12/84

Press space bar to continue.
```

The program options menu will appear after pressing the space bar. This screen lists the options available to the user.

```
        $$$$$   $$$$$   $   $   $$$$$   $$$$$   $$$$$
          $       $     $$ $$   $   $   $   $   $   $
          $       $     $ $ $   $$$$$   $       $$$$$
          $       $     $   $   $       $   $   $
          $       $     $   $   $       $$$$$   $

                  Program Options Menu

         B(ack-up Program and/or Work disk (Format and Copy)
         R(eplace Work disk
         E(nter cruise data for a tract
         P(rint output tables for a tract
         D(elete a tract from the cruise data file
         C(ompress cruise data file
         T(erminate program

         Give desired option:
```

<u>**B(ack-up Program and/or Work Disks.**</u> The program has a built-in back-up (B) option that allows the user to format disks and make back-up copies of both the program disk and work disk. When the user purchases the TTMP Cruise Program, the royalty is paid to Softech Microsystems Inc. and NCI copyrights of the UCSD p-System. The user has the right to make two back-up copies of the program disk for use on the computer but does not have the right to reproduce the program for distribution. The user should make a back-up copy of the program and work disks and store the originals in a safe place before using the program.

To make back-up copies hit "B," and the following instructions will appear on the screen. Data entered by the user is shown in a box $\boxed{\quad}$.

```
            * * * F O R M A T   A N D   C O P Y * * *

  Which disk do you wish to produce a back=up for?

 ( "A"=Program disk,  "B"=Work disk, E(scape ) ==> [A]

  Remove Work disk in Drive B and replace it with
  the disk to be formatted and copied onto.

  Note:  This new disk must be double sided/double density.

  Press space bar to continue.
```

When format and copy are complete, the screen will display the following instructions.

```
            * * * F O R M A T   A N D   C O P Y * * *

   Formatting and copying for new Program disk completed.
   Remove this disk from Drive B, label it, and replace
   it with the Work disk you removed earlier.

    Note: You must have a Program disk in Drive A
          and a Work disk in Drive B to continue
          running TTMPCP.

   Press space bar to continue.
```

To make a back-up of the work disk enter "B" and follow the instructions which appear on the screen. After making a copy of the work disk, replace it with a program disk in the A drive and then hit the space bar to continue. The program options menu will again appear on the screen.

<u>R(eplace Work Disk</u>. When the user wants to replace the work disk in the B drive with another work disk without rebooting, the "R" option for replacing work disks must be used. When "R" is pressed the following insructions will appear on the screen.

```
  You may change the Work disk in Drive B at this
  time.
  The disk you replace it with must also be a Work
  disk and may be newly created or one that has
  been used previously.

  Press space bar to continue.
```

E(nter Cruise Data. To enter cruise data for a tract, press the "E" and the following table headings input screen will appear:

```
Listed below are headings that will appear on your output tables.
Please enter information as indicated by cursor.

LANDOWNER :[JOHN DOE]                      CASE NO : [16A]

ADDRESS :[ATHENS, GA]                      DISTRICT NO :[14]

TRACT LOCATION :[GLYNN CO.]                TRACT SIZE (AC):[40]

FORESTER :[SMITH]                          PHONE:[912-546-2441]

ADDRESS :[WAYCROSS, GA]              NO. AREAS CRUISED IN TRACT:[1]

PHYSIOGRAPHIC REGION (T):  COASTAL         DATE (T):  84 / 12 / 09

Are you satisfied with the entries as shown? (Y or N) : [Y]
```

The user enters the heading information in the box describing the cruise and presses the enter key and the cursor moves to the next entry. The headings with a (T) are toggle entries. The user presses the space bar to toggle in the desired answer and then presses the enter key or carriage return to enter the selection into memory. For example, the toggle selections for physiographic region are Coastal, Piedmont, or Mountain. The year, month, and day are each toggle entries. The last question in this screen asks if the user is satisfied with the entries. If the user enters "N" for "no," the following edit instructions will appear at the top of the screen:

```
To correct entry indicated by cursor, press SPACE BAR and re-enter, or retoggle.
If entry is correct, a CARRIAGE RETURN moves cursor to the next entry.
```

When the user is satisfied with the tract heading entries and presses a "Y" for "yes," the screen for entering area information shown below will appear:

```
Enter the necessary information for Area  1, as indicated by the cursor.
For toggle questions (T) hit toggle (SPACE BAR) until appropriate answer
appears.  Press carriage return (CR) to accept entry.

ACREAGE : [40]               STAND ID./LOCATION : [PINE-HARDWOOD]

                             TYPE OF CRUISE (T) : PRISM

PRISM FACTOR (T):  10 BAF

NUMBER OF PLOTS : [40]               GROWTH PROJECTION (T): YES

YEARS PROJECED (T):   5              INCREMENT CORE DATA ? (T): NO

Are you satisfied with the entries as shown? (Y or N) : [Y]
```

The user enters the acreage for the area and an alpha-numeric indentification or name for the area cruised. The type of cruise, blow-up factor, and number of plots entered in this screen are for all trees tallied or trees $\geq$ 5.0 inches d.b.h. if saplings were cruised differently. Cruise information for saplings tallied by a different cruise procedure will be entered later in the program. The toggle is used to select from fixed-area, prism, strip, or 100 percent tally for type of cruise. When selecting fixed-area cruise, the toggle is used to select the plot size--1/4, 1/5, 1/10, 1/20, 1/50, 1/100 acre, or other--and the user enters a radius in feet. For prism cruise, the toggle is used to select a prism basal-area factor (BAF) of 10, 5, or other, and the user enters a BAF factor. When entering fixed-area or prism cruises the user must enter the number of plots or points tallied in the area or the program will default to one plot or point. When strip cruise is selected, the user can enter the width and cumulative length of the strip in feet or enter the percentage of the area in the strip. For growth projection, the toggle allows the user to enter "yes" or "no." If growth projection is requested, the toggle is used to select the number of years growth to be projected (1 to 5) and whether increment core measurements are to be entered for making growth projections. To obtain growth projections for one or more areas in a tract, growth projection must be requested for the first area entered.

At the bottom of this screen, the program asks if the user is satisfied with the entries. If the user enters "N," the following edit instructions will appear at the top of the screen:

```
To correct entry indicated by cursor, press SPACE BAR and re-enter, or retoggle.
If entry is correct, a CARRIAGE RETURN moves cursor to the next entry.
```

When the user is satisfied with the area information entries and presses "Y," the screen that allows the user to select the tree dimensions recorded during a cruise will appear as shown below:

```
    TREE DIMENSIONS RECORDED DURING CRUISE AS CURRENTLY SET IN PROGRAM

===========================================================================
              TREE        DIMENSIONS   STEM PULPWOOD    DBH        HEIGHT
SPECIES    SIZE CLASS      MEASURED       TOP DOB     INTERVAL    INTERVAL
                                           (IN.)        (IN.)    (FT./LOGS)
===========================================================================

 PINE       SAPLINGS        DBH                          2
 PINE       PULPWOOD        D+H4            4            2           10
 PINE       SAWTIMBER       D+MH            4            2          LOGS

H-HWD       SAPLINGS        DBH                          2
H-HWD       PULPWOOD        D+H4            4            2           5
H-HWD       SAWTIMBER       D+MH            4            2          LOGS

S-HWD       SAPLINGS        DBH                          2
S-HWD       PULPWOOD        D+H4            4            2           5
S-HWD       SAWTIMBER       D+MH            4            2          LOGS
===========================================================================
Are you satisfied with the entries as shown? (Y or N) : [Y]
```

If the user is not satisfied with the preselected dimensions recorded as shown and presses "N," the following edit instructions will appear at the top of the screen:

```
Indicate (Y or N) if satisfied with line shown.
To correct entry indicated by cursor, press SPACE BAR to toggle responses.
If entry is correct, a CARRIAGE RETURN moves cursor to the next entry.
```

The screen showing tree dimensions recorded is edited a line at a time. If satisfied with the line indicated by the cursor press "Y," if not, press "N" and the cursor will move to the next entry in the line. All entries are a toggle. The d.b.h. or d.b.h. and height combinations under dimensions measured from which the user can select are listed on page 3 for each tree size class. For stem pulpwood d.o.b. top, the user can toggle-in 1 to 6 inches for pine or hardwood pulpwood and pine sawtimber and 1 to 8 inches for hardwood sawtimber. D.b.h. interval can be 1 or 2 inches and height interval can be 5 or 10 feet or 1/2 logs. The tree dimension selected must be the same for hard hardwoods and soft hardwoods except for the stem pulpwood top d.o.b.

When the user is statisifed with the entries for dimensions measured and presses "Y," the following screen showing default values for pounds per cord equivalents and sawtimber form class will appear:

```
DEFAULT VALUES FOR PINE, HARD HARDWOOD, AND SOFT HARDWOOD

                          POUNDS PER            SAWTIMBER
                        CORD EQUIVALENT        FORM  CLASS
=================================================================

PINE  =>                   5600.00                 78

H-HWD =>                   5700.00                 78

S-HWD =>                   5700.00                 78

=================================================================

Are you satisfied with the entries as shown? (Y or N) : Y
```

If the user wants to change one or more of these preselected values and presses "N," the following edit instructions will appear at the top of the screen:

```
To correct entry indicated by cursor, press SPACE BAR and re-enter, or retoggle.
If entry is correct, a CARRIAGE RETURN moves cursor to the next entry.
```

The space bar is used to delete the current value indicated by the cursor and the user can enter values ranging from 4,000 to 8,000 for pounds per cord and form class values ranging from 65 to 90.

When the user is satisfied with the entries and presses "Y," the screen that allows the user to select output tables will appear as shown below:

```
              O U T P U T   T A B L E   O P T I O N S

    ==================================================================
                                    ESTIMATE
                           PER ACRE              PER AREA
    ==================================================================
    TABLE 1-- BD FT BY DBH CLASS
      DOYLE
      SCRIBNER                                      Y
      INT. 1/4

    TABLE 2-- TREE COMPONENT BY DBH CLASS
      TONS                                          Y
      CORDS                                         Y
      CUNITS

    TABLE 3-- SUMMARY TABLE
      CURRENT                                       Y
      PROJECTED                                     Y
    ==================================================================
    Are you satisfied with the entries as shown? (Y or N) : Y
```

If the user is not satisfied with the preselected output tables as shown and presses "N," the following edit instructions will appear at the top of the screen:

```
To correct entry indicated by cursor, press SPACE BAR and re-enter, or retoggle.
If entry is correct, a CARRIAGE RETURN moves cursor to the next entry.
```

Examples of Tables 1, 2, and 3 are shown on pages 43, 44, and 46, respectively. The user can have a table printed on a per acre or per area basis, or both. This screen also allows the user to select the board-foot rules to be used to estimate board-foot volumes shown in Table 1, the units of measure to be displayed in Table 2, and if Table 3 is to be printed showing current and projected estimates. The space bar is used to toggle a "Y" if the user wants the table printed, or a blank if the user does not want it printed.

When the user is satisfied with the entries and presses "Y," the screen allowing the user to select the species tallied in the cruise will appear as shown below:

```
        Listed below are the tree species for which tree compo-
        nent weight and volume equations are available for the
        Coastal  region.  Indicate those tallied in Area 1 with
        a Y(es.  Press N(o or <SP> to continue through list.

           PINE------------->   X    PLANTATION PINE------>

           HARD HARDWOODS--->   X    CYPRESS-------------->

           SOFT HARDWOODS--->   X

           OAK SP.---------->

           LIVE OAK--------->

           SWEEETGUM-------->

           PINE2------------>

           SAND PINE-------->

   Are you satisfied with the selections made above? (Y or N) : [Y]
```

The species or species groups available for each physiographic region are shown on pages 5 to 7. The user can select up to six species or species groups per area and a total of nine per tract. The user presses "Y" if a species is tallied and "N," if not. If the user is not satisfied with the entries and presses "N," the species selections are deleted and the selection process starts over.

When the user is satisfied with his species selections and presses "Y," the additional options screen will appear as shown below:

```
                    ADDITIONAL PROGRAM OPTIONS

                       Respond Y(es or N(o

  => Were saplings cruised using a method different
       from that used in cruising pulpwood/sawtimber? [N]
```

If the user cruised saplings differently than trees ≥ 5.0 inches d.b.h. the program will ask for the type of cruise used and for information related to the cruise, such as prism factor or plot radius and number of points or plots on which saplings were tallied. The cruise information originally entered for the area is assumed to apply to the trees ≥ 5 inches d.b.h.

After completing the above question the following option question will appear:

```
  => Do you desire the sawlog stem, for natural pine,
       to be separated into plylogs and small sawlogs? [Y]
```

When the user answers "yes," the following questions will appear on the screen:

```
   For the calculation of plylog weights and volumes, enter
  the following tree dimension information:
                                         DEFAULT   LOWEST ACCEPTABLE
                                          VALUE         VALUE
   Minimum d.b.h. class (in.): [14]       13.0          11.0

   Minimum d.o.b.       (in.): [10]       10.0           8.0

   Enter a <CR> is you wish to use the default value.
```

The user can then enter the minimum d.b.h. tree from which plylogs can be cut and minimum d.o.b. top to which they can be harvested, or enter a <CR> to use the default values.

After answering the above question, a third question will appear if two or more areas have been cruised within a tract:

```
=> Do you wish to have Table 3 printed on a
   tract level (i.e. over all areas cruised)?
```

When the user answers "Y," Table 3A will be printed summarizing all areas in the tract. Table 3B will also be printed summarizing board-foot volumes across all areas.

When the user tallies plantation pine, the following question will appear:

```
=> Do you wish chipping-sawlog output for planta-
   tion pine species?                              [Y]
```

If the user enters "Y," the following questions will appear:

```
For the calculation of chipping-sawlog weight and volumes, enter
the following tree dimension information:
                                    DEFAULT   LOWEST ACCEPTABLE
                                     VALUE          VALUE
Minimum d.b.h. class (in.): [7]       8.0            6.0

Minimum d.o.b.       (in.): [6]       6.0            5.0

Enter a <CR> is you wish to use the default value.
```

The user can then enter the minimum d.b.h. tree from which chipping sawlogs can be cut and the minimum d.o.b. top to which they can be harvested, or enter a <CR> to use the default values.

After answering the option questions, the user is asked to enter area cruise data by species and tree size class. The program asks that sapling tallies be entered first as shown for the example cruise on pages 11 and 12.

```
INPUT:  N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

                     PINE - SAPLINGS (<= 4.0 IN.)
  DBH    TREE COUNT

? [2           6]
? [4          18]
? [E]
```

To enter the pine tree counts for saplings tallied by d.b.h. only, the user enters the d.b.h. class, presses the space bar and the cursor moves under the "tree count" heading. The user then enters the count and presses the carriage return. To end the sapling input, the user presses "E." If no saplings were tallied the user would press the "N" for no data.

After entering the sapling counts and pressing "E," the screen for inputing pine pulpwood tree counts will appear as shown below:

INPUT: N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

PINE - PULPWOOD (>= 5.0 IN.)
HT. TO 4 IN. TOP(FT.)

DBH	10	20	30	40	50	60	70	80	90	100	110	120	130	140
? 6	4	11	12											
? 8		6	17	27	8									
? 12				2	1									
? 16					2									
? E														

To enter tree counts for pine pulpwood tallied by d.b.h. and height to 4-inch top, the user enters the d.b.h. class and then moves the cursor using the space bar under each height class for which trees were tallied, and enters the appropriate counts. After entering the counts for a d.b.h. class, the user presses the carriage return and the question mark appears on the next line under d.b.h. asking the user to enter the next d.b.h. class for which trees were tallied.

After entering the pulpwood counts and pressing "E," the screen for inputing pine sawtimber will appear as shown below:

INPUT: N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

PINE - SAWTIMBER (>= 9.0 IN.)
MERCAHNTABLE HT. (LOGS)

DBH	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
? 10		5	20	20	1							
? 12		2	16	25	8							
? 14			16	12								
? 16			2	15	14							
? 18			1	2	3	1						
? 20			1	4	4	1						
? E												

Examples of Tables 1, 2, and 3 are shown on pages 43, 44, and 46, respectively. The user can have a table printed on a per acre or per area basis, or both. This screen also allows the user to select the board-foot rules to be used to estimate board-foot volumes shown in Table 1, the units of measure to be displayed in Table 2, and if Table 3 is to be printed showing current and projected estimates. The space bar is used to toggle a "Y" if the user wants the table printed, or a blank if the user does not want it printed.

When the user is satisfied with the entries and presses "Y," the screen allowing the user to select the species tallied in the cruise will appear as shown below:

```
     Listed below are the tree species for which tree compo-
     nent weight and volume equations are available for the
     Coastal  region.  Indicate those tallied in Area 1 with
     a Y(es.  Press N(o or <SP> to continue through list.

        PINE------------->   X    PLANTATION PINE------>

        HARD HARDWOODS--->   X    CYPRESS-------------->

        SOFT HARDWOODS--->   X

        OAK SP.---------->

        LIVE OAK--------->

        SWEEETGUM-------->

        PINE2------------>

        SAND PINE-------->

Are you satisfied with the selections made above? (Y or N) : [Y]
```

The species or species groups available for each physiographic region are shown on pages 5 to 7. The user can select up to six species or species groups per area and a total of nine per tract. The user presses "Y" if a species is tallied and "N," if not. If the user is not satisfied with the entries and presses "N," the species selections are deleted and the selection process starts over.

When the user is satisfied with his species selections and presses "Y," the additional options screen will appear as shown below:

```
                    ADDITIONAL PROGRAM OPTIONS

                       Respond Y(es or N(o

   => Were saplings cruised using a method different
      from that used in cruising pulpwood/sawtimber? [N]
```

If the user cruised saplings differently than trees $\geq$ 5.0 inches d.b.h. the program will ask for the type of cruise used and for information related to the cruise, such as prism factor or plot radius and number of points or plots on which saplings were tallied. The cruise information originally entered for the area is assumed to apply to the trees $\geq$ 5 inches d.b.h.

After completing the above question the following option question will appear:

```
   => Do you desire the sawlog stem, for natural pine,
      to be separated into plylogs and small sawlogs? [Y]
```

When the user answers "yes," the following questions will appear on the screen:

```
  For the calculation of plylog weights and volumes, enter
 the following tree dimension information:
                                         DEFAULT   LOWEST ACCEPTABLE
                                          VALUE          VALUE
  Minimum d.b.h. class (in.): [14]        13.0            11.0

  Minimum d.o.b.       (in.): [10]        10.0             8.0

  Enter a <CR> is you wish to use the default value.
```

The user can then enter the minimum d.b.h. tree from which plylogs can be cut and minimum d.o.b. top to which they can be harvested, or enter a <CR> to use the default values.

After answering the above question, a third question will appear if two or more areas have been cruised within a tract:

```
=> Do you wish to have Table 3 printed on a
   tract level (i.e. over all areas cruised)?
```

When the user answers "Y," Table 3A will be printed summarizing all areas in the tract. Table 3B will also be printed summarizing board-foot volumes across all areas.

When the user tallies plantation pine, the following question will appear:

```
=> Do you wish chipping-sawlog output for planta-
   tion pine species?                              [Y]
```

If the user enters "Y," the following questions will appear:

```
For the calculation of chipping-sawlog weight and volumes, enter
the following tree dimension information:
                                 DEFAULT   LOWEST ACCEPTABLE
                                  VALUE          VALUE
Minimum d.b.h. class (in.): [7]    8.0            6.0

Minimum d.o.b.       (in.): [6]    6.0            5.0

Enter a <CR> is you wish to use the default value.
```

The user can then enter the minimum d.b.h. tree from which chipping sawlogs can be cut and the minimum d.o.b. top to which they can be harvested, or enter a <CR> to use the default values.

After answering the option questions, the user is asked to enter area cruise data by species and tree size class. The program asks that sapling tallies be entered first as shown for the example cruise on pages 11 and 12.

```
INPUT:  N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

                          PINE - SAPLINGS (<= 4.0 IN.)
  DBH     TREE COUNT

? [2          6]
? [4         18]
? [E]
```

To enter the pine tree counts for saplings tallied by d.b.h. only, the user enters the d.b.h. class, presses the space bar and the cursor moves under the "tree count" heading. The user then enters the count and presses the carriage return. To end the sapling input, the user presses "E." If no saplings were tallied the user would press the "N" for no data.

After entering the sapling counts and pressing "E," the screen for inputing pine pulpwood tree counts will appear as shown below:

```
INPUT:  N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

                          PINE - PULPWOOD (>= 5.0 IN.)
                              HT. TO 4 IN. TOP(FT.)
 DBH   10   20   30   40   50   60   70   80   90   100   110   120   130  140

? 6    4    11   12
? 8         6    17   27   8
? 12                  2    1
? 16                       2
? E
```

To enter tree counts for pine pulpwood tallied by d.b.h. and height to 4-inch top, the user enters the d.b.h. class and then moves the cursor using the space bar under each height class for which trees were tallied, and enters the appropriate counts. After entering the counts for a d.b.h. class, the user presses the carriage return and the question mark appears on the next line under d.b.h. asking the user to enter the next d.b.h. class for which trees were tallied.

After entering the pulpwood counts and pressing "E," the screen for inputing pine sawtimber will appear as shown below:

```
INPUT:  N(o data, <SP> accepts entry, <CR> returns for new dbh, E(nd of input

                          PINE - SAWTIMBER (>= 9.0 IN.)
                             MERCAHNTABLE HT. (LOGS)
 DBH   0.5  1.0  1.5  2.0  2.5  3.0  3.5  4.0  4.5   5.0   5.5   6.0

? 10        5    20   20   1
? 12        2    16   25   8
? 14             16   12
? 16             2    15   14
? 18             1    2    3    1
? 20             1    4    4    1
? E
```

Mainframe Example

The mainframe version is an interactive program designed to use remote terminals for input to produce output at the terminal or routed to a line printer. The user provides information by answering prompted questions and by entering a cruise summary of tree counts by species or species groups. When entering a cruise the user has the choice of using preselected options stored in the program (Appendix B) or of answering option questions to meet the user's specific needs. How to answer option questions is illustrated in the following example, which also shows the versatility of the program. Mandatory questions that must be answered for each cruise when preselected options are used and no growth estimates are needed are indicated by an asterisk (*).

Logon. The TTMP Cruise Program is stored on a mainframe in compiled object code and a user needs the phone number for the computer, a user ID, and password to access the program. The logon procedures are slightly different at each installation. See local instructions for logon. After logon, the user selects the appropriate procedure depending on whether the output is routed to the terminal or a line printer. A programmer's guide describing the mainframe FORTRAN V code, subroutines, and procedures used to compile and execute the program is available upon request from the authors.

Enter Cruise Data. After the user calls TTMP Cruise Program with the appropriate procedure, the program will start. The user answers each question as it appears after the question mark (?) and hits the carriage return (CR) at the end of each entry. After each line of data is entered it will be printed or echoed back at the terminal. The data entered by the user are shown in a box $\boxed{}$.

```
WELCOME TO THE TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM-- AN ADP
PROGRAM FOR ESTIMATING TOTAL TREE, SAW LOG, PULPWOOD AND FIREWOOD
WEIGHTS AND VOLUMES FROM STANDING TREE CRUISE DATA. TTMPCP WAS
DEVELOPED BY THE USDA FOREST SERVICE SOUTHEASTERN FOREST EXPERIMENT
STATION IN COOPERATION WITH THE GEORGIA FORESTRY COMMISSION AND THE
UNIVERSITY OF GEORGIA SCHOOL OF FOREST RESOURCES.
```

```
*  1.  ENTER THE FOLLOWING ON ONE LINE -- SEPARATE WITH COMMAS:
           DISTRICT NUMBER,
           CASE NUMBER,
           LANDOWNER NAME, AND
           OWNER ADDRESS.
   ? 14,16A,JOHN DOE,MAIN ST ATHENS GA 30602   CR
     14,16A,JOHN DOE,MAIN ST ATHENS GA 30602

*  2.  ENTER THE FOLLOWING ON ONE LINE -- SEPARATE WITH COMMAS:
           PHYSIOGRAPIC REGION (2 = COASTAL, 4 = PIEDMONT, 6 = MOUNTAIN),
           ACREAGE IN TOTAL TRACT,
           NUMBER OF AREAS CRUISED SEPARATELY WITHIN TRACT,
           TRACT LOCATION,
           FORESTERS NAME,
           FORESTERS ADDRESS, AND
           FORESTERS PHONE NUMBER.
   ? 2,40,1,GLYNN CO,SMITH,WAYCROSS GA,912-546-2441   CR
     2,40,1,GLYNN CO,SMITH,WAYCROSS GA,912-546-2441

*  3.  ENTER THE FOLLOWING FOR AREA 1:
         ACREAGE,
         TYPE OF CRUISE (1=FIXED AREA PLOT, 2=POINT SAMPLE, 3=STRIP CRUISE,
          4=100% CRUISE),
         NUMBER OF PLOTS SAMPLED OR '1' IF STRIP OR 100% CRUISE USED,
         TYPE OF STAND ( 1=NATURAL, 2=PLANTATION), AND
         AREA IDENTIFICATION AND/OR LOCATION.
       SEPARATE EVERYTHING BY COMMAS.
   ? 40,2,40,1,PINE-HARDWOOD   CR
     40,2,40,1,PINE-HARDWOOD

*      DO YOU WANT GROWTH PROJECTION? (Y OR N)
   ? YES   CR
     YES
```

(To obtain growth projections for one or more areas in a track, growth projection must be requested for the first area entered.)

```
       ENTER NUMBER OF YEARS GROWTH IS TO BE PROJECTED (5 YEARS MAX)
   ? 5   CR
     5
```

(The number of years' growth projected for Area 1 is used for all areas in a tract for which growth is requested.)

```
       IS INCREMENT CORE DATA TO BE ENTERED FOR GROWTH
       PROJECTION?  (Y OR N)
   ? NO   CR
     NO

       IDENTIFY BOARD-FOOT RULES TO BE USED IN ESTIMATING PROJECTED BOARD-FOOT
       VOLUMES FOR SPECIES CRUISED IN TRACT (SAME RULES USED FOR
       ALL AREAS).  ENTER SPECIES CODE:
```

(Since the board-foot rules used to calculate percent growth for each species group must be the same for all areas to allow for calculation of tract totals this question must be answered for the tract during input for Area 1.)

```
PINE=1, HARD-HARDWOOD=2, SOFT-HARDWOOD=3, OAK SP.=4, LIVE OAK=5,
SWEETGUM=6, PINE2=7, SAND PINE=8, PLANT PINE=9, CYPRESS=10.

 FOLLOWED BY CODE FOR BOARD-FOOT RULE (DOYLE=1, SCRIBNER=2,
 INTERNATIONAL 1/4=3).  SEPARATE ALL ENTRIES BY A COMMA.
 ENTER CODES BY ONE SPECIES PER LINE. SIGNAL END OF INPUT
 WITH AN 'END'.
      ENTER: SPECIES, BD.-FT. RULE
? 1,2   CR
  1,2
? 2,1   CR
  2,1

? 3,1   CR
  3,1
? END   CR
  END

IF YOU DESIRE CHIPPING SAW ESTIMATES, ENTER 'YES' FOLLOWED BY
MINIMUM CHIPPING SAW TREE DBH AND TOP DIAMETER.  SEPARATE ENTRIES
WITH A COMMA.  IF YOU DO NOT DESIRE CHIPPING SAW ESTIMATES,
ENTER 'NO'.  DEFAULT IS NO; MINIMUM CHIPPING SAW DBH ACCEPTED
IS 6-INCHES, DEFAULT IS 8-IN.; MINIMUM TOP DOB ACCEPTED IS 5-INCHES,
DEFAULT IS 6-IN.

? YES,8,6    CR
  YES,8,6
```

(The above question is displayed only when entering plantation cruise data.)

```
                TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -  JOHN DOE                               CASE NO. - 16A
ADDRESS -    MAIN ST ATHENS GA 30602                DISTRICT NO. -     14
TRACT LOC. - GLYNN CO                               TRACT SIZE(AC) -   40.00
FORESTER -   SMITH                                  PHONE - 912-546-2441
ADDRESS -    WAYCROSS GA                            DATE - 84/12/09
PHYSIOGRAPHIC REGION - COASTAL          NO. AREAS CRUISED IN TRACT - 1

AREA - 1  ACREAGE -   40.00  STAND ID - PINE-HARDWOOD
TYPE OF CRUISE - POINT       BLOW-UP FACTOR -  10.00 STAND TYPE - NATURAL
NUMBER OF PLOTS -   40       GROWTH PROJECTION - YES
YEARS PROJECTED - 5          INCREMENT .CORES - NO

*     THE ABOVE INFORMATION SUMMARIZES THE GIVEN INPUT FOR
      AREA 1.  IF YOU ARE SATISFIED WITH THE ENTRIES YOU
      MADE, ENTER 'YES'.  IF YOU ARE NOT SATISFIED WITH ANY OF
      THIS INFORMATION, ENTER THE QUESTION NUMBERS (1,2, OR 3) YOU
      WISH TO CHANGE.  MAKE SURE TO SEPARATE BY COMMAS.
? YES   CR
  YES
```

(If 1, 2 or 3 is entered, question 1, 2 or 3 will be repeated so it can be answered correctly.)

* 4. PRESELECTED PROGRAM OPTIONS HAVE BEEN STORED FOR THE MOST COMMONLY USED TREE DIMENSIONS AND PREFERRED OUTPUT TABLES BY STAND TYPE AND CRUISE OBJECTIVE AS OUTLINED IN USER MANUAL. IF YOU DO NOT WANT TO USE THE PRESELECTED OPTIONS, ENTER 'NO'. IF YOU WANT TO USE THE PRESELECTED OPTIONS, ENTER 'YES' FOLLOWED BY THE CODE FOR TYPE OF STAND CRUISED:

1=NATURAL PINE, 2=PLANTED PINE, 3=HARDWOOD OR PINE-HARDWOOD

FOLLOWED BY CODE FOR PURPOSE OF CRUISE:

1=TIMBER SALE, 2=MANAGEMENT PLAN, 3=DETAILED CRUISE

SEPARATE ENTRIES WITH COMMAS.

? $\boxed{\text{NO}}$ CR
NO

(When preselected options are used the program will immediately ask for cruise data entry (page 39). See Appendix B for preselected cruise options.)

PRESELECTED DIMENSIONS MEASURED, CRUISE PARAMETERS, & OUTPUT TABLES

SPECIES	SIZE CLASS	DIMENSIONS MEASURED	STEM PULPWOOD TOP DOB (IN.)	DBH INTERVAL (IN.)	HEIGHT INTERVAL (FT./LOGS)
PINE	SAPLINGS	DBH		2	
PINE	PULPWOOD	D+H4	4	2	10
PINE	SAWTIMBER	D+MH	4	2	LOGS
H-HWD	SAPLINGS	DBH		2	
H-HWD	PULPWOOD	D+H4	4	2	10
H-HWD	SAWTIMBER	D+MH	4	2	LOGS
S-HWD	SAPLINGS	DBH		2	
S-HWD	PULPWOOD	D+H4	4	2	10
S-HWD	SAWTIMBER	D+MH	4	2	LOGS

	POUNDS PER CORD EQUIVALENT	SAWTIMBER FORM CLASS
PINE =	5600.0	78.
H-HWD =	5700.0	78.
S-HWD =	5700.0	78.

OUTPUT TABLES

	ESTIMATE PER ACRE	ESTIMATE PER AREA
TABLE 1		Y
A. DOYLE		Y
B. SCRIBNER		Y
C. INT. 1/4		
TABLE 2		Y
A. TONS		
B. CORDS		Y
C. CUNITS		
TABLES 3A & 3B		
CURRENT		Y
PROJECTED		Y

AS SHOWN IN THE TABLES ABOVE, TTMPCP HAS STORED PRESELECTED CRUISE PARAMETERS AND OUTPUT OPTIONS. ENTER 'YES' IF YOU WANT TO USE THESE STORED INPUT AND OUTPUT OPTIONS. ENTER 'NO' IF YOU WANT TO CHANGE ONE OR MORE OF THE STORED OPTIONS.

? $\boxed{\text{NO}}$ CR
NO

MENU OF OPTION QUESTIONS

6. CHANGE CRUISE BLOW-UP FACTOR
7. CHANGE POUNDS PER CORD EQUIVALENTS
8. CHANGE TREE DIMENSIONS MEASURED AND CRUISE PARAMETERS
9. SELECT PLYLOG AND SMALL SAWLOG OUTPUT
10. SELECT TABLE 1, SAWLOG BD. FT. VOLUME BY DBH, AND BD. FT. RULE(S) USED IN TABLE 1
11. SELECT TABLE 2, TREE COMPONENT BIOMASS BY DBH, AND UNITS OF MEASURE FOR TABLE 2
12. CHANGE SAWTIMBER FORM CLASS
13. SELECT TABLES DESIRED FOR PER ACRE, PER AREA, AND FOR TRACT OUTPUTS
14. SELECT BASAL AREA OUTPUT

5. ENTER NUMBER(S) OF QUESTIONS YOU WANT TO ANSWER OR 'ALL' IF YOU WANT TO ANSWER ALL QUESTIONS. SEPARATE NUMBERS WITH COMMAS.

? $\boxed{\text{ALL}}$ CR
ALL

6. THE USER MAY CHANGE THE TYPE OF CRUISE AND/OR A CRUISE SPECIFICATION (I.E. PLOT AREA, PRISM FACTOR, ETC.) FROM WHAT WAS PREVIOUSLY SPECIFIED BY THE USER OR BY DEFAULT. ALSO, A CRUISE TYPE MAY BE SPECIFIED FOR SAPLINGS (TREES < 5.0 INCHES). ENTER 'NO' IF NO CHANGES REQUIRED. ELSE ENTER TREE SIZE CODE (1= SAPLINGS, 2= TREES>= 5-IN., 3= ALL TREES), FOLLOWED BY TYPE OF CRUISE (1= FIXED AREA, 2= POINT, 3= STRIP, 4= 100%). LIST ALL CODES IN ONE INPUT STRING SEPARATED BY COMMAS.

NOTE: IF A TYPE OF CRUISE IS SPECIFIED FOR SAPLINGS, THE USER MUST ALSO ENTER A TYPE FOR THE CLASS OF TREES>= 5-IN. (AND VICE VERSA).

? $\boxed{1,1,2,2}$ CR
1,1,2,2

(In this example saplings (1) were tallied by using fixed area (1) and trees $\geq$ 5 inches (2) were tallied by using a point cruise (2).)

ENTER RADIUS OF PLOT IN FEET FOR FIXED AREA PLOT USED TO CRUISE SAPLINGS:
? $\boxed{16.65}$ CR
16.65

(The user enters the radius of the plot in feet. Listed below are some commonly used circular plot radii, in feet:)

1/4 acre = 58.55	1/10 acre = 37.23	1/50 acre = 16.65
1/5 acre = 52.66	1/20 acre = 26.33	1/100 acre = 11.78

ENTER NUMBER OF PLOTS USED IN CRUISING SAPLINGS:
? $\boxed{10}$ CR
10

ENTER PRISM FACTOR FOR POINT SAMPLE CRUISE USED TO TALLY TREE>=5 IN:
? $\boxed{10}$ CR
10

ENTER NUMBER OF POINTS USED IN CRUISING TREE>=5 IN:
? $\boxed{40}$ CR
40

(If a strip cruise is used, program will ask for two entries.)

ENTER WIDTH OF STRIP OR PERCENT OF AREA CRUISED:
? $\boxed{66}$ CR
66

(User enters width of strip in feet or percent of area cruised.)

```
ENTER TOTAL LENGTH OF STRIP OR 0 IF PERCENT OF AREA CRUISED
ENTERED ABOVE:
? [2000] CR
  2000
```

(User enters total length of strip in feet or zero.)

```
7. THESE ARE THE POUND/CORD EQUIVALENTS FOR YOUR PHYSIOGRAPHIC AREA:
     PINE IS              5600.0
     HARD-HARDWOOD IS     5700.0
     SOFT-HARDWOOD IS     5700.0

IF YOU ARE SATISFIED, ENTER 'YES'; IF NOT, ENTER THE DESIRED CHANGES.
ENTER SPECIES (1=PINE, 2=HARD-HARDWOOD, 3=SOFT-HARDWOOD), COMMA,
FOLLOWED BY ITS POUND/CORD EQUIVALENT.
ENTER 'END' TO SIGNAL THE END OF CHANGES.
? [2,5750]  CR
  2,5750
? [3,5750]  CR
  3,5750
? [END]  CR
  END

8. IN THIS SECTION YOU CAN SPECIFY THE DIMENSIONS MEASURED, THE PULP-
   WOOD TOP DIAMETER, AND THE HEIGHT AND DBH INTERVAL USED IN TALLYING
   A GIVEN SIZE CLASS. IT IS ASSUMED HARD-HARDWOOD AND SOFT-HARDWOOD
   HAVE THE SAME DIMENSIONS EXCEPT FOR STEM PULPWOOD TOP DOB.
ENTER: THE SIZE CLASS (1=SAPLING, 2=PULPWOOD, 3=SAWTIMBER)
       DIMENSIONS MEASURED (1=DBH, 2=DBH & TH, 3=DBH & HT4, 4=DBH & MHT,
        AND 0=NOT MEASURED),
       STEM PULPWOOD TOP DOB (MAX. DOB: PINE=6 IN., HARDWOOD=8 IN., OR
        0=NONE),
       DBH INTERVAL (1=1 INCH, 2=2 INCH),
       AND HEIGHT INTERVAL (5=5 FT., 10=10 FT., AND 0=NOT MEASURED OR LOGS),
       SEPARATED BY COMMAS--ONE SIZE CLASS PER LINE.
   NOTE: IF THERE ARE NO DATA FOR A SIZE CLASS, ENTER THE SIZE
         CLASS CODE AND A '0', SEPARATED BY A COMMA.
   IF SATISFIED WITH THE STORED PARAMETERS, ENTER 'YES' ELSE ENTER 'NO'
   AND YOU WILL BE PROMPTED BY SPECIES.
? [NO]  CR
  NO

ENTER DESIRED PINE CHANGES. IF NO CHANGES NEEDED, ENTER 'NONE'. SIG-
NAL END OF INPUT STREAM WITH AN 'END'.
  ENTER: SIZE CLASS, DIMENSION MEASURED, PULP TOP DOB, DBH INTERVAL,
         HEIGHT INTERVAL.
? [NONE]  CR
  NONE
```

```
ENTER DESIRED HARD-HARDWOOD CHANGES.  IF NO CHANGES NEEDED, ENTER 'NONE'.
SIGNAL END OF INPUT STREAM WITH AN 'END'.
  ENTER: SIZE CLASS, DIMENSION MEASURED, PULP TOP DOB, DBH INTERVAL
         HEIGHT INTERVAL.
? [1,1,0,2,0]   CR
  1,1,0,2,0
? [2,3,4,2,10]   CR
  2,3,4,2,10
? [3,4,5,2,0]   CR
  3,4,5,2,0
? [END]   CR
  END

ENTER DESIRED SOFT-HARDWOOD CHANGES.  THE ONLY DIFFERENCE BETWEEN
HARD-HARDWOOD AND SOFT-HARDWOOD PERMITTED IS STEM PULPWOOD TOP DOB.
IF HARD AND SOFT-HARDWOOD PULP TOP DOB IS THE SAME, ENTER 'SAME'. IF
A DIFFERENT PULP TOP DOB IS USED FOR SOFT-HARDWOOD ENTER THE SIZE CLASS,
COMMA, AND THE TOP DOB DESIRED.  SIGNAL END OF INPUT STREAM WITH AN 'END'.
? [3,4]   CR
  3,4
? [END]   CR
  END

 9.  IF YOU DESIRE SAW-LOG STEM DIVIDED INTO PLYLOGS AND SMALL SAW LOGS,
     ENTER 'YES' FOLLOWED BY MINIMUM PLYLOG DBH CLASS FOLLOWED BY MINIMUM UP-
     PER STEM PLYLOG DOB.  SEPARATE ENTRIES WITH A COMMA.  IF YOU DO NOT
     DESIRE PLYLOG ESTIMATES, ENTER 'NO'.  DEFAULT IS NO; MINI-
     MUM PLYLOG DBH ACCEPTED IS 11-IN., DEFAULT IS 13-IN.,: MINIMUM PLYLOG
     TOP DOB ACCEPTED IS 8-IN., DEFAULT IS 10-IN.
? [YES,14,10]   CR
  YES,14,10

10.  TABLE 1 - GROSS SAW-LOG BOARD-FOOT VOLUME BY
     D.B.H. CLASS - IS OPTIONAL.
     DO YOU WANT TABLE 1 (YES OR NO)?
? [YES]   CR
  YES

     WHAT BOARD FOOT RULE DO YOU DESIRE FOR TABLE 1?
     ANY OR ALL OF THE FOLLOWING ARE AVAILABLE:
       1=DOYLE, 2=SCRIBNER, 3=INTERNATIONAL 1/4
     ENTER THE CODES SEPARATED BY COMMAS OR 'SAME' IF YOU
     WISH TO USE THE PRESTORED LOG RULE OPTION.
? [1,2]   CR
  1,2
```

(See Appendix B for prestored options.)

```
11.  TABLE 2 - TREE COMPONENT BIOMASS BY D.B.H. CLASS - IS OPTIONAL.
     DO YOU WANT TABLE 2 (YES OR NO)?
? [YES]   CR
  YES
```

SUMMARY OF PINE TREE COUNT INPUT DATA

PINE - SAPLINGS

DBH	TREE COUNT
2	6
4	18

PINE - PULPWOOD

HT. TO 4 IN. TOP(FT.)

DBH	10	20	30	40	50	60	70	80	90	100	110	120	130	140
6	4	11	12											
8		6	17	27	8									

PINE - PULPWOOD

HT. TO 4 IN. TOP(FT.)

DBH	10	20	30	40	50	60	70	80	90	100	110	120	130	140
12				2	1									
16					2									

PINE - SAWTIMBER

MERCHANTABLE HT.(LOGS)

DBH	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
10		5	20	20	1							
12		2	16	25	8							
14			16	12								
16			2	15	14							
18			1	2	3	1						
20			1	4	4	1						

* THE ABOVE TABLE SUMMARIZES THE GIVEN PINE INPUT. IF YOU ARE SATISFIED, ENTER 'YES'. IF YOU WANT TO MAKE CORRECTIONS IN THE ABOVE TABLE, ENTER THE SIZE CLASSES YOU WISH TO CHANGE OR MAKE ADDITIONS TO (1=SAPLINGS, 2=PULPWOOD, 3=SAWTIMBER, 4=LARGE PULPWOOD). SEPARATE CODES WITH COMMAS.

? $\boxed{\text{YES}}$ CR

YES

HARD-HWD CRUISE DATA INPUT SECTION

ENTER HARD-HWD CRUISE DATA.
YOU WILL BE PROMPTED BY SIZE CLASS - IF THERE ARE NO DATA FOR A SIZE CLASS, ENTER 'NONE'. SIGNAL END OF DATA INPUT, FOR EACH SIZE CLASS, WITH AN 'END'.

At this point in the program the user would enter the tree counts by d.b.h. and height classes by tree size class in the same manner as was done for the pine. The program would then print out the summary of the hard hardwood input for the user to check and make corrections. After telling the program the hard hardwood input data were correct, the program would ask for soft hardwood data input.

After the cruise data for each species tallied in an area have been entered, the program will ask the following question if more than one area in a tract has been cruised.

DO YOU WANT TO CONTINUE THE NEXT AREA (Y OR N)
?

Data entry for each area in a tract starts with question 3 (page 30). After answering question 3 for an area the following question will be asked:

THE STORED PRESELECTED CRUISE PARAMETERS USED FOR THE PREVIOUS AREA WILL BE USED FOR THIS AREA UNLESS SPECIFIED OTHERWISE. ENTER 'YES' TO REUSE THESE STORED OPTIONS OR 'NO' IF CHANGES ARE DESIRED.

If the above question is answered "Yes," the program will immediately ask for cruise data entry. If the above question is answered "No," the program will ask question 4 (page 32).

After all cruise data for each area have been entered, the computer will calculate estimated weights and volumes and route output to the terminal or line printer.

Output and Examples

Output from this program is designed to provide the forester, landowner, or timber buyer with information to evaluate the utilization options for marketing the timber. The output from the program shows the aggregate weight and volume of the total tree above-stump for trees in the stand by species or species groups. It breaks down these estimates into saw logs, plylogs, pulpwood, crown firewood, and logging residue and gives these estimates in tons, cords, cunits and board feet per acre or by area and tract totals. This information is provided in four basic output tables: a table showing board-foot volume by d.b.h., a table showing total-tree and tree-component biomass by d.b.h. class, a summary table, and a table showing projected annual growth by stand component and species.

Exhibit 3 is an example of the output displayed in Tables 1A, 1B, and 1C which show predicted gross board-foot volumes based on the Doyle, Scribner, or International 1/4-inch board-foot rules, respectively. These output tables show the predicted board-foot volume by d.b.h. class, the totals for each species, and the total board feet over all species for the specified form class; also displayed are the average saw-log heights and numbers of trees by species and d.b.h. class.

Exhibit 4 is an example of the output displayed in Tables 2A, 2B, and 2C which show estimated total-tree and tree-component biomass expressed in tons, cords, and cunits, respectively. These output tables show predicted biomass for the total tree above-stump, stem from butt to the specified pulpwood top, saw-log stem, stem pulpwood, and hardwood crown firewood $\geq$ 4 inches d.o.b. Stem pulpwood consists of the stem from butt to the specified pulp d.o.b. top in pulpwood trees and the stem pulpwood above the sawtimber top in sawtimber trees. When planted pine cruise data are analyzed and chipping saw logs are requested, Table 2 will display the weight or volume of chipping logs instead of saw logs. Also shown in Table 2 is the average height and the estimated number of trees by d.b.h. classes.

EXHIBIT 3.--EXAMPLE OF TABLE 1B SHOWING ESTIMATED SCRIBNER BOARD-FOOT VOLUME FOR FORM CLASS 78 BY DBH CLASS.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC. -	GLYNN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 912-546-2441	
ADDRESS -	WAYCROSS GA	DATE - 84/12/09	

TABLE 1B--PREDICTED SCRIBNER GROSS SAWLOG BD.FT. VOLUME BY DBH CLASSES.
CURRENT ESTIMATES - YIELD PER ACRE

DBH (IN.)	AVERAGE HEIGHT -------(LOGS)-------			EST. NO. OF TREES -------(NUMBER)-------			SAWLOG VOLUME-SCRIBNER,FC /1/ -----(THOUSAND BOARD FEET)-----			
	PINE	HHWD	SHWD	PINE	HHWD	SHWD	PINE	HHWD	SHWD	ALL SPECIES
10	1.7	.0	.0	21.1	.0	.0	.8	.0	.0	.8
12	1.9	1.5	2.0	16.2	1.6	2.5	1.2	.1	.2	1.4
14	1.7	1.8	2.4	6.5	3.7	5.1	.7	.4	.7	1.7
16	2.2	2.0	2.5	5.6	.7	.7	.9	.1	.1	1.2
18	2.3	2.0	.0	1.0	.3	.0	.2	.1	.0	.3
20	2.3	.0	.0	1.1	.0	.0	.3	.0	.0	.3
ALL CLASSES				51.6	6.3	8.4	4.1	.7	1.0	5.8

/1/ FORM CLASS: PINE= 78.; SOFT HWD= 78.; HARD HWD= 78.

EXHIBIT 4.--EXAMPLE OF TABLE 2A SHOWING ESTIMATED TOTAL-TREE AND TREE-COMPONENT BIOMASS IN TONS BY DBH CLASS.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. -	16A
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC. -	GLYNN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE -	912-546-2441
ADDRESS -	WAYCROSS GA	DATE -	84/12/09

TABLE 2A--PREDICTED TOTAL TREE AND COMPONENT BIOMASS BY DBH CLASSES.
CURRENT ESTIMATE - YIELD PER ACRE

DBH	AVERAGE HEIGHT	EST. TREES	TOTAL TREE	STEM TO PULP TOP /1/	SAWLOGS	STEM PULPWOOD	FIREWOOD >= 4 IN.
(IN)	(FT.&LOGS)	(NO.)	-----------	----------	TONS	----------	-----------
			PINE				
			--SAPLINGS--				
2	.0	68.8	.6				
4	.0	51.6	2.9				
			--PULPWOOD--				
6	23.0	34.4	5.1	3.3		3.3	
8	36.4	41.5	13.0	10.6		10.6	
12	43.3	1.0	.7	.6		.6	
16	50.0	.4	.5	.4		.4	
			--SAWTIMBER--				
10	1.7	21.1	9.9	8.8	7.1	1.7	
12	1.9	16.2	12.7	10.4	8.4	1.9	
14	1.7	6.5	6.9	5.3	4.1	1.2	
16	2.2	5.6	8.5	6.7	5.6	1.1	
18	2.3	1.0	1.9	1.5	1.3	.2	
20	2.3	1.1	2.7	2.1	1.8	.4	
ALL CLASSES		249.1	65.4	49.9	28.3	21.6	

/1/ STEM PULPWOOD TOP:
PULPWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
SAWTIMBER - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.

The summary consists of two tables, Table 3A and Table 3B. Table 3A (Exhibit 5) shows the predicted total biomass of all trees in the stand in tons, cords, and cunits for each species and all species combined. Estimated total biomass is displayed for saplings (1.0 to 4.0 inches), and for trees $\geq$ 5.0 inches d.b.h. The biomass in trees $\geq$ 5.0 inches is divided into material in the stem to the specified pulpwood top and material in the crown (branches and stem above the pulp d.o.b. top). The stem to a pulpwood top is further separated into saw-log and pulpwood components. The pulpwood component consists of estimates of pulpwood from pulpwood-size trees and of that which comes from the tops of sawtimber-size trees. When natural pine data are analyzed and the user selects the plylog option, the saw-log stem is separated into plylogs and small saw logs and their weights and volumes displayed. The amount of crown that is $\geq$ 4 inches d.o.b. is also displayed for hardwoods as crown firewood. When planted pine cruise data are analyzed and the chipping-log option selected, chipping-log estimates are displayed instead of saw-log estimates in Table 3A.

Table 3B (Exhibit 6) displays the total board-foot volume for each species by the desired log rules for all saw logs, small saw logs, and plylogs. This table also shows the estimated average basal areas per acre in square feet and average quadratic mean d.b.h. for saplings, pulpwood, and sawtimber-size trees for each species.

Output Table 4 (Exhibit 7) shows the projected annual growth by stand component for each species tallied. Annual growth estimates are based on 5-year increment-core measurements of radial growth entered by the user, or stored average annual radial growth values. The present volume per acre, present growth per acre per year, and total annual growth for the stand-by-stand component are displayed. Annual growth is expressed in board feet for saw logs, in cords for pulpwood, and in tons for total-tree chips. When planted pine chipping-log estimates are desired, chipping-log annual growth is expressed in cords. The stem to pulp top growth values in Exhibit 5 are for the total stem from butt to the pulp top and the pulpwood values are for pulpwood from pulpwood-size tree and tops of sawtimber-size trees. Percent annual change per acre is also shown for each stand component.

Using the stand table projection method, the current tree tallies can be projected for up to 5 years and Tables 3A and 3B can be reprinted to show estimates of future weights and volumes. Output Tables 1 to 3 can be printed on a per acre or area basis. Tables 3A and 3B, the summary tables showing current or projected weight and volume, can be printed to summarize all areas within a tract. Table 4, the table showing annual growth, can also be printed to summarize growth by stand component for a tract.

Interpretation of Output

The TTMP Cruise Program is designed to predict gross total-tree and tree-component stand weights and volumes by using regional species equations. Thus, these estimates should be interpreted and used carefully. Estimates are made assuming efficient utilization will be followed during timber harvesting. If the loggers fail to cut saw logs to the upper stem limit cruised, or cut stem pulpwood to only a 6-inch rather than a 4-inch small end diameter, the program will overestimate product yields. Therefore, users should change pulpwood top diameters used in the program to coincide with local harvesting practices.

The output tables showing biomass by d.b.h. classes (Tables 2A, 2B, 2C) and the summary (Table 3A), contain weight and volume estimates for the basic components of the tree. These basic values permit users to combine component estimates to simulate harvesting practices in their area. For example, in some areas only hardwood saw logs can be sold commercially and no market for hardwood pulpwood exists. Stem pulpwood estimates therefore would be combined with crown firewood and marketed as firewood.

EXHIBIT 5.--EXAMPLE OF TABLE 3A WHICH SUMMARIZES THE PREDICTED TOTAL-TREE AND TREE-COMPONENT WEIGHTS AND VOLUMES BY SPECIES.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC. -	GLYNN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 912-546-2441	
ADDRESS -	WAYCROSS GA	DATE - 84/12/09	

TABLE 3A--SUMMARY OF PREDICTED TOTAL TREE AND COMPONENT WEIGHT AND VOLUME.
CURRENT ESTIMATE - YIELD PER ACRE

COMPONENT	PINE	HARD-HWD	SOFT-HWD	ALL TREES
	GREEN TONS OF WOOD AND BARK			
TOTAL TREE(ALL)	65.4	19.5	18.4	103.3
SAPLINGS(< 5 IN.)	3.5	3.5	3.1	10.1
TOTAL TREE(> 5 IN.)	61.9	16.0	15.2	93.2
STEM TO PULPWOOD TOP /1/	49.9	11.5	12.2	73.6
ALL SAWLOGS /2/	28.3	5.0	7.0	40.3
SMALL SAWLOGS /5/	19.8	.0	.0	19.8
PLYLOGS /6/	8.5	.0	.0	8.5
PULPWOOD (ALL)	21.6	6.5	5.1	33.2
PULPWOOD TREES	15.0	4.5	3.2	22.7
SAWTIMBER TOPS	6.6	2.0	2.0	10.5
TOTAL CROWN	12.1	4.5	3.1	19.6
CROWN FIREWOOD>= 4IN	.0	.9	.7	1.6
	CORDS OF WOOD AND BARK /4/			
TOTAL TREE(ALL)	23.4	6.9	6.4	36.7
SAPLINGS(< 5 IN.)	1.2	1.2	1.1	3.6
TOTAL TREE(> 5 IN.)	22.1	5.6	5.4	33.1
STEM TO PULPWOOD TOP /1/	17.8	4.1	4.3	26.1
ALL SAWLOGS /2/	10.1	1.8	2.5	14.3
SMALL SAWLOGS /5/	7.1	.0	.0	7.1
PLYLOGS /6/	3.0	.0	.0	3.0
PULPWOOD (ALL)	7.7	2.3	1.8	11.8
PULPWOOD TREES	5.4	1.6	1.1	8.1
SAWTIMBER TOPS	2.3	.7	.7	3.7
TOTAL CROWN	4.3	1.6	1.1	7.0
CROWN FIREWOOD>= 4IN	.0	.3	.2	.6
	VOLUME OF WOOD (CUNITS)			
TOTAL TREE(ALL)	17.6	5.0	5.3	27.8
SAPLINGS(< 5 IN.)	.9	.9	.9	2.7
TOTAL TREE(> 5 IN.)	16.7	4.1	4.3	25.1
STEM TO PULPWOOD TOP /1/	13.5	3.0	3.5	20.0
ALL SAWLOGS /2/	7.8	1.3	2.1	11.2
SMALL SAWLOGS /5/	5.5	.0	.0	5.5
PLYLOGS /6/	2.3	.0	.0	2.3
PULPWOOD (ALL)	5.7	1.7	1.5	8.8
PULPWOOD TREES	4.1	1.2	1.0	6.2
SAWTIMBER TOPS	1.6	.5	.5	2.6
TOTAL CROWN	3.2	1.1	.8	5.1
CROWN FIREWOOD>= 4IN	.0	.2	.2	.4

/1/ STEM PULPWOOD TOP:
PULPWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
SAWTIMBER - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
/2/ SAWLOG MERCHANTABILITY: 7-IN. FOR PINE W/MIN DBH 9-IN., 9-IN. FOR HARDWOOD OR THRU LOG GRADE NO. 3 MERCHANTABILITY W.MIN DBH 11-MIN.
/3/ NUMBER MAY NOT ADD DUE TO ROUNDING ERROR.
/4/ POUNDS PER CORD: PINE=5600. HHWD=5700. SHWD=5700.
/5/ SMALL SAWLOGS - MIN 8 F. W/ MIN 7-IN. DOB SMALL END.
/6/ PLYLOGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END, MIN DBH - 14.0.

EXHIBIT 6.--EXAMPLE OF TABLE 3B WHICH SUMMARIZES THE PREDICTED SAW-LOG BOARD-FOOT VOLUMES AND BASAL AREA PER ACRE BY SPECIES.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC. -	GLYNN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 912-546-2441	
ADDRESS -	WAYCROSS GA	DATE - 84/12/09	

TABLE 3B--SUMMARY OF PREDICTED TOTAL TREE AND TREE COMPONENT WEIGHT AND VOLUME.
CURRENT ESTIMATE - YIELD PER ACRE

COMPONENT	PINE	HARD-HWD	SOFT-HWD	ALL TREES
SAWLOG BOARD-FOOT VOLUME---(MBF)/1/				
ALL SAWLOGS				
DOYLE	2.6	.4	.6	3.7
SCRIBNER	4.1	.7	1.0	5.8
SMALL SAWLOGS				
DOYLE	1.6	.0	.0	1.6
SCRIBNER	2.6	.0	.0	2.6
PLYLOGS				
DOYLE	1.1	.0	.0	1.1
SCRIBNER	1.5	.0	.0	1.5
BASAL AREA PER ACRE (SQ.FT.)				
SAPLING TREES	5	4	5	14
PULPWOOD TREES	22	6	5	33
SAWTIMBER TREES	43	6	8	57
ALL TREES	70	16	18	104
QUADRATIC MEAN D.B.H. (IN.)				
SAPLING TREES	3.0	3.2	2.6	2.9
PULPWOOD TREES	7.3	7.4	7.1	7.3
SAWTIMBER TREES	12.4	14.0	13.6	12.7
ALL TREES	7.3	5.6	4.6	6.2

/1/FORM CLASS: PINE= 78.; SOFT HWD= 78. HARD HWD= 78.

EXHIBIT 7.--EXAMPLE OF TABLE 4 WHICH SHOWS PROJECTED ANNUAL GROWTH OVER 5 YEARS BY STAND COMPONENT.

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC.-	GLUNN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 912-546-2441	
ADDRESS -	WAYCROSS GA	DATE - 84/12/09.	

TABLE 4.--BASIC INVENTORY AND PROJECTED ANNUAL GROWTH

STAND COMPONENT	PRESENT VOLUME PER ACRE	PRESENT GROWTH PER ACRE PER YEAR	TOTAL ANNUAL GROWTH PER AREA	PERCENT ANNUAL CHANGE PER ACRE
AREA 1-- 40.00 ACRES-PINE-HARDWOOD				
PINE				
ALL SAWLOGS (MBF SCRIB)	4.1	.233	9.34	5.67
SMALL SAWLOGS (MBF)/1/	2.6	.188	4.70	4.49
PLYLOGS (MBF)/2/	1.5	.116	4.64	7.73
STEM TO PULP TOP (CORDS)	17.8	.630	25.18	3.54
PULPWOOD (CORDS)	7.7	.124	4.95	1.61
TOTAL TREE CHIPS (TONS)	65.4	2.074	82.98	3.17
HARD-HWD				
ALL SAWLOGS (MBF DOYLE)	0.4	.018	0.71	3.98
STEM TO PULP TOP (CORDS)	4.1	.152	6.07	3.75
PULPWOOD (CORDS)	2.3	.111	4.42	4.83
TOTAL TREE CHIPS (TONS)	19.5	.545	21.81	2.79
SOFT-HWD				
ALL SAWLOGS (MBF DOYLE)	0.6	.019	0.75	2.99
STEM TO PULP TOP (CORDS)	4.3	.102	4.06	2.38
PULPWOOD (CORDS)	1.8	.056	2.25	3.12
TOTAL TREE CHIPS (TONS)	18.4	.339	13.57	1.85
ALL SPECIES				
ALL SAWLOGS (MBF)				
SAWLOGS (DOYLE)	1.1	.036	1.46	3.40
SAWLOGS (SCRIB)	4.1	.233	9.34	5.67
STEM TO PULP TOP (CORDS)	26.1	.883	35.32	3.38
PULPWOOD (CORDS)	11.8	.290	11.62	2.46
TOTAL TREE CHIPS (TONS)	103.3	2.959	118.35	2.86

/1/SMALL SAWLOGS - MIN 8 FT. W/ MIN 7-IN. DOB SMALL END.
/2/PLYLOGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END, MIN DBH - 14.0.

NOTE: NEGATIVE REFLECTS MOVEMENT OF MATERIAL INTO LARGER SIZE COMPONENT OR MORTALITY GREATER THAN GROWTH.
GROWTH ASSUMES APPROX. 1% ANNUAL MORTALITY.

The TTMP Cruise Program assumes that the cruise analyzed was a random sample and will therefore lead to unbiased estimates. These biomass estimates, however, contain errors due not only to harvesting differences but also to biomass prediction equations and timber cruise procedures. When timber is 100 percent cruised, the error associated with the cruise is minimized since all trees are tallied. Preliminary tests of the program that used this cruise procedure indicate that predicted total tree, total stem to pulpwood top, and saw-log weights and volumes will be within ± 10 percent of the actual weights and volumes if d.b.h. and some estimate of height are tallied. Biomass of upper stem pulpwood and crown firewood varies considerably more. Users should use these component estimates carefully until they gain field experience as to their reliability. Biomass estimates based on fixed-area plots, point sampling, or strip cruising can contain more error than those based on a 100 percent cruise. To minimize sampling error, plots and strips must be located without bias, border trees must be measured carefully to determine if they are in or out of the cruise, and a sufficient number of plots and strips must be taken.

The growth projections calculated by this program are designed to provide growth information for short-term management planning and when stands are cruised but not harvested for 1 to 5 years. When stand projections are made with the radial growth values stored in the program and which are based on the regional average for the species group, users should apply these values carefully. The stand cruised could be growing at a rate different from the average for their physiographic region. When accurate growth projections are required, the user should enter increment-core growth values for the pulpwood and sawtimber trees cruised. The trees to be bored must be selected randomly to avoid bias in growth estimates.

An average mortality rate (page 10) is assumed in the program when projected growth is calculated. These mortality rates, however, may not be applicable to the stands cruised. Thus, the user should adjust the reported projected growth to account for local mortality rates.

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APPENDIX

Appendix A--Computational Procedures

Regression equations are stored in the program for estimating the green weight of wood and bark (excluding foliage) and volume of wood in the total-tree above-stump and its components that use d.b.h. (D) or d.b.h. in combination with total height (Th), height to a 4-inch d.o.b. top (H4), or saw-log merchantable height (Mh). Shown below are the tree components estimated by using these independent variables by tree size class.

Tree size class	Independent variable	Component estimated
Saplings	D^2, D^2+Th	Total-tree above-stump
Pulpwood and large pulpwood	D^2, D^2+Th, D^2+H4	Total-tree above-stump, stem from butt to tip
Large pulpwood hardwoods only	D^2, D^2+Th, D^2+H4	All material in total tree $\geq$ 4-in. d.o.b.
Sawtimber	D2, D2+Th, D2+H4, D2+Mh	Total-tree above-stump, saw-log stem, All materials in total tree $\geq$ 4-in. d.o.b. (Hardwoods only)

Component Weights and Volumes

The following allometric regression equations are used to estimate

component weights and volumes:

$$Y = a(X)^b \tag{1}$$

or

$$Y = a(X_1)^b (X_2)^c \tag{2}$$

where:

Y = component weight or volume

$X = D^2$ or $D^2 * Th$ or $D^2 * H4$

$X_1 = D^2$

X_2 = Th or H4 or Mh

When trees are tallied by d.b.h., or by d.b.h. and total height or height to 4-in. d.o.b. top, weight and volume of stem to sawtimber and pulpwood tops are estimated by using the following ratio equation (Clark and Thomas 1984) to estimate the proportion of the predicted total-stem weight or volume to the specified top d.o.b.:

$$Y_R = e^a (d^b D^c) \quad (3)$$

where:

Y_R = stem to top d.o.b./total-stem ratio

d = specified top diameter in inches

D = tree diameter at breast height in inches

a,b,c = regression coefficients

e = base of natural logs

Since equation (3) is used to estimate the proportion of the stem to any top d.o.b., the user has the option of specifying the pulpwood d.o.b. top to be used in analyzing the cruise data. A different top d.o.b. can be specified for pine, hard hardwoods, and soft hardwoods.

When sawtimber trees are tallied by d.b.h., or by d.b.h. and total height or height to a 4-inch top, a fixed sawtimber top d.o.b. of 7 inches is used for pine and 9 inches for hardwoods. Tallying hardwoods by total height or height to a 4-inch top can result in an overestimate of the saw-log portion of the stem. This occurs because hardwoods generally do not have enough stem quality to produce grade 3 logs to a 9-inch top in large diameter trees.

When trees are tallied by d.b.h. and saw-log merchantable height, the following ratio model (Clark and Thomas 1984) is used to expand estimated saw-log weight or volume to pulpwood stem weight or volume to any d.o.b. top above the saw-log top.

$$Y_R = e^a \left[(Mh)^b \left(\left(1 - \left(\frac{d}{.78D} \right)^2 \right)^2 \right)^c \right] \quad (4)$$

where:

Y_R = stem to top d.o.b./saw-log stem ratio

Mh = saw-log merchantable height in feet

d = specified top diameter in inches

D = tree diameter at breast height in inches

a,b,c = regression coefficients

e = base of natural logs

Equation (4) allows the user to specify the pulpwood top diameter desired for sawtimber trees tallied by d.b.h. and saw-log merchantable height in logs. Stem pulpwood above the saw-log top in sawtimber-size trees is estimated by subtracting estimated stem weight or volume to saw-log top from stem weight or volume to the pulpwood top.

Crown (branches plus stem above pulp top) weights and volumes are estimated by subtracting predicted stem weight or volume to the pulp d.o.b. top from predicted total-tree weight or volume. Weight and volume of hardwood crown firewood $\geq$ 4 inches is predicted by subtracting stem weight or volume to the pulp top from the predicted weight or volume of all material in the tree $\geq$ 4 inches d.o.b.

The user has the option of separating the saw-log merchantable stem of pines into plylogs and small saw logs. When sawtimber pines are tallied by d.b.h. and saw-log merchantable heights, the heights to the minimum plylog d.o.b. top are estimated by using the following equation based on those developed by Bennett and Swindel (1972):

$$Ph = [(H-4.5)(\frac{D-Pd}{D})]a + [((H-4.5)(\frac{D-Pd}{D}))^2]b \qquad (5)$$

where:

Ph = height to plylog minimum d.o.b.

D = tree diameter at breast height in inches

Pd = minimum plylog d.o.b. in inches

H = saw-log stem merchantable height, total height or height to 4-inch top

a,b = regression coefficients (different coefficients are used for each height)

The minimum plylog d.o.b. top (Pd) can be specified by the user or the default value (10 inches) used. The user can also specify the minimum d.b.h. tree from which plylogs can be harvested. The plylog height estimated with equation (5) is rounded back to 8.7-foot segments plus 0.5 foot for stump height. A tree must contain a minimum of two 8.7-foot peeler blocks to make a plylog tree.

The rounded plylog height (Ph) is then substituted for saw-log merchantable heights in the D^2+Mh equations and the weight and volume of the plylog stem estimated. Weights and volumes of small saw logs are estimated by subtracting the estimated weight or volume of plylog stem from the weight or volume of the saw-log stem.

When pine trees are tallied by d.b.h. and total height (Th) or d.b.h. and height to 4-inch top (H4), Th or H4 are substituted in equation (5) and appropriate coefficients used to estimate the height to the specified plylog d.o.b. The estimated plylog height is then rounded back to 8.7-foot intervals plus 0.5 foot for a stump and the following taper curve equation used to estimate the final plylog d.o.b. (Pd) at this point on the stem (Bennett and Swindel 1972).

$$Pd = a\left[\frac{D(H-Pht)}{(H-4.5)}\right] + b[(H-Pht)(Pht-4.5)] + c[H(H-Pht)(Pht-4.5)]$$

$$+ d[(H-Pht)(Pht-4.5)(H+Pht=4.5)] \qquad (6)$$

where:

Pd = d.o.b. at the rounded plylog height in inches

D = tree diameter at breast height in inches

H = tree total height or height to 4-inch d.o.b. top in feet

Pht = rounded plylog height from equation (5) in feet

a,b,c = regression coefficients

The proportion of total-stem weight or volume to the estimated plylog d.o.b. (Pd) is estimated by substituting (Pd) for d in equation (3). The weight or volume of small saw logs is estimated by subtraction. When sawtimber trees are tallied by d.b.h. only, no plylog or small saw-log estimate is made.

When analyzing plantation pine cruise data, the user has the option of separating the stem to the pulpwood top into chipping logs and upper stem pulpwood. The user can specify a minimum d.o.b. top to which chipping logs can be cut and the minimum d.b.h. tree from which chipping logs can be processed. The proportion of total-stem weight or volume to a user-specified minimum chipping-log top d.o.b. is estimated by using equation (3). The upper stem pulpwood weight or volume is estimated by subtracting the weight or volume of chipping-log stem from the weight or volume of the stem to the pulpwood d.o.b. top.

Board-Foot Volume Equations

Equations for estimating the Doyle, Scribner, and International 1/4-inch saw-log stem board-foot volumes were developed from Mesavage and Girard's volume tables form class 78 (Mesavage and Girard 1956). These equations are listed below:

Doyle Board Foot (trees 9 to 24 inches d.b.h.)

$$Y = 0.00153(D^2)^{1.60122}(L^3)^{0.21566} \quad (7)$$

$$R^2 = 0.99 \quad S_{y.x}\log_{10} = 0.0315$$

Doyle Board Foot (trees greater than 24 inches d.b.h.)

$$Y = 0.00244(D^2)^{1.48489}(L^3)^{0.23199} \quad (8)$$

$$R^2 = 0.99 \quad S_{y.x}\log_{10} = 0.0358$$

Scribner Board Foot

$$Y = -16.40224 + 0.06777(D^2) + 0.02376(D^2L) - 0.00265(DL^2) + 0.000097(L^3) \quad (9)$$

$$R^2 = 0.99 \quad S_{y.x} = 2.8 \text{ bd. ft.}$$

International 1/4-inch

$$Y = -2.788196 + 0.04587(D^2) + 0.02560(D^2L) - 0.00291(DL^2) + 0.00015(L^3) \quad (10)$$

$$R^2 = 0.99 \quad S_{y.x} = 3.0 \text{ bd. ft.}$$

where:

Y = stem volume to saw-log merchantable top in board feet

D = tree d.b.h. in inches

L = tree saw-log merchantable height with 0.5-foot stump allowance in feet (1 log = 16.3 feet)

The predicted volumes from equations (7), (8), (9), and (10) and predicted volumes from board-foot equations by Wiant and Castaneda (1977) were compared with the Mesavage and Girard tables. The sums of the residuals squared showed that the Scribner and International 1/4-inch equations listed above performed better than Wiant and Castaneda's but that their Doyle equation listed below was a better predictor than equations (7) and (8).

<u>Wiant and Castaneda's Doyle Board-Foot Equation</u>

$$Y = (0.55743 * (Log)^2 + 41.51275 * (Log) - 29.37337) +$$

$$((2.78043 - 0.04516 * (Log)^2 - 8.77272 * (Log)) * (D)) +$$

$$((0.04177 - 0.01578 * (Log)^2 + 0.59042 * (Log)) * (D)^2) \quad (11)$$

$$R^2 = 0.99$$

where:

Log = number of 16-foot saw logs

D = tree d.b.h. in inches

Thus, equations (9), (10), and (11) are used in the program to estimate saw-log stem board-foot volume of sawtimber-size trees. The user can specify the log rule and form class to be used for estimating pine, hard hardwood, and soft hardwood board-foot volumes. For each unit change in form class, the predicted board-foot volumes are adjusted up or down by 3 percent (Mesavage and Girard 1956).

When sawtimber-size trees are tallied by total height or height to 4-inch d.o.b. top, the height to a saw-log top (7 inches d.o.b. for pine, 9 inches d.o.b. for hardwoods) is estimated with the following equations:

Independent variable (Emh)	Regression equation	Coefficient of determination (R^2)	Standard error (Sy.x)
			(Feet)
PINE			
Height to 7-in. d.o.b. top	$Y = -346.429 + 104.919\sqrt{\log_{10}D^2} + 127.315(\log_{10}Th)$	0.87	4.2
	$Y = -280.191 + 83.871\sqrt{\log_{10}D^2} + 114.16711(\log_{10}H4)$	0.91	3.5
HARD HARDWOODS			
Height to 9-in. d.o.b. top	$Y = -346.975 + 122.4777\sqrt{\log_{10}D^2} + 106.170(\log_{10}Th)$	0.81	5.3
	$Y = -282.233 + 109.559\sqrt{\log_{10}D^2} + 88.303(\log_{10}H4)$	0.82	5.2
SOFT HARDWOODS			
Height to 9-in. d.o.b. top	$Y = -410.120 + 170.044\sqrt{\log_{10}D^2} + 101.663(\log_{10}Th)$	0.81	6.4
	$Y = -366.421 + 148.392\sqrt{\log_{10}D^2} + 101.792(\log_{10}H4)$	0.84	5.9

where:

Emh = estimated saw-log stem height to 7-inch d.o.b. for pine, 9-inch d.o.b. for hardwoods in feet

D = tree diameter at breast height in inches

Th = tree total height

H4 = height to 4-inch d.o.b. top in feet

a,b,c = regression coefficients

The estimated saw-log heights (Emh) and recorded d.b.h. are then used to estimate saw-log board-foot volume by using the appropriate log rule equations (9), (10), or (11).

Appendix B--Preselected Program Options

Preselected options are stored in the mainframe program for the commonly used tree dimensions, d.b.h. and height intervals, pulpwood top diameters, output tables by stand type, and cruise objective. The user can select to use the stored options (question 4, page 32) or answer option questions 6 to 14 as desired.

The type of stand--natural pine, plantation pine, hardwood or pine-hardwood--determines the tree dimensions used for measuring the trees in a cruise. The table below summarizes the tree dimensions measured and stem pulpwood d.o.b. top stored by stand type and tree size class. The stored dimensions measured are the same for natural pine, and hardwood or pine-hardwood stands.

Tree size class	Dimensions measured	Stem pulpwood top d.o.b.
		(Inches)
	NATURAL PINE AND HARDWOOD OR PINE-HARDWOOD	
Sapling	d.b.h.	
Pulpwood and large pulpwood	d.b.h. and height to 4-in d.o.b. top	4
Sawtimber	d.b.h. and saw-log height in logs	4
	PLANTATION PINE	
Sapling	d.b.h.	
Pulpwood and large pulpwood	d.b.h. and total height	4
Sawtimber	d.b.h. and total height	4

The preselected d.b.h. and height-class intervals used to record tally trees are determined by the cruise objective--timber sale, management plan, detailed cruise. Shown below are the d.b.h. and height-class intervals stored by cruise objective, stand type, and tree size class.

Stand type	D.b.h. interval (All tree classes)	Height interval (Saplings)	(Pulpwood)	(Sawtimber)
	(Inches)	-----(Feet)-----		(Feet or logs)
	TIMBER SALE OR MANAGEMENT PLAN			
Natural pine	2	None	10	1/2
Planted pine	1	None	5	5
Pine-hardwoods	2	None	10	1/2
	DETAILED CRUISE			
Natural pine	1	None	5	1/2
Planted pine	1	None	5	5
Pine-hardwoods	1	None	5	1/2

The purpose of the cruise determines the output tables printed. All preselected tables are area tables except Tables 1 and 2 under the management plan objective, which are per acre tables. Shown below are the output tables printed and their units of measure by cruise objective and stand type.

Output tables and units of measure	Output tables printed (Y=yes,blank=no)								
	Timber sale			Management plan			Detailed cruise		
	Natural pine	Planted pine	Pine hwd	Natural pine	Planted pine	Pine hwd	Natural pine	Planted pine	Pine hwd
TABLE 1									
A. Doyle			Y			Y			Y
B. Scribner	Y		Y	Y		Y	Y		Y
C. International									
TABLE 2									
A. Tons							Y	Y	Y
B. Cords		Y		Y	Y	Y	Y	Y	Y
C. Cunits							Y	Y	Y
TABLES 3A & 3B									
Current	Y	Y	Y	Y	Y	Y	Y	Y	Y
Projected				Y	Y	Y			
TABLE 4				Y	Y	Y			

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. ______ Case No. ________ Landowner ____________ Address ____________
Geographic Region ______ Acreage in Tract ______ No. Areas in Tract _____ Tract Location ____________
Forester ____________ Address ____________ Phone ____________
Area No. ________ Area Acreage ____ Type Cruise ________ No. Plots ______ Planted or Natural ______
Area Identification ____________ Species ____________ Date ______

PLOT NO.	DBH	COUNT			DBH	COUNT				DBH	COUNT			DBH	COUNT		
	2				4					2				4			
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20		PULPWOOD--HEIGHT TO 4-INCH TOP (FEET)															
		10	20	30	40	50	60	70	80	10	20	30	40	50	60	70	80
	6																
	8																
	10																
		SAWTIMBER--SAW-LOG MERCHANTABLE HEIGHT (LOGS)															
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
	12																
	14																
	16																
	18																
	20																
	22																

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. ______ Case No. ______ Landowner ______________ Address ______________

Geographic Region ______ Acreage in Tract ______ No. Areas in Tract ____ Tract Location ______________

Forester ______________ Address ______________ Phone ______________

Area No. ______ Area Acreage ____ Type Cruise ______________ No. Plots ____ Planted or Natural ______

Area Identification ______________ Species ______________ Date ______

PLOT NO. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

DBH									
2	SAPLING COUNT				DBH 4	SAPLING COUNT			
	PULPWOOD--HEIGHT TO 4-INCH TOP (FEET)								
	10	20	30	40	50	60	70	80	90
6									
8									
	SAWTIMBER--SAW-LOG MERCHANTABLE HEIGHT (LOGS)								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
10									
12									
14									
16									
18									
20									

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. ______ Case No. _______ Landowner _____________________ Address ______________________________

Geographic Region _______ Acreage in Tract ________ No. Areas in Tract _____ Tract Location ____________________

Forester __________________________ Address ___________________________ Phone ___________________________

Area No. _________ Area Acreage _____ Type Cruise ___________________ No. Plots _____ Planted or Natural _________

Area Identification ____ Species _________________________ Date _______

Plot No.																
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM--Summary Form for Recording Cruise Counts

District No. ______ Case No. ________ Landowner ____________________ Address ____________________

Geographic Region _______ Acreage in Tract _______ No. Areas in Tract _____ Tract Location ____________________

Forester ____________________ Address ____________________ Phone ____________________

Area No. ____________ Area Acreage ____ Type Cruise ____________ No. Plots _______ Planted or Natural ____________

Area Identification ____________________ Species ____________________ Date ____________

Plot No.	Species ______	Sapling	2	4	Species ______	Sapling	2	4
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Clark, Alexander, III; Burgan, Thomas M.; Field, Richard C.; Dress, Peter E.
User's manual for Total-Tree Multiproduct Cruise Program. Gen. Tech. Rep. SE-31. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1985. 65 pp.

This interactive computer program uses standard tree-cruise data to estimate the weight and volume of the total tree, saw logs, plylogs, chipping logs, pulpwood, crown firewood, and logging residue in timber stands. Input is cumulative cruise data for tree counts by d.b.h. and height. Output is in tables: board-foot volume by d.b.h.; total-tree and tree-component biomass by tons, cords, and cunits; a summary table; and projected annual growth by stand component and species. This manual describes the FORTRAN V mainframe and the PASCAL microcomputer programs and how to enter data to obtain the desired output.

KEYWORDS: Computer program, inventory, biomass, tree weight, tree volume.

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The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives —as directed by Congress—to provide increasingly greater service to a growing Nation.

General Technical Report SE-32 is available on microfiche which can be found in the collection on third floor in the cabinets behind the information desk.

No. 32 received in binder after this volume.

United States
Department of
Agriculture

Forest Service

**Southeastern Forest
Experiment Station**

General Technical
Report SE-33

Performance and Quality-Control Standards for Composite Floor, Wall, and Truss Framing

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Performance and Quality-Control Standards for Composite Floor, Wall, and Truss Framing

Part I. Preface

1.0 Origin and Use of the Standards

These standards offer building-code authorities and consumers the assurance that composite framing will perform as intended and that manufacturers will maintain its quality at specified levels. They have been prepared by the Materials Science and Engineering for Wood-Based Composite Structural Framing Unit, USDA Forest Service, Athens, GA, where COM-PLY framing is being developed, and are intended for interim use so that manufacturers can proceed with production. Permanent uniform standards for COM-PLY framing will be developed by the manufacturers, in collaboration with building-code officials, consumer groups, and government agencies.

2.0 The Product

Composite, or COM-PLY, framing is designed for residential and light commercial building construction. It consists of wood veneer facings laminated to a flakeboard core. Two or more veneer faces are laminated to the narrow face of the framing with the grain of the veneer parallel to the long axis of the framing.

When used for truss framing, COM-PLY is connected with light-gauge metal truss plates. Manufacturers shall design trusses in accordance with the current Truss Plate Institute (TPI) Design Specifications for Wood Trusses.

3.0 Purpose of the Performance Standards

To make satisfactory and safe use of COM-PLY products, consumers must be able to determine their strength, stiffness, dimensional stability, and durability. Performance standards provide the means for measuring such attributes and for developing product specifications. Manufacturers select the specifications for any given product; specifications do not restrict the materials, methods, or processes that can be used in manufacture. Performance standards, however, do set forth the materials, methods, and processes to be used in obtaining approval for a product by a regulatory agency. An agency may accept or reject a product on the basis of one or more specified tests that measure how strong, stiff, stable, and durable it is. Moreover, the standards set forth the procedures for retesting whenever materials, methods, or processes used during production are changed. The levels of performance, the test methods, and the policies governing acceptance or rejection outlined in these standards represent the consensus of regulatory agencies and COM-PLY manufacturers.

4.0 Purpose of the Quality-Control Standards

Quality-control standards specify the tests that manufacturers shall apply regularly during production to evaluate physical and mechanical properties of COM-PLY framing. Such testing assures that acceptable quality is being maintained. Manufacturers are responsible for maintaining the quality of the product by making adjustments in materials or manufacturing processes whenever necessary. The quality levels set forth in this standard have the agreement of regulatory agencies and manufacturers who will be using the standard. Because some tests must be performed daily, they are designed to be relatively inexpensive and easy to perform. Testing may be done by the manufacturer, provided that records are kept by an inspection agency, or for audit by such an agency. Manufacturers may trademark production COM-PLY framing only after it has been checked according to procedures set forth in this standard and has been shown to meet specifications. Manufacturers may not trademark COM-PLY framing that falls below accepted standards.

COM-PLY® is a registered trademark of the American Plywood Association.

Part II. Policies Governing the Use and Enforcement of the Standards

1.0 Products to Which the Standards Apply

Standards apply only to composite framing intended for use in residential, farm, or commercial floor, wall, and truss framing that uses light-gauge metal plate connectors. The material manufactured under these standards is not intended for use with full exterior exposure to weather. Throughout service life, COM-PLY should be in a protected location without direct exposure to weathering.

2.0 Definition of a Qualified Inspection and Testing Agency

All tests shall be performed by a qualified inspection and testing agency (hereafter referred to as the auditor), which is defined as one that:

- Operates an inspection system that evaluates the quality-control system of its contracting plants.
- Provides the facilities and the personnel to perform the inspection and to verify the testing as described herein.
- Determines the individual plant's ability to produce in accordance with these standards.
- Provides periodic inspection of the plant's production operations and production quality to assure compliance with these standards.
- Enforces the proper use of the inspection agency quality marks and certificates.
- Has no financial interest in or is not financially dependent upon any single company manufacturing any portion of the product being inspected or tested.
- Is not owned, operated, or controlled by any such company.
- Provides a technical review board to advise the inspection and testing agency and to arbitrate disputes between the agency and the manufacturer. Such a review board shall include a recognized independent authority in the field of engineered structural wood products to serve as chairman, and at least one registered engineer knowledgeable in the design and use of structural glued wood products.

3.0 Policies Governing Performance Standards

3.1 Purpose and Scope

The purpose of the performance standard is to assure that composite framing will perform as intended. Such assurance is attained by testing the product for such attributes as strength, durability, and stability. These policies govern such testing, which is the basis for determining whether a manufacturer shall have the privilege of trademarking a COM-PLY product. Policies also govern tests that must be done to determine whether the privilege of trademarking is to be reinstated after having been withdrawn.

3.2 Product Markings

Each piece of composite framing that complies with this standard shall be marked with a trademark and with information as specified below, depending on the type of framing, as indicated in parentheses:

- Intended use (floor, wall, truss).
- Working stress in bending, F_b (floor, wall, truss).
- Working stress in short-column compression, F_c (wall, truss).
- Working stress in tension, F_t (truss).
- Modulus of elasticity to be used in long-column design, E_{bf} (wall, truss).

- Modulus of elasticity to be used for beam deflecting, E_b (floor).

- Modulus of elasticity to be used for short-column design, E_{cs} (wall, truss).

- Manufacturer's type number (floor, wall, truss).

- Manufacturer's name or mill number (floor, wall, truss).

- Date and shift of manufacture (floor, wall, truss).

- Name of the auditor or testing company certifying quality (floor, wall, truss).

An acceptable trademark might look like this:

Composite Truss Framing
F_b = 1850 E_{bf} = 1500000
F_c = 2000 E_{cs} = 1300000
F_t = 1000 Type 3
ABC Lumber Company 8/12/86-2
XYZ Testing Company

The trademark may include manufacturer and testing company logos. The lettering and ink used for the trademark must remain legible after 1 year of outdoor weathering.

3.3 Qualifying for Trademarking Privileges

A manufacturer may trademark a COM-PLY product when:

- All of the performance tests have been performed, the product has passed the minimum requirements, and working stresses have been established.

- The initial quality-control test has been performed and the results recorded.

- The product specification has been written and includes the values for the initial quality-control test.

3.4 Required Testing or Retesting

Testing or retesting is required:

- Whenever a new product or manufacturing type that uses new process methods and/or materials is to be produced.

- Whenever there is a major change in specifications that affects the strength, durability, or dimensional stability of an old or previously manufactured product.

- Whenever production has not restored quality above the withdrawal level for any of the daily quality-control tests after three repeat samplings within any 6-day period and a followup daily sample by the auditor verifies that quality is at the withdrawal level.

- Quarterly or semiannually to demonstrate that performance is being maintained, as set forth in the performance standard.

For cases 1 and 2 the entire performance series of tests must be performed. For case 3 only those properties that have been shown to be unacceptable need be retested; the auditor stipulates the test required. In case 4 the retesting of performance shall be limited to the type of periodic test specified in section 5.0 of the quality-control standard.

3.5 Test Records

Records of the results of all tests are the property of the manufacturer who pays for the cost of running them. The auditor shall keep on file copies of all test records and correspondence for at least 2 years and shall supply the manufacturer with the number of copies agreed upon. The auditor shall retain current copies of manufacturer's product specifications for reference but shall not divulge their contents without the manufacturer's consent.

3.6 Settlement of Disputes Between the Manufacturer and the User

Should a dispute arise between the manufacturer and a user concerning the performance of a COM-PLY product, the performance standards may be used to settle the dispute. They should agree upon a qualified independent testing laboratory to run the performance tests. The laboratory will usually be the one that certified the product in question. If the product fails to qualify for strength, durability, or stability within ± 10 percent of the trademarked or required values, it is suggested that the manufacturer pay the costs of running the test; otherwise, the user shall pay such costs.

4.0 Policies Governing Quality-Control Standards

4.1 Purpose and Scope

The purpose of the quality-control standard is to assure that the composite framing being made has the quality indicated by the trademark and original test. Such assurance is attained by collecting samples of the product daily and testing them for quality. These policies govern testing that is designed to detect whether quality has dropped to a level that requires some adjustment by the manufacturer to bring the level back up to standard. These policies also specify the procedures to follow when withdrawing trademarking privileges from a manufacturer who fails to maintain the quality of the product and when restoring trademarking privilges to a manufacturer who raises the quality of the product to acceptable levels.

4.2 Levels of Quality

Three levels of quality--acceptable, warning, and withdrawal--are designated in the quality-control standards. The manufacturer's quality-control personnel are responsible for keeping the production superintendent informed of the current level of quality of composite framing being produced. The manufacturer is responsible for correcting unsatisfactory quality and for paying the costs of the quality-control program.

4.2.1 Acceptable quality.--Unless notified otherwise by the auditor or quality-control personnel, the manufacturer may assume that quality of a composite framing product is acceptable and may place the trademark on all pieces produced.

4.2.2 Warning levels and suspension of trademark.--Whenever quality drops below acceptable levels, quality controllers shall warn the production superintendent as soon as practically possible, providing details about the attributes of the product that have dropped to a warning level. Thereafter, testing for any attribute that has dropped to the warning level shall be done on samples taken at the intensive level. The production superintendent must correct the problem within the next three sampling units after being notified that quality has dropped or quality controllers shall issue a second warning. If quality is not corrected in the third unit after the second warning, quality-control personnel shall issue a third warning. If quality is not restored to acceptable levels by the third unit after the third warning, the quality controllers shall notify the auditor that trademarking privileges are being suspended.

The auditor shall not permit trademarking to resume until the production superintendent submits one intensive sample unit that meets the acceptable level of quality for the attribute in question. As soon as one intensive sample unit is passed as acceptable, the quality controllers shall inform the manufacturer that trademarking may be resumed and shall confirm the decision in writing.

4.2.3 Unacceptable quality and withdrawal of trademark.--Whenever quality drops to an unacceptable level, the quality controllers shall immediately notify the production superintendent and the auditor that trademarking will cease.

When the manufacturer has made changes in production to correct the problem and the auditor has verified that quality has been restored to acceptable levels, trademarking may be resumed. As soon as one sample tested by the auditor meets the acceptable level, the auditor shall notify the manufacturer that trademarking may be resumed and shall confirm this decision in writing.

Part III. Performance Standards

1.0 Introduction

To determine how composite, or COM-PLY, floor, wall, and truss framing will perform, the manufacturer or auditor shall perform tests to evaluate working stresses, durability, and dimensional stability under certain specified conditions. This standard prescribes the test methods and materials to use to measure the strength, durability, and dimensional stability of COM-PLY. It details the physical and mechanical properties that COM-PLY must exhibit, and it describes the test methods to use or prescribes the use of procedures described elsewhere. Limitations on use of this standard are set forth, as are recommendations concerning records and materials.

2.0 Marking and Qualifying Several Types of Products

Since a mill may produce several grades of framing, the manufacturer shall stamp on each piece a type number that indicates its performance level. (The number does not rate the quality; it simply differentiates types of framing.) COM-PLY framing manufacturers may agree to limit the number of types of framing in order to avoid confusion of consumers.

Manufacturers shall qualify the performance for each type of framing except when the building-code agency waives such requirements. When a manufacturer wants to market more than one type of floor, wall, or roof truss framing and each type has distinctive design properties, the manufacturer shall qualify each type under these standards.

3.0 Strength

3.1 General Requirements and Notations

3.1.1 Requirements.--Determine the safe working stresses for composite framing according to procedures specified by this standard. Make certain that working stresses for roof truss framing are provided to design trusses as described in the current TPI method and that working stresses for floor and wall framing are provided to design joists and studs conforming to engineering requirements of building codes. Mark key working stresses on each piece of framing. The manufacturer shall supply users with published information about all working stresses.

3.1.2 Notations.--The symbols used in this standard have the following meanings:

E_b = design value for modulus of elasticity in edgewise bending, psi

E_{bf} = design value for modulus of elasticity in flatwise bending, psi

E_{cs} = design value for modulus of elasticity for short columns, psi

E_t = design value for tensile modulus of elasticity parallel to veneer face grain, psi

F_b = design value for extreme fiber in edgewise bending, psi

F_{bf} = design value for extreme fiber in flatwise bending, psi

F_c = design value in compression parallel to veneer face grain, psi

$F_{c\perp}$ = design value in compression perpendicular to veneer face grain, psi

F_t = design value in tension parallel to veneer face grain, psi

F_v = design value in horizontal shear of the flakeboard, psi

F_1 = allowable increase for load sharing among adjacent bending members; the value is 1.15 when computing bending stresses for repetitive loading; otherwise, the value is 1.0

F_2 = safety factor; use 1.5 unless otherwise stated

F_3 = adjustment factor to account for the duration of the test load; use the average time to test for computing F_3; to find F_3, use the following equation or the graph relating duration of load; to design values in the National Design Specifications (NDS) for Wood Construction published by the National Forest Products Association: $F_3 = 1.72624/T^{0.0354831}$, where T is the average test time in minutes

F_4 = adjustment factor for the duration of the intended service load; unless otherwise stated, assume the service load is normal (10 years) and the value for F_4 is 1.0; values for F_4 are 0.9 for permanent loads, 1.0 for 10-year normal loads, 1.15 for 2-month snow loads, 1.25 for 1-week snow loads, 1.33 for 1-day wind or earthquake loads, and 2.0 for 1-second impact loads

N = number of specimens

S = standard deviation of strength or stiffness property from test

T = average test time in minutes

$t_{0.05}$ = statistical <u>t</u> at 0.05 confidence level for N-1 degrees of freedom

x = average strength or stiffness property from test

3.2 Number of Test Specimens

Randomly select at least 10 test specimens from production material in 10 or more loads from the press where veneer is applied to the cores of framing. Test all specimens at an equilibrium moisture content of 10 ± 2 percent, which can be attained by conditioning the specimens to a constant weight at controlled temperature and relative humidity.

Because of the relatively small number tested, the minimum sample of 10 is penalized statistically. However, there is little statistical advantage to testing more than 30 specimens.

3.3 Working Stresses

<u>3.3.1 Strength equation.</u>--Use the following equation to determine working stresses for strength properties:

$$\text{Working stress} = \left[x - \frac{t_{0.05}\,S}{\sqrt{N}} - t_{0.05}\,S \right] \frac{F_1}{F_2 \cdot F_3/F_4}, \quad (1)$$

<u>Note 1</u>: See Part III, section 3.1.2, <u>Notations</u>, for meaning of symbols.

<u>3.3.2 Stiffness equation.</u>--Use the following equation to determine working stress for stiffness properties:

$$\text{Stiffness} = x - \frac{t_{0.05}\,S}{\sqrt{N}} \quad (2)$$

Note 2: See Part III, section 3.1.2, Notations, for meaning of symbols.

3.4 Tests for Strength and Stiffness Performance

3.4.1 Bending working stress (edgewise).--Determine the average modulus of rupture (MOR) and standard deviation for a specimen having a test span of not less than 20 times the depth of the beam and using quarter-point loads following the procedures in American Society for Testing and Materials (ASTM) D 198-84, ¶4 to ¶9. Record the time required to perform each test and compute the average time to test. Use the midspan width and depth to compute the MOR of each specimen. Use the average MOR for the value of x (eq. 1) to compute the working stress in bending, F_b. Compute two values for working stress in bending: one for repetitive bending using F_1 = 1.15 and one for single-member loading using F_1 = 1.0.

3.4.2 Bending modulus of elasticity (edgewise).--Determine the average modulus of elasticity (MOE) and standard deviation for the same specimens used to compute F_b, and by the same ASTM procedure (see section 3.4.1). Use the midspan width and depth to compute the MOE of each specimen. Use the average MOE for the value of x (eq. 2) to compute the working value for E_b in bending.

3.4.3 Bending working stress and modulus of elasticity (flatwise).--Determine the F_{bf} and E_{bf} in the flatwise direction using the same procedures used for F_b and E_b edgewise. (Note: flatwise F_{bf} and E_{bf} values may be needed for certain column designs or where framing material is to be used for plank, purlin, deck board, and the like.) This test is not required for framing marked only for use as joists or studs.

3.4.4 Compression parallel to face grain of veneer.--Determine the average short-column ultimate compressive strength (F_c) and standard deviation for specimens 8-1/2 inches long (with grain of veneer) following procedures in ASTM D 198-84, ¶12 to ¶18. Specimens may be cut from remnants of the bending test. If butt joints are used in both the veneer and core, then test a double set of specimens, one set with core joints and one with veneer joints. Use the set with the lower average ultimate strength for determining working stresses in compression. If only one component (veneer or core) contains butt joints, then only one set of specimens that contains the butt joint need be tested. If no butt joints are used but other joints such as scarf joints are used in the components, then half the specimens shall contain core joints and half contain veneer joints. Record the time to perform each test and compute the average time to test. Use the midlength width and depth to compute the short-column compressive stress of each specimen. Use the average ultimate short-column stress for the value of x (eq. 1) to compute the working stress (F_c) for short-column compression. This test is not required for framing marked only for use as joists.

3.4.5 Compressive modulus of elasticity.--Determine the MOE in compression for the same specimens used to compute F_c by using the procedures in ASTM D 198-84, ¶12 to ¶18. Use the midlength width and depth to compute the short-column MOE values for each specimen. Use the average short-column MOE for the value of x (eq. 2) to compute the working stress (E_{cs}) for column design. This test is not required for framing marked only for use as joists.

3.4.6 Tension working stress.--Determine the average ultimate tensile strength and standard deviation for all specimens following the procedures in ASTM D 198-84, ¶28 to ¶34. The length of the specimen shall be the sum of the grip lengths and the test length between grips. The test length between grips shall not be less than 48 inches but shall be long enough to include the maximum number and minimum spacing of joints that typically occur in the veneer and flakeboard core. All test specimens shall contain a typical core joint and a veneer joint in each veneer laminate. Record the time required to perform each test and record the average time to test.

Use the average time to test for computing F_3 (eq. 1). The value of F_1 is 1.0 and the value of F_2 is 1.5. Use the width and depth at the midtest length to compute the ultimate tensile strength of each specimen. Use the average ultimate tensile strength for the value of x (eq. 1) to compute the working tension stress (F_t). This test is not required for framing marked only for use as joists or studs.

3.4.7 Tension modulus of elasticity.--Determine the average tensile MOE and standard deviation for the same specimens used to compute the working tension stress (F_t) following the procedures in ASTM D 198-84, ¶28 to ¶34. Use the width and depth at midtest length to compute the MOE of each specimen. Use the average MOE for the value of x (eq. 2) to compute the working value for E_t in tension. This test is not required for framing marked only for use as joists or studs.

3.4.8 Bearing working stress (edges).--Determine the average ultimate edge-bearing stress ($F_{c\perp}$) and standard deviation for a 6-inch-long specimen following the procedures in ASTM D 143-83, ¶79 to ¶84. Specimens may be cut from an undamaged section from the bending test. The test-bearing area shall be the thickness of the framing across the veneer grain (approximately 1.5 inches) by 2.0 inches with the veneer grain. Record the time required to perform each test and compute the average time to test. Use the average ultimate edge-bearing stress for the value of x (eq. 1) to compute the working stress in edge-bearing ($F_{c\perp}$). This test is not required for framing marked only for use as studs.

An alternative to this test may be used to determine the allowable working stress in compression perpendicular to grain ($F_{c\perp}$). See the Natural Design Specification for Wood Construction (NDS) by the National Forest Products Association for the species that corresponds to the face veneer of the composite member.

3.4.9 Shear working stress.--Determine the average ultimate shear stress and standard deviation for a block-shear specimen cut from the flakeboard core following the procedures in ASTM D 143-83, ¶90 to ¶94. Specimens may be cut from end trimmings of specimens used for bending or tension tests, or may be taken from randomly selected end trimmings of production material. Record the time to perform each test and compute the average time to test. Use the average ultimate shear stress for the value of x (eq. 1) to compute the working stress for horizontal shear (F_v). This test is not required for framing marked only for use as truss or stud framing.

3.4.10 Lateral load resistance for nails driven into veneer facing.--Test an equal number of specimens for both 6d and 8d common wire nails driven into the narrow edge of the framing so the nail shank is imbedded in the flakeboard core. Determine the average ultimate lateral load and standard deviation for specimens with a 1/2-inch-thick plywood cleat following the procedures in ASTM D 1761-77, ¶12 to ¶18. Record the load that occurs at 0.015 inch of joint slip. Record the time required to perform each test and compute the average time to test. Assume the service load to be wind or earthquake with a duration of load factor (F_4) equal to 1.33. Use the average ultimate lateral nail load for the value of x (eq. 1) to compute the safe lateral load per nail. The load per nail must not be less than 68 pounds. (Note: 68 pounds is the safe lateral wind load for 6d nails in Group III woods and 8d nails in Group IV woods, according to NDS.) The average load at 0.015 inch of joint slip must not be less than 51 pounds per nail. (Note: the NDS value for normal load is 51 pounds for 6d nails in Group III woods and 8d nails in Group IV woods.)

This test is not mandatory but may be requested by the manufacturer or building-code official.

3.4.11 Lateral load resistance for end and toe-nailed joints.--Test stud-to-plate joint nail strength and joist-to-header joint nail strength. For studs, follow procedures to test for loads as specified in USDA Forest Service Research Paper SE-155, the section on strength of nailed joints, with one exception: allow lateral deformations up to 0.015 inch. For joists, follow procedures to test for loads as specified in USDA Forest Service Research Paper SE-222, the section on joists supported by nails.

This performance test is not mandatory but may be requested by the manufacturer or building-code official.

3.4.12 Withdrawal load resistance for nails driven into veneer facing.--Test an equal number of specimens for 6d and 8d common wire nails and 1-1/4-inch gypsum wallboard nails driven into the narrow edge of the framing so the nailhead is one-half inch from the face of the framing. Determine the average ultimate withdrawal load and standard deviation for each set of specimens following procedures in ASTM D 1761-77, ¶1 to ¶11. Record the time required to perform each test and compute the average time to test. Assume the service load to be wind for the 6d and 8d nails and permanent load for the 1-1/4-inch gypsum wallboard nails. The service duration of load factor (F^4) is 1.33 for test of 6d and 8d nails and 0.9 for test of the 1-1/4-inch gypsum wallboard nails. Use the average ultimate withdrawal load for the value of x (eq. 1) to compute the safe withdrawal load per nail. The safe withdrawal load per nail must not be less than 37 pounds for 6d nails, 56 pounds for 8d nails, and 15 pounds for 1-1/4-inch gypsum wallboard nails. (Note: the safe withdrawal loads for 6d and 8d nails are equivalent to the withdrawal loads in NDS for such nails that have been driven in wood having a specific gravity of 0.42 and with 1-1/2 and 2 inches, respectively, of shank penetration. The safe load for the 1-1/4-inch gypsum wallboard nail is equal to the dead load of 1/2-inch gypsum board and a deep fill of attic insulation supported on nails spaced 7 inches on center and for trusses spaced 2 feet on center.) The withdrawal test for the 1-1/4-inch gypsum wallboard nail is not required for framing marked for use only as joists or studs.

These tests are not mandatory but may be requested by the manufacturer or building-code official.

3.4.13 Truss plate lateral fastener resistance.--The truss plate manufacturer shall be responsible for testing the lateral fastener resistance of light-gauge metal truss plates per tooth, nail, plug, square inch, or other unit unless the manufacturer of composite truss framing volunteers to make such tests. The truss plate manufacturer shall test lateral plate resistance by using each plate type on each type of composite truss framing. The tests should follow procedures in TPI Appendix C, Design Specification for Metal Plate Connected Wood Trusses, TPI-85, except as follows:

•Test only control specimens that have a veneer moisture content of 10 ± 2 percent. (Note: composite truss framing is fabricated dry (4 to 6 percent moisture content), eliminating some potential hazards associated with wet fabrication. As a result, the TPI moisture response test has been altered somewhat.)

•Test a minimum of 10 specimens.

•Test plate that is rectangular, with a length approximately twice the width.

•Do not allow the plate to fail in net section of the metal during the test.

•Determine the allowable design load based upon ultimate load by using 1 and not by dividing by 3 as shown in paragraph 104.1(c) of the TPI standard. In computing normal loads, use the average ultimate load value per tooth, nail, plug, or square inch of plate for the value of x (eq. 1). Assign F_4 a value of 1.0 to compute normal loads. Compute the value of F_3 on the basis of the average time it takes to perform the load test.

Use the results of this test on composite truss framing as the basis for the engineering design of truss connectors.

4.0 Durability

4.1 General Requirements

Evaluate the durability of composite framing according to methods specified by this standard. Composite framing should be able to withstand both the outdoor weathering that occurs on the job site and the changes in the moisture and temperature that occur after the framing is installed. Because composite framing is a glued wood product, testing the durability of the bonds in it is particularly important. (Resin bonds are used to make the flakeboard core and adhesive bonds are used in laminating the veneers to the core.)

4.2 Tests for Durability

To test the durability of composite framing, follow the procedures of the ASTM D 1037-78, ¶118 to ¶124, or the French Standard NFB51 293, V313 accelerated aging test. The effect of aging on composite framing must not cancel out its bending, tensile, or compressive strength and stiffness. However, testing only for bending strength and stiffness is sufficient.

Use the same number of test specimens and the same methods for selecting and conditioning specimens as those prescribed for strength performance, with the following exceptions. Select a specimen only 2 x 4 or 2 x 6 inches wide and no longer than 8 feet; longer specimens cannot fit into most freezers, and wider specimens of that length would not have a proper depth-span ratio for the bending test. For controls, use the specimens from the test for bending working stress (edgewise) that were bent to failure without aging. Using methods described above, obtain a control value for bending MOE (edgewise) before aging on specimens selected for test of aging.

Age all specimens in accordance with ASTM D 1037-78, ¶120. For aging by the V313 test method, soak the specimens in water at 20 °C (68 °F) for 3 days, then freeze them in air at -12 °C (10 °F) for 1 day, and dry them in air at 60 °C (158 °F) for 3 days; repeat the cycle twice. After aging, test the specimens for bending stiffness and MOR using procedures described above (see Part III, sections 3.4.1 and 3.4.2).

4.3 Performance Required

Aged specimens must retain 50 percent of the stiffness before aging and 50 percent of the MOR obtained in the bending strength tests of unaged specimens.

5.0 Dimensional Stability

5.1 Tests for Stability

Select specimens and condition them according to methods prescribed for tests of strength, except that length may be 8 feet for all specimens. Then, at quarter-points and midpoints along the length of each specimen, measure the width and thickness to the nearest 0.001 inch at the center of each face. Mark the points on the specimens. Then place each specimen in a metal frame so that one end rests against a fixed stop and the other against the stem of a dial gauge calibrated to the nearest 0.001 inch. A rod calibrated to the nearest 0.1 inch may be used to measure the distance between the fixed stop and the gauge stem when the dial gauge reads zero. Record the length of each specimen for later comparison after water soaking. Finally, measure the amount of warpage in all specimens according to the methods prescribed in the lumber-grading rules.

After measuring all specimens, immerse them in water at 68 ± 6 °F (20 ± 3 °C) for 24 hours. Separate the specimens with spacer blocks so that all surfaces touch the water. After the soaking period, remeasure all specimens at the same locations to obtain relative increase in width, thickness, and length. Then measure the amount of warpage in each specimen. Compute the average percentages of increase in width, thickness, and length for the test specimens after water soaking, as well as the average warpage in bow, twist, and crook.

5.2 Performance Required

After water soaking, average dimensional increases of all specimens must not exceed 8.0 percent for width, 10.0 percent for thickness and 0.1 percent for length. The average warpage must not exceed that described as "light" in lumber-grading rules for the length and width nearest that of the specimen size.

Part IV. Quality-Control Standards

1.0 Introduction

Quality control is the basis for assigning the stress ratings and trademarks on each piece of composite structural framing offered for sale. Consumers and building-code officials depend upon certified trademarking to design and build sound structures. Moreover, the maintenance of high quality ultimately affects the health, welfare, and safety of building occupants.

This standard prescribes a means for evaluating the quality of COM-PLY framing as it is being produced to ensure that its strength, stiffness, durability, and dimensional stability are maintained and that its stress rating and trademarking are valid. The quality of COM-PLY framing should be evaluated daily. Its strength and stiffness should be evaluated quarterly, and its durability semiannually.

The trademark on the product should indicate key design stresses, the manufacturer's product type number, the producing mill number or name, and the symbol or mark of the agency certifying the quality of the product (see Part II, section 3.2, for details). By placing this information on COM-PLY framing, the manufacturer indicates that the strength, durability, and dimensional stability required for a quality product have been established.

2.0 Responsibilities of the Manufacturer and the Auditor

2.1 Product Specification

The manufacturer shall provide the auditor with a written product specification for each type of product manufactured. The specification shall contain detailed information on the processes, methods, and materials used for manufacturing each type product.

The quality of any flakeboard depends not only on the quality and type of materials used but also on every operation in the production line. For this reason, when the quality of COM-PLY framing drops below acceptable levels, the manufacturer or auditor must examine the causes in all factors--materials and methods--in seeking the cause. By keeping accurate records of the method of manufacture and specifications that are used when the board has satisfactory quality, the manufacturer provides the essential information for restoring quality if it falls below acceptable levels. Because some materials and processing methods are proprietary, auditors must take care to safeguard the manufacturer's product specifications so that manufacturing trade secrets will not be divulged.

The product specification should be as detailed as is practical and should include information about both materials and processes.

<u>2.1.1 Materials</u>.--Specifications should describe:

- Wood: species, moisture content, and specific gravity.

- Veneer: thickness, moisture content, and quality.

- Laminating adhesive: type, spread rate, assembly time, curing temperature, pressure applied, and clamp time.

- Resin binder and wax: types, percentage in flakeboard.

- Flakeboard: density, internal bond, MOE, MOR, thickness swelling, water absorption, and linear expansion.

2.1.2 Processes.--Specifications should describe:

- The method of conditioning veneer peeler blocks and drying veneer.

- The method of preparing flakes and the geometry of flakes produced.

- The amount of fines contained in or removed from dried flakes.

- The moisture content of dried flakes.

- The method of blending flakes with resin and wax.

- The method of forming (single or multiple heads) and orienting flakes in the mat.

- The flakeboard press times, temperature, speed of closure, pressure, and method of controlling thickness (with or without stops).

2.2 Testing Management and Records

2.2.1 Manufacturer's Responsibilities.--The manufacturer shall be responsible for the day-to-day quality of the product. The manufacturer shall employ qualified inspectors to perform the quality-control functions and to prepare records showing the results of quality-control tests. The manufacturer shall keep records of each day's production for at least 1 year.

2.2.2 Auditor's Responsibilities: Testing performed by the manufacturer.--The auditor shall review the records kept by the manufacturer to determine that quality of the product is being maintained. The auditor shall approve the qualifications of all applicants for quality-control positions with manufacturing firms; once quality controllers are hired, the auditor shall train them to perform all quality-control tests prescribed in this standard. The auditor shall make random, unannounced visits to the production facility to check quality control at least 12 times each year. During these visits the auditor shall select the quality-control samples to be tested for at least one shift of production and shall perform all of the daily quality-control tests required by this standard. The auditor shall provide a copy of the audit, which shall become part of the manufacturer's quality-control files.

2.2.3 Auditor's Responsibilities: Testing performed by the auditor.--The manufacturer has the option of contracting with the auditor to perform all quality-control functions. When the auditor rather than the manufacturer's employees performs all quality-control functions, the auditor may conduct tests either at the mill or at the auditor's laboratory, as agreed upon by the manufacturer and auditor. When testing is done in the auditor's laboratory, the manufacturer shall select the samples and ship them to the auditor's laboratory no less frequently than once a week, and the auditor shall also make random, unannounced visits to the mill to select samples for testing. The manufacturer shall hold that portion of production represented by the quality-control samples until the auditor completes the test and verifies the product's conformance to the standards.

2.2.4 Quality-controller's responsibilities.--The quality-control supervisor must notify the mill production superintendent immediately whenever quality of the product is found to be unacceptable.

3.0 Testing and Assurance: General Procedures

3.1 Principal Objective

The integrity of COM-PLY framing depends on the quality of adhesion between its components. Unsatisfactory adhesion seriously reduces the quality of the product, especially its durability and dimensional stability. A principal objective of quality control is to check daily the quality of the adhesive bonding of all components.

3.2 Sampling Unit

The basic quality-control sample for daily tests shall be a nominal 8-foot unit. The unit shall be cut as indicated in figure 1 into test specimens for monitoring the bondline, thickness swelling, joint strength, and flakeboard MOR, MOE, density, internal bond, and shear strength. Select units following the procedures prescribed for performance testing (see Part III, section 3.2), except that moisture content of the component shall be 6 ± 2 percent, the typical range immediately after fabrication.

3.3 Sample Size and Rate

Quality controllers shall monitor quality by testing at a rate of three units per shift per press line, or 0.02 percent of production, whichever is greater, for intensive sampling and one-third that rate for normal sampling. The mill shall supply the auditor with information on production volume. A normal rate of sampling is permissible if the results of daily tests indicate acceptable quality. Use the average value from daily quality tests as a basis for trademarking the product. If the quality drops below acceptable levels, quality controllers shall notify the mill production supervisor, and sampling shall proceed at the intensive rate. Average test values for a sample size of at least nine units shall be used as a basis for determining the quality levels (acceptable, warning, and unacceptable). When sampling at a normal rate, use a moving average for the nine units most recently tested for the daily average test value.

3.4 Test Unit Layout

The test specimen layout in figure 1 is arbitrary and not fixed. The location of the veneer joint (F) and core joint (G) specimens is critical because each of these specimens must contain an approximately midlength joint. Cut these specimens from the unit first. Next, the specimen for MOR, MOE, and density of the core (H) should be cut from the unit because of its critical length. Next in order are the specimens for thickness swelling and water absorption (E), veneer bond and core shear (A, B, C, D, K, and L), and, last, flakeboard internal bond (I and J).

3.5 Setting Standard Levels for Daily Tests

Use 30 units to establish the initial quality-control levels for each product as standard levels for daily tests, excepting only those for strength and durability. Incorporate the average values from these initial tests in the product specification. Randomly select the units used for determining the standard level from the same production runs used to establish product performance. Base the daily quality-control values on three consecutive shifts of production (not necessarily occurring in one day), with specimens cut from a minimum of nine basic units for intensive sampling or three basic units for normal sampling.

3.6 Quality-Control Levels

There are three levels of results for all daily quality-control tests.

3.6.1 Acceptable.--When test results are acceptable, the manufacturer is entitled to trademark the framing.

3.6.2 Warning.--When test results fall below the acceptable levels but do not drop to the unacceptable level, quality controllers shall warn the production superintendent that quality is falling below standard.

3.6.3 Unacceptable.--When test results fall to unacceptable levels,

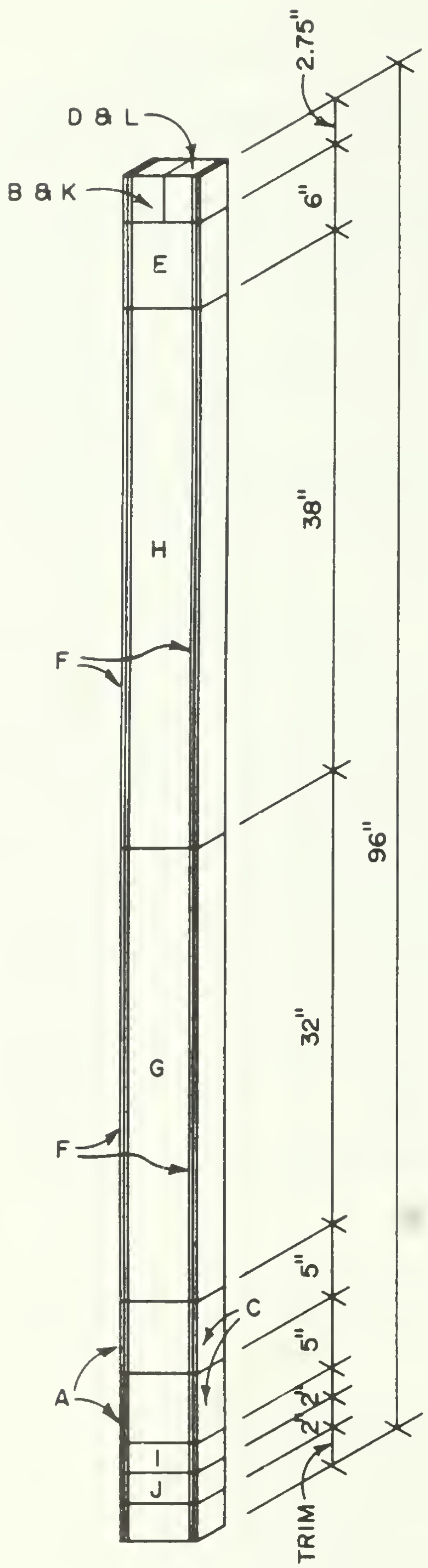

Figure 1.--Guide for cutting the basic quality-control unit.

Specimens for testing:

A = Bondline for veneer-to-veneer dry shear

B = Bondline for veneer-to-core dry shear

C = Bondline for veneer-to-veneer wet shear

D = Bondline for veneer-to-core wet shear

E = Thickness swelling and water absorption

F = Tensile strength of joint in veneer

G = Bending strength of joint in core

H = MOR, MOE, and specific gravity of core

I & J = Internal bond

K = Dry shear in the core

L = Wet shear in the core

Note: Unit shown is a 2 x 4 with two outer veneers on each edge.

quality controllers shall notify the production superintendent that the quality of the product is unacceptable and cannot be trademarked.

4.0 Testing and Assurance: Daily Test Procedures

4.1 Laminating Adhesive Veneer-to-Core Bond and Core Shear Strength

Cut one piece 2-3/4 inches long from the basic quality-control unit (B & K and D & L). Cut this piece further into two pieces as indicated by the "cut" line in figure 2. Then prepare block shear specimens from the left and right portions of each 2-1/2-inch-long piece cut from the unit. Place one of the block shear specimens (D & L) in a vacuum-pressure vessel and submerge in water at 70 ± 30 °F. Draw a vacuum of 25 inches of mercury on the vessel and maintain for 10 minutes. Then release the vacuum and place a pressure of 75 psi on the vessel for 50 minutes. Repeat the vacuum-pressure cycle. Use this water-soaked specimen in tests of the flakeboard and of the veneer-to-core bondline for shear strength and wood failure in the wet condition. Use the other block shear specimen in tests of the flakeboard and of the veneer-to-core bondline for shear strength and wood failure in the dry condition. For block shear tests, follow the method specified in ASTM D 905-49(81), ¶2, ¶7.

An average dry-block shear strength below 500 psi and wood failures below 80 percent are unacceptable. An average wet-block shear strength below 250 psi and wood failures below 70 percent are unacceptable. An average shear strength and wood failure values of at least 90 percent are acceptable.

4.2 Thickness Swelling and Water Absorption

Cut one specimen (E) 6 inches long from the basic quality-control unit. Test the specimen for swelling of the flakeboard core and water absorption by using the procedures in ASTM D 1037-78, ¶102 to ¶106 as a guideline. Average thickness swelling and water absorption values that are no more than 10 percent higher than the standard level are acceptable. An average more than 20 percent higher than the standard level or more than 14.4 percent, whichever is larger, is unacceptable.

4.3 Joint Strength

This test is not required if butt joints are used in both the veneer and flakeboard core components. If butt joints occur in one component but not the other, the test is required only for the component containing the glued structural joint. A glued structural joint may be a scarf, finger, stepped-scarf, tongue-and-groove, or other type joint used to improve structural performance of the product. In figure 1, specimen G is for testing joints in flakeboard cores and specimen F is for testing joints in veneer laminates that contain glue structural joints at midlength of the test specimens.

Cut away the veneer laminates on each edge of part G and either discard or use for part F. Following the procedures described in ASTM D 198-84, ¶4 to ¶9, load specimen G in flatwise bending. Use two-point loading with load points a minimum of 2 inches outside of the joint area. Check that the span-depth ratio of specimen G is at least 14 to 1 but no more than 20 to 1.

Average daily tests of flatwise bending strength (MOR) of flakeboard cores containing glued structural joints that are at least 90 percent of the standard levels are acceptable. Daily averages that drop below 80 percent of the standard are unacceptable.

Cut part F from the edge of the flakeboard core along parts G and H as shown in figure 1. Then cut end joint tension specimens from individual veneer laminates within part F as shown in figure 3. Take one specimen for each laminate glued to a single edge of a sample unit. For example, a nominal 2 x 4 having two veneer laminates glued to each

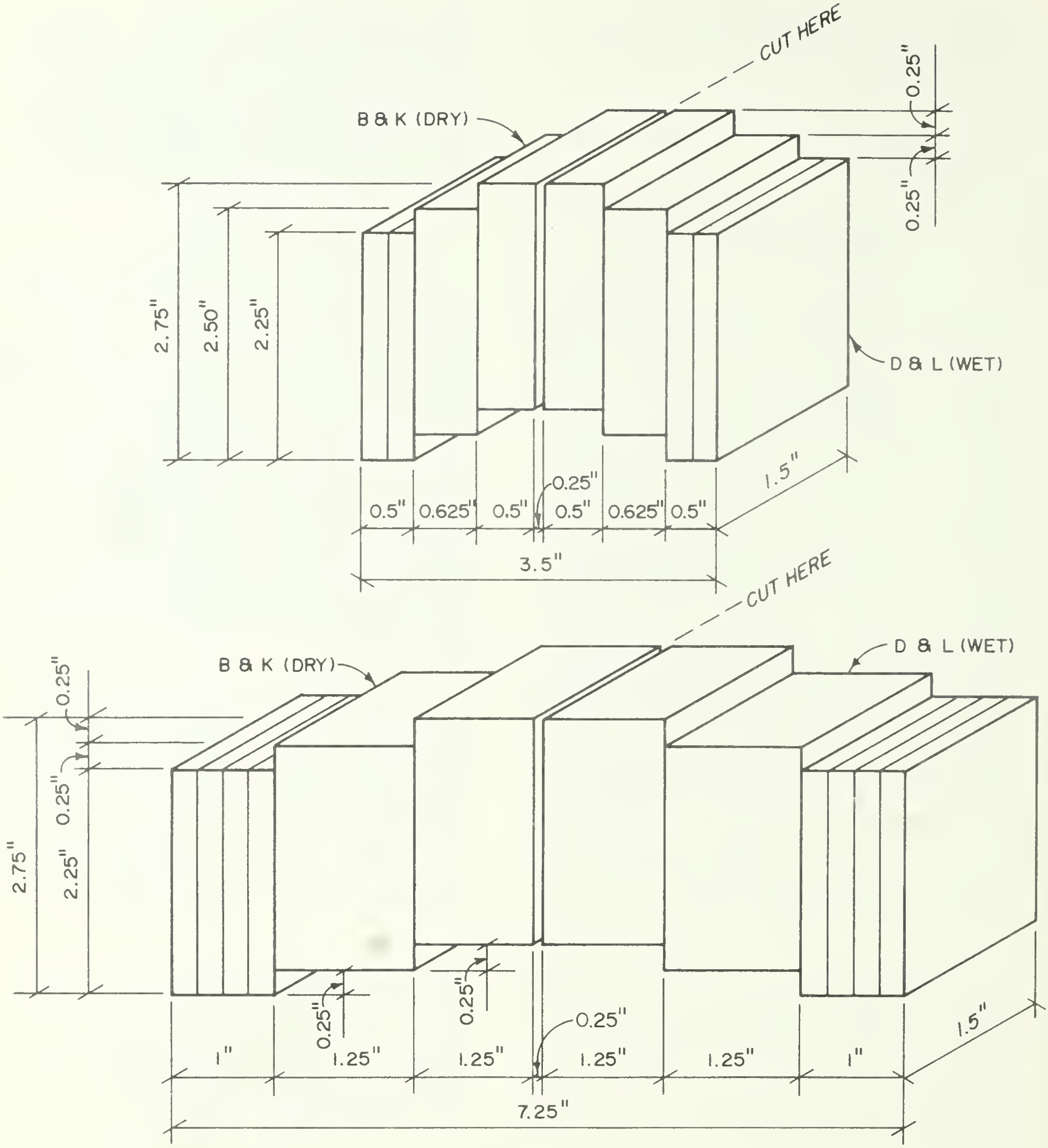

Figure 2.--Guide for cutting specimens for evaluation of dry and wet block shear strength of veneer-to-core bondline and flakeboard core. Specimen for 2 x 4 member is above, and specimen for 2 x 8 member below.

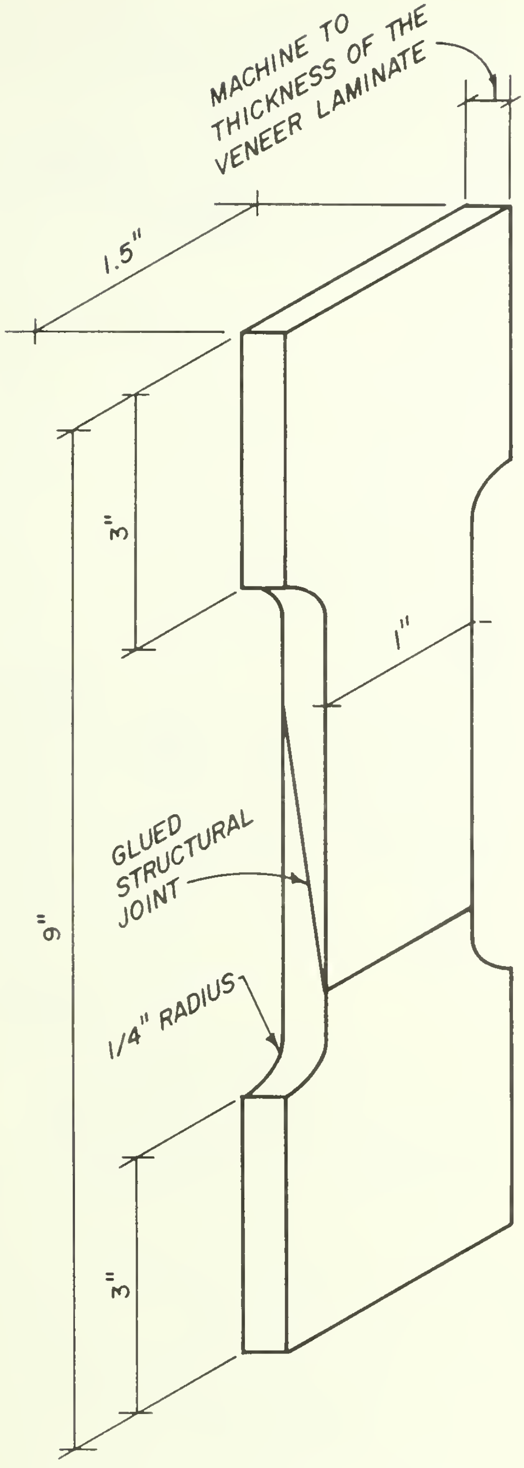

Figure 3.--Guide for cutting tne specimen for evaluating dry tensile strength of joints in veneer laminates. Specimen is F in figure 1.

edge, or a total of four laminates, would require two test specimens, one from either of the two outer veneers and one from either of the two inner veneers.

Machine the specimen to a thickness of the veneer laminate, taking care to maintain a uniform thickness of specimen and to remove veneer or flakeboard on either face that would affect tensile strength of the specimen. Discard specimens containing knots, burls, extensive cross-grain, or holes that severely reduce tensile strength of the wood; be certain that in other respects the specimen is representative of production.

Test the specimen in tension by using the procedures in ASTM D 2339-82, ¶6 and ¶8. Jaws of the tension fixture should grip the specimen not closer than 0.5 inch from the necked-down portion.

To establish standard levels, make a set of 30 specimens not containing a glued structural joint, as shown in figure 3, and test in tension for each species of veneer used in the product. To establish the standard for the quality of bond for end joints in the veneer, average the ultimate tensile stress psi (g/cm^2) of the 30 specimens.

Average daily test results for ultimate tensile stress for wood failure that reach at least 80 percent of the standard values are acceptable. Daily averages that drop below 70 percent of the standard are unacceptable.

4.4 Modulus of Rupture, Elasticity, and Specific Gravity of the Flakeboard Core

Cut one piece 38 inches long (H) from the basic quality-control unit. Cut away the veneers from each side of the flakeboard core and use them for part F or discard. Next, cut the width of the piece to 3 inches (2.5 inches for nominal 2 x 4's) and the length to 24 times the depth plus 2 inches. Determine the specific gravity MOR, and MOE, and by using the procedures in ASTM D 1037-78, ¶9, ¶11 to ¶20, with these exceptions: test only conditioned specimens and none that are soaked. It is permissible to use an incremental load known to be below the proportional limit in lieu of the proportional limit load to calculate MOE. The load-deflection curve need not be plotted.

Average values of flakeboard MOR and MOE that are at least 90 percent of the standard levels are acceptable. Average values that drop below 80 percent are unacceptable.

Average values of flakeboard specific gravity that are at least 95 percent of the standard levels are acceptable. Average values that drop below 90 percent are unacceptable.

4.5 Internal Bond of Core

Cut two sections 2 inches long (I and J), from the basic quality-control unit. Reduce these two pieces from the unit width to 2 inches by removing an equal amount of veneer and flakeboard along each edge so that the final size is the thickness of the piece (approximately 1-1/2 inches) by 2 inches square. Test the specimens for internal bond using the procedures in ASTM D 1037-78, ¶28 to ¶31.

Average internal bond values that are at least 90 percent of the standard levels or 80 psi are acceptable. Average values that drop below 70 psi are unacceptable.

4.6 Laminating Adhesive Veneer-to-Veneer Bond

Cut pieces either 4 or 5 inches long from the laminated veneer portion of the basic quality-control unit (A and C). Cut additional pieces from part F as needed. Prepare two sets of tension shear specimens from the pieces, as shown in figure 4. The larger specimen (1-1/2 inches by 5 inches) is preferable to the smaller specimen (1 inch by 4 inches) if large tension grips are available. Cut away waste veneer or flakeboard removed when preparing the specimen with a smooth cutting saw to eliminate points of stress concentration; make the cut as close as practically possible to glue lines on the outer facings of the specimen. Prepare one specimen for each glue line in a piece, one set of specimens for dry testing, and one set for wet testing. Place the tension shear specimens for wet testing in a vacuum-pressure vessel and submerge in water at 70 > 30 °F. Draw a vacuum of 25 inches of mercury on the vessel and maintain for 10 minutes. Release the vacuum and place a pressure of 75 psi on the vessel for 50 minutes. Repeat the vacuum-pressure cycle. Test these water-soaked tension shear specimens for shear strength and wood failure in the wet condition. Test the remaining tension shear specimens for shear strength in the dry condition. Follow procedures for making the tension shear test as specified in ASTM D 2339-82, ¶6, ¶8.

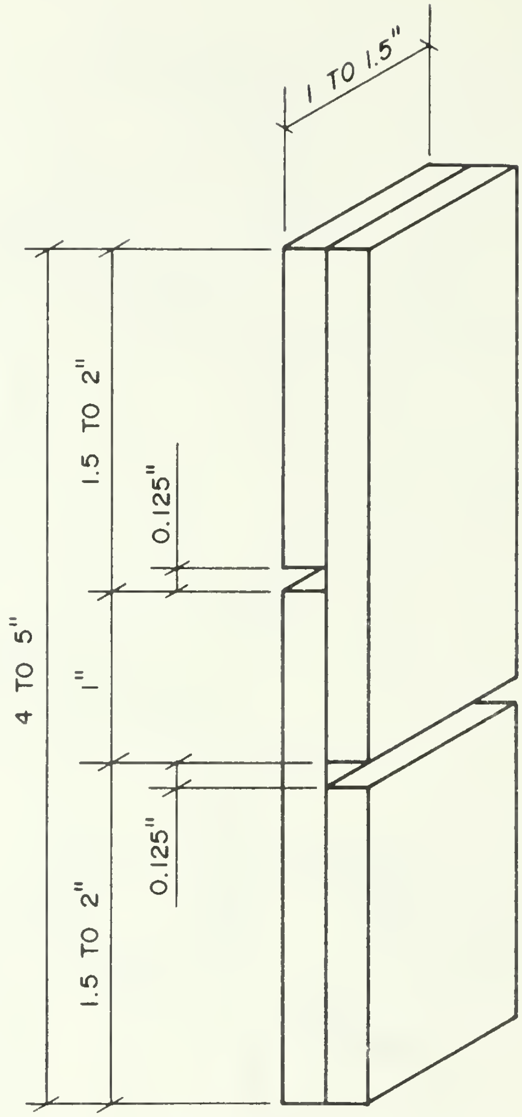

Figure 4.--Guide for cutting the tension shear specimens for testing the quality of laminated veneer-to-veneer adhesive bond. Specimens shown as A and C in figure 1.

Average dry tension shear strength less than 800 psi and wood failures less than 70 percent are unacceptable. Average wet tension shear strength less than 400 psi and wood failures less than 70 percent are unacceptable. Average daily shear and wood failure values that are at least 90 percent of the standard values are acceptable. Average values that drop below 80 percent are unacceptable.

4.7 Truss Plate Lateral Fastener Resistance

The manufacturer of the plates shall select one well-established brand of pressed-in-tooth-type truss plates to use as the standard for quality control. To determine the standard level for quality control for framing to be marked for use as truss framing, test 30 specimens, as required by the performance standard. Fabricate test specimens from truss framing randomly selected from production runs. Average results of tests for ultimate load per tooth, plug, or square inch of truss plate that are at least 90 percent of the average for the standard level are acceptable. Average values that drop below 80 percent are unacceptable. Apply this test only to framing marked for use in truss framing.

5.0 Testing and Assurance: Periodic Test Procedures

5.1 Quarterly Monitoring for Strength and Stiffness

Select for testing 10 specimens every quarter-year in accordance with procedures for determining edgewise bending strength and stiffness. Use the average values from these quality tests as a basis for trademarking the product, for determining that performance has dropped below acceptable levels, and for withdrawing trademarking privileges or for requiring a complete retesting.

Although it is important to check strength performance quarterly, it is not necessary to check all of the strength attributes covered in the performance standard. Only the edgewise bending strength and stiffness properties need be checked quarterly to determine if strength properties of the product are being maintained. Use a sample size of 10 pieces. Follow the procedure used in the performance standard to establish the bending stress F_b and MOE E_b (see Part III, sections 3.4.1 and 3.4.2). If the MOR and MOE of the quality-control sample are within 10 percent of the values developed in the performance evaluation that established the working stresses for bending strength and stiffness, performance is acceptable.

If either the MOR or MOE of the quality-control samples is more than 10 percent lower than the performance values used to establish working stresses, the quality controllers shall notify the superintendent that process methods or materials must be changed to ensure that working stresses marked on the product are maintained. Followup action by the production superintendent and quality controllers are described in Part II, section 4.2.2.

If either the MOR or MOE of the quality-control sample is more than 15 percent lower than the performance values used to establish working stresses, the quality controllers shall notify the production superintendent to cease trademarking the product. Reinstatement procedures are described in Part II, section 4.2.3.

5.2 Semiannual Monitoring of Durability

Check the durability of the COM-PLY product semiannually, or for each 6 months of production, using a sample size of 10 pieces. Follow the same procedure used in the performance standard for durability (see Part III, section 4.0). Aged specimens should have at least 50 percent of the strength and stiffness of the unaged specimens that were used to establish product performance. If data from the original durability performance tests are not available, use a second sample of 10 unaged specimens as controls.

Aged specimens that have retained less than 50 percent of either the unaged strength or stiffness are unacceptable.

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Performance and quality-control standards. Gen. Tech. Rep. SE-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1985. 20 pp.

Users must be assured that composite structural members are satisfactory for their intended purposes. Standards are provided for strength, stiffness, durability, and dimensional stability of composite floor, wall, and truss-framing members. Methods for enforcing compliance with the standards are suggested.

Keywords.--Strength, stiffness, dimensional stability, durability.

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The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

United States
Department of
Agriculture

Forest Service

Southeastern Forest
Experiment Station

General Technical
Report SE-34

Technology Transfer in Integrated Forest Pest Management In the South

TECHNOLOGY TRANSFER IN INTEGRATED FOREST PEST MANAGEMENT IN THE SOUTH

Gerard D. Hertel, Susan J. Branham, and Kenneth M. Swain, Sr., Editors

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Southeastern Forest Experiment Station
Asheville, North Carolina

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A synopsis of the technology transfer activities of the Forest Service's Integrated Pest Management Research, Development and Applications Program for Bark Beetles of Southern Pines, and the Southern Region, 1980-85, with emphasis on State demonstration projects and user involvement.

KEYWORDS: Research and development; technical information; information management; research applications; technology transfer; information systems; multimedia packaging; demonstration projects.

PREFACE

A large number of State and Federal experiment stations, universities, and Federal, State, and private resource management organizations have participated in the USDA Forest Service's Integrated Pest Management Research, Development and Applications Program for Bark Beetles of Southern Pines (IPM Program) and in Southern Region-sponsored State demonstration projects since 1980. The objectives of both of these accelerated efforts have been to more fully utilize available knowledge and to develop or improve and demonstrate methods for detecting, evaluating, predicting, preventing, and suppressing losses due to the five bark beetle species and three tree-killing pathogens affecting southern pines.

Nearing the completion of the IPM Program, we thought it appropriate to review and synthesize the results of the transfer efforts of the IPM Program and the Southern Region. Activities during the past 5 years have concentrated on planning, executing, packaging, and disseminating a substantial amount of new or improved technology. This involved individual and collective efforts of many Federal and State pest management and forestry specialists as well as those of representatives of Federal, State, industry, and university organizations who developed the technology or provided advice on its use.

The information presented here is for the benefit of those interested not only in the approach that was used in technology transfer but also in the results from a variety of transfer activities across the South. The IPM Program and Southern Region Forest Pest Management staffs are indebted to this publication's editors and the chapter authors for their contributions.

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BACKGROUND AND APPROACH

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Occasionally, regional or national problems arise that require and benefit from accelerated research and development efforts. Such programs are usually undertaken in response to the need for more adequate technology to deal with a specific issue. Large numbers of individuals in many disciplines and organizations are brought together to address the topic of concern. Within the established time frame, research, development, and applications activities are completed and the new technology incorporated into operational programs as rapidly as possible.

This report describes how one such accelerated effort provided more effective ways of dealing with a regional problem involving five bark beetle species and three tree-killing diseases affecting southern pine forests, and how this information was delivered to its ultimate users through an aggressive technology transfer effort.

BACKGROUND

In the early 1970's, the southern pine beetle (SPB) was in epidemic status across the South. Resource managers and landowners expressed a need for new or improved means for dealing with this pest. Robert Long, then Assistant Secretary of Agriculture, asked the U.S. Department of Agriculture's Cooperative State Research Service and the Forest Service to pool their resources to plan and undertake an aggressive research and development program. Congress appropriated funds for this purpose in fiscal year 1975, and the 5-year Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP) was initiated in February of that year.

The next 5-1/2 years of the ESPBRAP significantly advanced our understanding of SPB populations and the forests in which they occur. Federal, State, university, and industry specialists worked together to provide new or improved methods for dealing with this major regional pest problem.

Continuing interest and support led to approval of a second 5-year accelerated program in fiscal year 1981. The Integrated Pest Management (IPM) Research, Development and Applications Program for Bark Beetles of Southern Pines was charged with completing and transferring the technology resulting from ESPBRAP and developing new or improved methods for dealing with a complex of bark beetles and tree-killing diseases affecting southern pines. This complex comprises southern pine beetle, three species of *Ips* engraver beetles, black turpentine beetle, fusiform rust, annosus root rot, and littleleaf disease. (For scientific names, see appendix I.)

IPM PROGRAM GOALS AND OUTPUTS

The Southern Region of the Association of State College and University Forestry Research Organizations (now known as the National Association of Professional Forestry Schools and Colleges) and the Forest Service organized a planning team in 1978 to identify current and future forest pest research and application needs in the South. Their report was further reviewed and commented upon by State, Forest Service, consulting, and industrial representatives. A technical committee was subsequently appointed to develop a 5-year plan that would guide the conduct of research, development, and applications efforts. That document was, in turn, reviewed by researchers, specialists, foresters, and administrators representing the southern forest research and applications community.

The resulting plan was structured around six target areas. Program management later described 17 measurable outputs (see appendix II, item 1) and one or more research or application final products for each output. The outputs were further defined for each funded project. An assessment was made as to how these project outputs contributed to the completion of specific Program final products and to whom (specific user groups) the completed technology should ultimately be directed.

AUDIENCE IDENTIFICATION

The users of technology developed through the IPM Program were defined primarily as owners and managers of pine timberlands. Program management recognized early that it was neither possible nor desirable for the Program to deal directly with this entire group. It was clear that many forestry organizations already had effective means for communicating with their clients. The Program, therefore, targeted as its direct audience the State and Private Forestry Organization of

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the Forest Service's Southern Region. Secondary organizations included National Forest and other Federal agency regional offices, State forestry organizations, the Cooperative Extension Service, and major timber companies with pest management specialists. Their communication network capabilities permitted the Program to direct new technology to a fairly limited number of organizations who, in turn passed it on in original or revised form to a large number of landowners and managers in the South with whom they already had professional contacts. This distribution system is illustrated below:

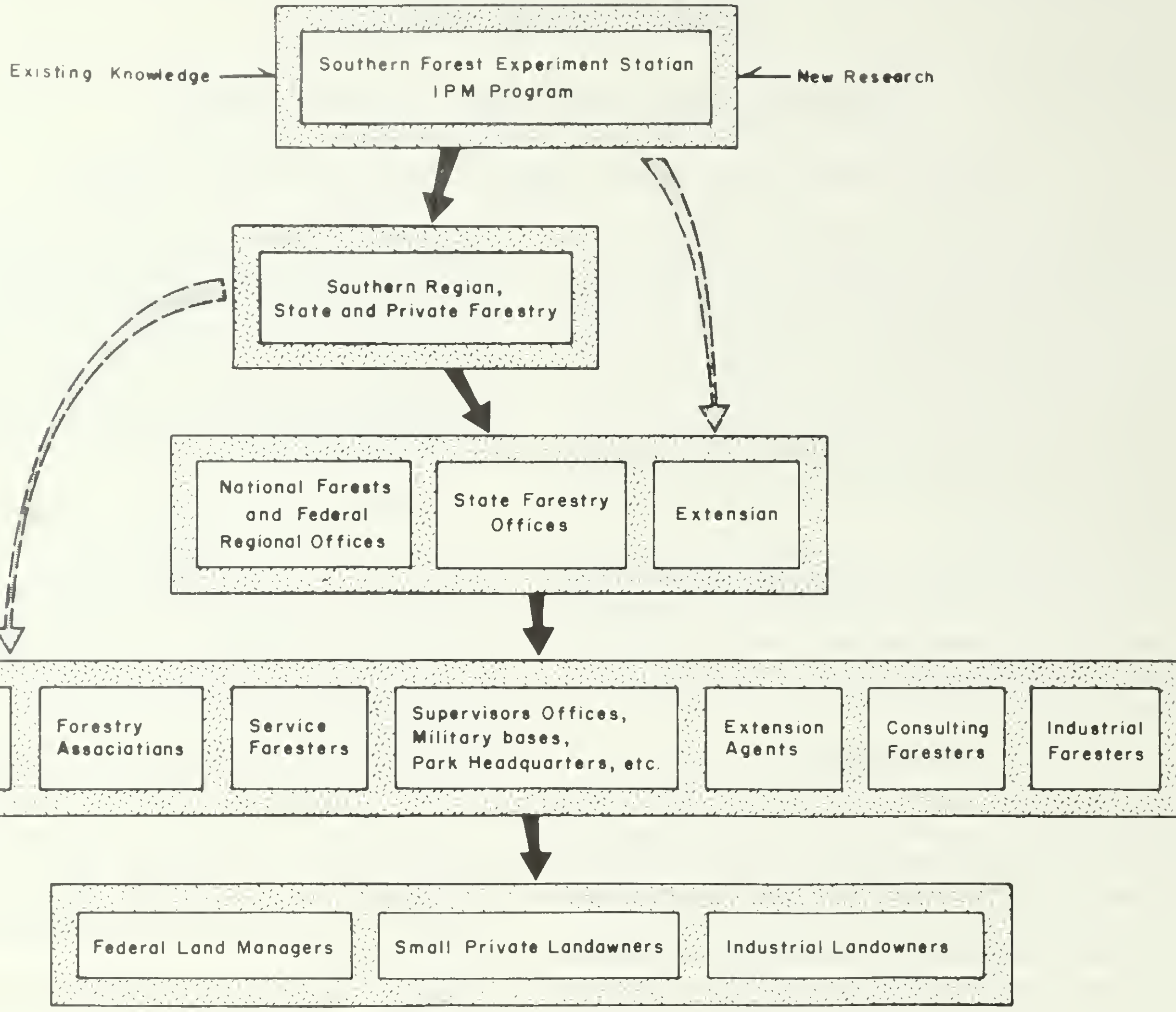

Figure 1—Flow of new technology from the IPM Program to various users in the South.

TECHNOLOGY TRANSFER APPROACHES

Several approaches were employed to provide research and development results to transfer agents and, on occasion, directly to forestry users. An abbreviated but very effective means of keeping a large audience informed on a very timely basis was through the Program newsletters—the Southern Pine Beetle News (ESPBRAP) and Pest Management News (IPM). On the average, 4 to 6 newsletters were mailed out to 2,000-plus readers each year. Other approaches included direct user involvement in the planning and execution of R&D projects; the preparation of technology transfer plans as a part of R&D proposals; involvement of R&D investigators in the technology transfer process (e.g., involvement in technology transfer teams, field and pilot studies); preparation, packaging, and delivery of written and visual materials to specialists and organizations; participation in training and professional society activities; and "hands-on" experience with computerized information management and decision support systems as well as involvement in the organization and conduct of demonstration projects.

Technology Transfer Plans

Funded investigators submitted an applications plan as part of their original plan of work and budget (see example in appendix III). In these plans, investigators interacted with potential users and learned to recognize that the effective transfer of knowledge from research to use involves six steps: 1) Defining the message (what do we want to say?); 2) defining the audience (with whom do we wish to communicate?); 3) defining the objective(s) (why do we want to reach the

Figure 2—Planning for the transfer of knowledge from research to application.

audience and when?); 4) defining the working team (who will be most effective in communicating the message?); 5) defining the media (what methods of communication will be used?); and 6) defining the evaluation criteria (was the transfer successfully completed?).

User Involvement

As part of the technology transfer plan, investigators were encouraged to identify the users or user groups to whom research products would be directed and to involve them in the planning and execution of the research. This involvement ensured that the final product would be "user compatible." It also greatly accelerated the technology transfer process because little modification was required for immediate application and users had confidence in the technology through their own involvement in its development.

Encouraging user involvement also resulted in closer working relationships among researchers who were themselves often users of research products. It also allowed close collaboration with Federal and State pest management specialists in plot selection, data collection, and interpretation of results, and it facilitated commitments of additional industrial, State, and Federal manpower and other resources to accomplish larger tasks that would otherwise be impossible with limited resources.

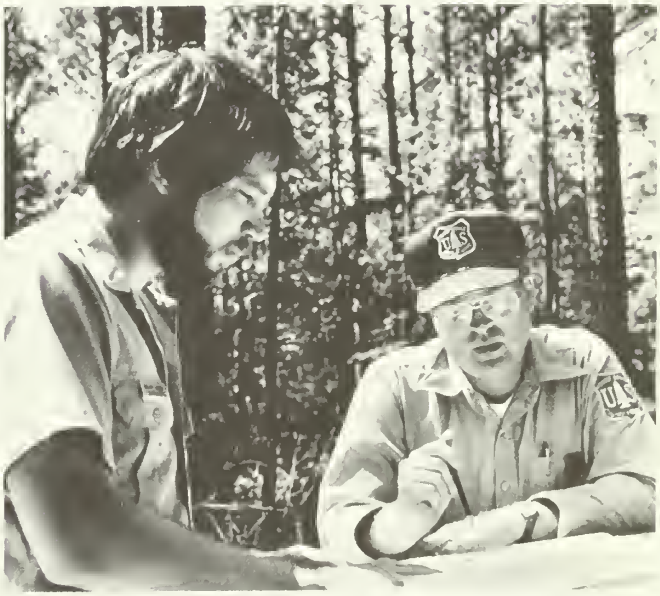

Figure 3—Collaboration between Federal foresters in plot selection and data collection.

Investigator Research and Development Activities

In addition to involving users directly in planning research and development activities, investigators were encouraged to participate in local professional society activities, to chair or participate in working group or technology transfer team activities, or to develop user-oriented audio-visual programs, publications, management guidelines, or other training aids in order to accelerate the packaging and/or distribution of results from each project.

Technology Transfer Teams

Experience in ESPBRAP revealed that technology transfer teams can be effectively used to facilitate the exchange of ideas, identify research results ready for transfer, devise innovative approaches for developing and disseminating information, and identify individuals most capable of carrying out these responsibilities. To a lesser extent, this idea was used in the IPM Program. Technology transfer teams active during ESPBRAP and the IPM Program are listed in appendix II, item 2.

Preparation and Packaging of Materials

Often good information fails to reach an intended audience because it is not properly packaged. Program management in ESPBRAP and IPM used many approaches to package or otherwise display and make available the results from research and development activities. These are tabulated in appendix II, item 3.

A complete listing of USDA Forest Service publications and visual aids developed with ESPBRAP, IPM, and S&PF support is presented in appendix II, item 4. The availability of these materials has been widely publicized in the professional forestry media. The Southern Region took responsibility for distributing all Agriculture Handbooks and southern pine beetle fact sheets; the ESPBRAP and IPM Programs distributed Technical Bulletins, General Technical Reports, and Program newsletters.

Some of the more applied Agriculture Handbooks have been assembled in a three-ring, indexed binder titled the "Forester's Handbook for Reducing Bark Beetle and Disease-Caused Losses in Southern Pines." This notebook has been distributed to State, industrial, and Federal foresters, and Federal and State pest management specialists. It has proven very useful, and its widespread popularity has led to further reproduction and distribution under the auspices of the National Association of State Foresters through the Texas Forest Service.

The IPM Program has given special emphasis to using popular journals to reach southern foresters. A partial listing of professional journals in which articles have appeared includes the *Southern Lumberman*, *Southern Journal of Applied Forestry*, *Forest Farmer*, *The Consultant*, and *Forests and People*. (See specific references in appendix II, item 4.)

Figure 4—Handbooks, newsletters, technical bulletins, and fact sheets transfer results to the user community.

Figure 5—"The Forester's Handbook for Reducing Bark Beetle and Disease-Caused Losses in Southern Pines."

Training of Specialists

As the end of the IPM Program approached, it became apparent that there was a need to make State, Federal, and Extension specialists aware of the computer- and noncomputer-based models and procedures developed by researchers over an 8-year span of the two accelerated programs. A listing of what were considered the most useful models by categories was prepared (appendix II, item 5). The physiographic regions in which the models could be used were then identified. A 3-ring administrative training manual was developed—"Predicting Southern Pine Beetle and Disease Trends" (Mason, Hertel, and Thatcher 1985)—that contained a summary (description, inputs, outputs, accessibility, sources of additional information) for each model. This served as the main reference source for informal training of Federal and State pest management specialists. The notebook was updated semi-annually and distributed to a broader audience in mid-1985.

Three formal training sessions were held in early 1984—in Georgia, North Carolina, and Louisiana. A total of 22 specialists attended. Practical examples were used and, where appropriate, each attendee had hands-on experience at a computer terminal. Following the training, the specialists were asked to use the information themselves, pass it on to others in their States or areas of operation, and provide feedback to developers for modification or improvement.

Participation in Professional Society, Association and Landowner Meetings

The Program management team in both ESPBRAP and IPM and cooperating State and Federal pest management specialists have made an effort to highlight new technology by developing and presenting displays with special themes at forestry-related meetings throughout the South. A special effort has been made to reach foresters through their annual State or regional Society of American Foresters or forestry association meetings (Texas, Louisiana, Mississippi, Southeastern, and Appalachian Society of American Foresters) and one SAF regional technical conference (held in Baton Rouge, LA, in 1982). Team members also presented papers at several national and regional symposia and workshops.

Information Management and Decision Support Systems

A broad array of computer models for assessing timber growth, beetle and disease impact, host-pest interactions, and management actions was developed or assembled through the two successive Programs. (A partial list is presented in appendix II, item 5). The large number and complexity of models and variation in their geographic applicability made knowledge of their availability, access, and operation difficult for users. To heighten user awareness and encourage application of the new technology, it was apparent that an urgent need existed to properly package and streamline means for gaining access to the systems. Several computer models were produced to make this information more accessible, interpretable, and user-friendly. These included the Integrated Pest Management Decision Key, the Southern Pine Beetle Decision Support System, CLEMBEETLE, and ITEMS (Integrated Timber and Economic Management Simulator).

The **Integrated Pest Management Decision Key** (IPM-DK) was independently developed by pest management specialists in the Southern Region and Southeastern Station (Anderson and others 1982), which contributed greatly to the technology transfer needs of the IPM Program. The IPM-DK is an interactive, user-friendly, microcomputer program that lists pest management options for the southern pine beetle, annosus root rot, fusiform rust, littleleaf disease, and other tree pests. The program considers environmental factors, economics, geographic location, pest interactions, and a variety of management options. New information can be incorporated into the system as it becomes available without waiting for final publication.

The **Southern Pine Beetle Decision Support System** (SPBDSS) developed at Texas A&M (Saunders and others 1985) is an interactive mainframe computer system designed to help decisionmakers use computerized and noncomputerized information to solve relatively unstructured questions. This system is capable of selecting and operating models in several subject areas—impact, population dynamics, economics, utilization, and stand growth and yield. Information provided permits the manager to make better decisions concerning different management situations.

The SPBDSS can be used in a number of ways. It can serve as a retrieval system to access data and models in response to user requests. Any model can be accessed and run independently. It can also be used to identify and select model(s) that would provide information most applicable to the user's local situation. The user can then access, sequence, and run the models of interest to obtain answers to his questions. Finally, the DSS can provide automatic selection and sequencing. After a question is asked, the DSS leads the user through a series of prompts, selects appropriate models, asks for necessary input data, runs the models, and displays the output. To date, 36 models dealing with southern pine beetle population dynamics, host tree dynamics, stand hazard rating, economics, impact evaluation, and utilization have been assembled and made available for the retrieval and model identification/ selection processes described. Twelve models have been interactively webbed together for automatic processing.

CLEMBEETLE was developed at Clemson University (Hedden 1985) to simulate losses from bark beetles and the effects of management practices on single or multiple stands for periods as short as a year or as long as a rotation. The program consists of a series of submodels for estimating the probability of southern pine beetle spot occurrence, the number of trees killed as a result of spot growth, the growth of timber stands, and the effect of stand treatment on timber growth and beetle impact. The program can be run on a mainframe computer or on one of several microcomputers—Radio Shack TRS 80, Apple II, or IBM-PC.

ITEMS (*I*ntegrated *T*imber and *E*conomics *M*anagement *S*imulator) is designed to simulate the performance of pine stands under varied management regimes and beetle infestation levels (Vasievich and Thompson 1985). The model's primary application is to test the economic effects of such management activities as site preparation, stand establishment, partial cutting, harvesting, and type conversion. The model projects the development of one or more stands over a period of years and contains components for cost and revenue projections for various management practices as well as routine accounting functions. Output is in the form of reports for each year of simulation.

The Fusiform Rust Yield−Slash model (Nance and others 1985) was developed at the Southern Forest Experiment Station to predict yields for unthinned slash pine plantations infected with fusiform rust. The system is an interactive, user-friendly, computer program that can be accessed on Forest Service Digital or Data General computers. Rust mortality functions were developed from data collected in six Southern States and incorporated into an existing stand growth and yield model, *U*nthinned *S*lash and *L*oblolly *Y*ields for *C*utover *S*ites in the *W*estern *G*ulf (USLYCOWG). The model requires rust level input at age 5 and predicts timber yields by diameter class at rotation age. A similar model is being developed for unthinned loblolly pine plantations infected with fusiform rust.

Demonstration Projects

The IPM Program sponsored demonstration projects in Texas, Mississippi, Alabama, and South Carolina to provide a means for transferring new technology to forest industry, National Forests, consultants, and/or private, nonindustrial landowners. In addition to these projects, the USDA Forest Service's Southern Region State and Private Forestry provided additional funds over a 3-year period (1981−83) to develop, package, and deliver new or improved technology to landowners with small holdings in eight Southern States. All of these projects achieved a great deal in the area of technology transfer and showed that the demonstration approach is a very effective means for accomplishing it. The sections that follow summarize work funded by both the Integrated Pest Management RD&A Program and the Southern Region to develop, package, and deliver new technology.

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II. TECHNOLOGY TRANSFER THROUGH DEMONSTRATION PROJECTS

HAZARD RATING STANDS FOR SOUTHERN PINE BEETLE AND ANNOSUS ROOT ROT IN ALABAMA

James R. Hyland and Robert C. Kucera[1]

INTRODUCTION

The two major pests in Alabama's pine resource are the southern pine beetle (SPB) and annosus root rot (ARR). Annual mortality resulting from SPB outbreaks has been valued at an average of $8 million during the last 10 years. Annual mortality due to ARR has been valued at $2.2 million over the same period. ARR losses also include a 4 percent growth reduction of live, infected trees, and this growth loss coincidentally increases the SPB hazard. Management of the State's forests offers the best long-term approach for reducing these losses.

The TREASURE Forest Plan is an approach designed to help the Alabama Forestry Commission forester or ranger use the latest technical information to assist forest landowners with their management needs. Special efforts have been made to design the plan around a particular concept. The TREASURE concept focuses on forest management strategies that consider all resource values that are compatible with landowner objectives. These values include outdoor recreation, timber, watersheds, esthetics, forage, environmental protection, and wildlife.

The plan also offers advantages to the forester when assisting forest landowners. Being standardized, it enables the forester to provide a consistent service regardless of variables like career experience, landowners' knowledge, and geographic location. Also, it encourages the forester to consider all available resource opportunities and options. Greater cooperation with other agencies and resource managers can be enhanced through this broad approach. And, because of computer capabilities, the forester has access to current data on every aspect of forest management. Demonstration forests have been one means of highlighting this overall TREASURE concept.

The demonstration forests in Alabama are a cooperative effort among the Alabama Forestry Commission (AFC), the Extension Service, and the Soil Conservation Service (SCS). There are 34 demonstration forests statewide totaling 19,578 acres and ranging from 140 to 2,000 acres. These forests are used locally as training sites for landowner conferences on all aspects of forest management (fig. 1).

The IPM demonstration project on Alabama's TREASURE forests and private lands had seven primary objectives:

1. Identify the best SPB hazard-rating system for Alabama.
2. Use SPB hazard rating on demonstration forests.
3. Determine the presence of and map ARR in recently cut stands.
4. Field test the cubic-foot ARR system developed by Alexander at Virginia Polytechnic Institute and State University (VPI&SU).
5. Monitor SPB and ARR interactions.
6. Use SPB and ARR preventive control approaches in TREASURE Forest Plans.
7. Package and deliver SPB/ARR hazard-rating technology to foresters, consultants, and landowners.

APPROACHES TO MEETING THE OBJECTIVES

Selecting the Best SPB Hazard-Rating System

The Alabama Forestry Commission felt that demonstration forests were a good place to "get the word out" on hazard ratings. To do this, two foresters were hired to hazard rate each demonstration forest for SPB.

The necessary data were taken for six hazard-rating systems—MS Hazard A (Kushmaul and others 1979; Nebeker and Honea 1984); MS Hazard B (Kushmaul and others 1979; Nebeker and Honea 1984); Sader Hazard (Sader and Miller 1976); P Hazard GA (Belanger 1985; Belanger and others 1981); TX Hazard (Mason 1985; Mason and others 1981); and AR Hazard (Ku 1985; Ku and others 1981). Field data were taken on a five-chain grid designed to pick up "pockets" that might exist in a stand. The collected data were sent to Mississippi State University (Nebeker and Honea 1984) for analyses. At the same time, stands were rated for management plan purposes by using the TX Hazard and Sader Hazard systems. The TX Hazard system was used in the lower Coastal Plain and the Sader system in the rest of the State.

After 2 years of data collection and analyses by Mississippi State University, one system was determined to be best for Alabama. The Kushmaul B system was later modified by Nebeker and Honea (Mississippi State), and renamed "MS Hazard B." It identified five hazard classes. In Alabama, the revised system is called the Mississippi–Alabama (MS-AL) system, but in Mississippi it is referred to as "Mississippi Hazard B." Hazard classifications are obtained by calculat-

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Figure 1—Landowner field conference on forest and pest management

ing a discriminant score and determining which hazard class is associated with that score.

The MS-AL system uses the following inputs: 1) Pine basal area/acre, 2) stand age 3) site index, and 4) total basal area/acre. The hazard classifications are obtained by calculating a discriminant score and determining which hazard class is associated with that score.

Score = 1.8342 (pine BA) + 0.4085 (total BA) + 0.705 (age) + 0.88 (site index) − 206.315.

> 220 = Very high
168-219 = High
62-167 = Medium
11- 61 = Low
< 10 = Very low

Hazard Rating the Demonstration Forests

Each demonstration forest was rated using the TX Hazard and Sader Hazard systems and an overlap map of the SPB and ARR ratings and recommendations to lower the hazard rating of high-hazard stands were sent to the landowner. These data were added to the management plan. The data will be used for timber cutting, planning (priority setting), and monitoring potential SPB and ARR infestation sites. The demonstration area will also be used to train other local landowners.

Evaluating and Mapping ARR-Infected Stands

Nine of the 34 demonstration forests were selected to determine the best method for rating soils as high or low ARR hazard. Information on 26 soil types was collected using a tube sampler, SCS soil maps, and a combination of the sampler and maps. These data were then analyzed to determine the best method of classifying the soils.

Combining tube sampling in the field with hazard classification based on SCS soil series descriptions was found to be the best method for hazard rating soils. The tube sampling was limited to verifying the accuracy of the SCS maps. The soils were rated as high or low hazard based on internal drainage and texture, mainly in accordance with the procedure developed by Koenigs (fig.2).

In the case of soil associations in which both high and low ARR hazard soils were combined in a mapping unit, the forester could rate the entire area as high or low ARR hazard. In this study, soil associations having both high-and low-hazard soils were classified as high ARR hazard. This was a conservative approach that focused landowner attention on prevention. It was felt that the absence of preventive action where it might be needed could result in greater potential loss.

As a result of this work, it was concluded that the best method of hazard rating stands for ARR is to use the soil

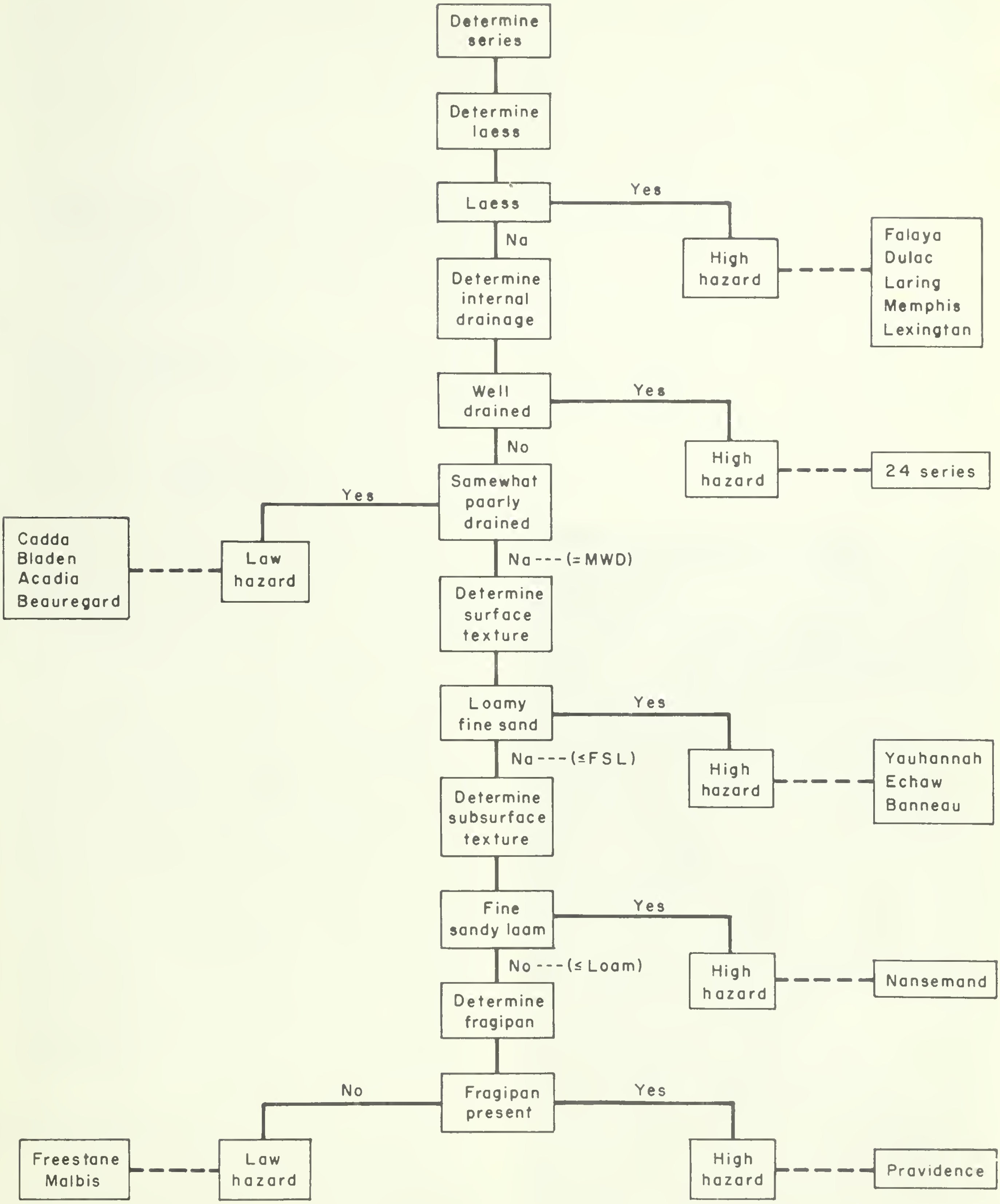

Figure 2—Annosus root rot soil series legend classification key.

maps and check them for accuracy occasionally with the tube sampler. Foresters were also encouraged to become familiar with the soils in their working area.

Field Testing the Cubic-Foot Soil Sampling System

A technique has been developed at Virginia Polytechnic Institute and State University to enable the forester to determine the actual level of annosus root rot infection and the corresponding growth rate of infected trees This has provided a basis for making stand management recommendations. The cubic-foot ARR colonization system was evaluated in thinned pine stands in Alabama (fig. 3). The data included years since thinning, d.b.h., live crown ratio, 5-year growth increment, and cubic-foot root colonization percentages. Data were taken using 20 cubic-foot samples per stand scattered uniformly over the stand. At each plot, the following data were collected: presence of ARR/SPB, ARR hazard according to the texture of the top 12 inches of soil and internal drainage, and data on four trees (d.b.h., radial growth for last 5 years, height to live crown, and total height). Increment cores were sent to VPI&SU for analysis. At every other plot (a total of 10 in each stand), a 1-cubic-foot soil sample was taken. The number of healthy roots and total number of roots in this cubic-foot sample were recorded. These data were then provided to Dr. Sam Alexander at VPI&SU for analyses.

Figure 3—Removal of cubic-foot soil sample to determine percentage infection of pine roots by annosus root rot.

Some of the data from thinned stands were needed to determine growth as affected by ARR infection. Experience had shown that as infection levels increase, growth rates differ from those that would be expected.

It was concluded that the cubic-foot sample for determining the percentage of root infection was a practical sampling approach. The cubic-foot sample was also found to be a helpful diagnostic technique for trees that have no visible conks.

Monitoring SPB/ARR Interactions

The presence and interactions of SPB and ARR in the same stands were monitored. Locations of confirmed ARR were mapped. High-hazard ARR sites were referenced to stands hazard rated and/or infested with SPB. Conversely, medium-to high-hazard stands for SPB or those actually infested by the beetle were referenced to ARR hazard and presence. In certain instances, for the purpose of making management recommendations, SPB hazard ratings were increased to the next more serious level on a site where ARR was present. Hazard-rating maps were made a part of the management plans on the demonstration forests.

The monitoring will continue to be an ongoing effort by the AFC and the results used to verify and update future hazard ratings and management plans.

Using Preventive Techniques in TREASURE Forests

In any plan involving a pine stand, the forester is required by the Alabama Forestry Commission to include SPB and ARR hazard ratings and management recommendations. The recommendations are standardized for consistency and the records maintained on the AFC computer.

Packaging and Delivering SPB/ARR Technology

Technology transfer has been accomplished through training sessions, the use of slide-tapes, magazine articles, TV public service announcements, show-me sessions, and the like. These have all been prepared and presented to train foresters and enable them to include IPM prevention techniques in their management plans and to acquaint landowners with those techniques that will improve the success of their efforts.

Training sessions have been provided to foresters and rangers in each of the 10 Commission districts. Two sessions held for industry and consultant foresters were attended by a total of 75 foresters. Dr. Evan Nebeker, Mississippi State University, and Dr. Sam Alexander, VPI&SU, served as instructors. Followup sessions were held with district and individual company personnel. (Industry sessions were cosponsored by the Alabama Forestry Association.)

A 20-minute slide-tape on "Management of SPB and ARR" was produced, with each district office provided a copy for use during landowner training sessions in each county.

The Commission publishes a magazine entitled "Alabama's TREASURED Forests," which is directed at the State's landowners. The Pest Management staff is responsible for submitting two articles per issue The following articles on

SPB ARR have been published in the magazine thus far:

"Know annosus root rot and react quickly." (by Kucera): 1(1):18; 1983.

"Hazard rating—a strategy for battle against the beetle." (by Hyland): 2(1):26–28; 1983.

"Control the southern pine beetle." (by Hyland): 2(4); 1983.

"Southern pine beetle and annosus root rot management." (by Hyland and Kucera): 4(1):17–18; 1985.

To promote the use of SPB hazard rating, a 30-second public service announcement (PSA) was produced. This PSA was sent to the 24 TV stations serving Alabama. In general, the PSA said: "It takes 30 years to grow a pine tree, but in only 30 days the southern pine beetle can destroy the tree. This destruction can be prevented. Contact your local AFC Office." The PSA won first prize in the International Association of Business Communicators Annual Awards Presentations.

During the last 2 years, each of the 34 demonstration forests in Alabama has held at least one show-me type training session on SPB and or ARR. The attendance for each session ranged from 50 to 100.

INFLUENCE OF THE DEMONSTRATION PROJECT ON ALABAMA FORESTS

Spinoffs from the management plan recommendations were directed at simplifying field foresters' decisions and backing them up with economic information. These efforts included:

1. Developing the "Annosus Root Rot Management Plan for Alabama."
2. Establishing a demonstration area in thinned pine stands using *Phlebia gigantea* in Houston County to prevent the spread of ARR. An economic analysis was conducted to demonstrate the value of preventing ARR in stands treated with *P. gigantea* vs. untreated stands.
3. Establishing a demonstration area in Anniston, where three stands were treated differently: one as a control, one with stumps treated with borax, and one with stumps treated with *P. gigantea*. Cost analyses of the different treatments are underway.
4. Organizing a demonstration of the VPI&SU sampling technique in Alabama at which interested pest management researchers and land managers were invited to comment on objectives, methods, and underlying theory.
5. Conducting a statewide survey to determine the incidence and severity of ARR.
6. Transferring the new or improved technology by internally updating AFC forest management policy and incorporating SPB and ARR hazard rating into the computerized TREASURE Forest Management Plans.

The success of this demonstration project has changed the general thinking of foresters from a "control SPB when it attacks" attitude to a "prevent the attack and thereby reduce losses" outlook. ARR thinking has changed from a "that's no problem" view to one of "we'd better do something."

Pine stands that have been hazard rated (or will be rated) will be monitored for SPB and or ARR mortality in the future. Data will be used to validate and update the hazard ratings.

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EFFECTS OF THINNING IN REDUCING STAND RISK TO SOUTHERN PINE BEETLE IN THE GEORGIA PIEDMONT

Terry S. Price[1]

INTRODUCTION

Over the past 20 years, the Georgia Forestry Commission (GFC) has pursued an aggressive southern pine beetle (SPB) control program that has varied in intensity from year to year. During the early 1960's, more than 5.5 million board feet of timber and 14,000 cords of beetle-infested wood were cut and chemically treated by the Commission. In the last 11 years, SPB outbreaks have increased in frequency and severity (fig. 1). Over 1.1 million cords of pulpwood and 195 million board feet of timber were salvaged during this period. The outbreak that occurred in 1979 killed more timber than previous outbreaks in the 1970's (table 1).

The correlation between SPB losses and forest structure is especially well illustrated by changes that have occurred in the forest resource of the Upper Piedmont (fig. 2) during the last two decades. Since 1953, the volume of softwood growing stock (trees less than or equal to 9 inches d.b.h.) has increased by 122 percent, while pine sawimber volume (trees greater than 9 inches d.b.h.) has increased 207 percent (table 2). These dramatic changes have resulted in a steady increase in stand density. It is this high density of pine sawtimber in combination with poor site conditions in the region that has resulted in extensive timber losses to the SPB. Moreover, dollar and volume losses of pine stumpage in the region between 1972 and 1980 are the highest reported for any subregion in the Southern United States, over $50 million or $2 per acre per year in the susceptible forest area (table 1).

Aggressive State and Federal programs of bark beetle detection and suppression have significantly reduced losses caused by the SPB. However, long-term reductions in losses to these insects can only be achieved by increasing the intensity of forest management. Since nonindustrial private landownerships account for over 4.6 million acres of susceptible pine forests (loblolly and shortleaf) in the Piedmont region of Georgia, the necessity for keeping these landowners informed of the latest technology and encouraging them to pursue management actions on a timely basis is quite apparent.

Activities such as thinning of overdense stands and harvesting of overmature pines can result in a reduction in severity of future SPB outbreaks (Belanger and Malac 1980). Demonstrating the value of thinnings in reducing pest impacts is most important. Nonindustrial private landowners throughout the Piedmont area of Georgia who have suffered severely from past outbreaks have traditionally been reluctant to reinvest in pine forestry. They have felt that no defenses were available to them for warding off or preventing beetle outbreaks. Some landowners in the region have even liquidated their pine stands as a means of alleviating the SPB problem. Also, these pine stands have not been reforested; instead, poor, low-quality hardwoods have claimed the sites.

The main objectives of the demonstration project instituted in Georgia were to show the nonindustrial private landowner (NIPL) a way of coping with SPB outbreaks as an alternative to clearcutting and, if possible, to compare two SPB hazard-rating systems. Other objectives were to develop guidelines for managing pine stands to reduce bark beetle-caused losses and to carry out accelerated technology transfer activities.

APPROACHES TO MEETING THE OBJECTIVES

Thinning Demonstrations

The basic approach used to demonstrate to the NIPL the value of selective thinnings was to identify susceptible loblolly/shortleaf pine stands throughout the Piedmont region of Georgia. These stands were chosen based on stand density, species composition, tree size, and location. Each stand was hazard rated by GFC entomologists using two rating systems—P Hazard GA (Belanger and others 1981) and TX Hazard (Mason 1979).

GFC foresters used the following marking guidelines:

1. Remove as many fusiform rust-infected trees as possible.
2. Favor loblolly pine over shortleaf.
3. Remove as many overmature trees as possible in uneven-aged stands.
4. Use selective marking; do not row thin in plantations.
5. Thin each stand so that the residual basal area (BA) will be equivalent to the site index.

There was no charge to landowners for marking services. The GFC foresters recommended thinning practices that minimize stand damage.

A total of 27 stands located in 16 counties was thinned during the project (table 3). Over 10,000 cords of suppressed, diseased, and highly susceptible trees were removed from the 27 stands by commercial sale. A wooden sign was erected on each site to inform the public about the demonstration.

Each landowner appeared to be satisfied with the results of the thinnings. SPB activity was not observed in any of the thinned stands nor in any adjacent unthinned stands. Beetle populations have been endemic throughout the region since 1980, except for a few isolated outbreaks that occurred in overmature dense stands.

The two hazard-rating systems proved to be useful in determining a stand's relative susceptibility to beetle attacks. The Piedmont model tended to rate more in the moderate category, whereas the Texas model tended to rate more in the high

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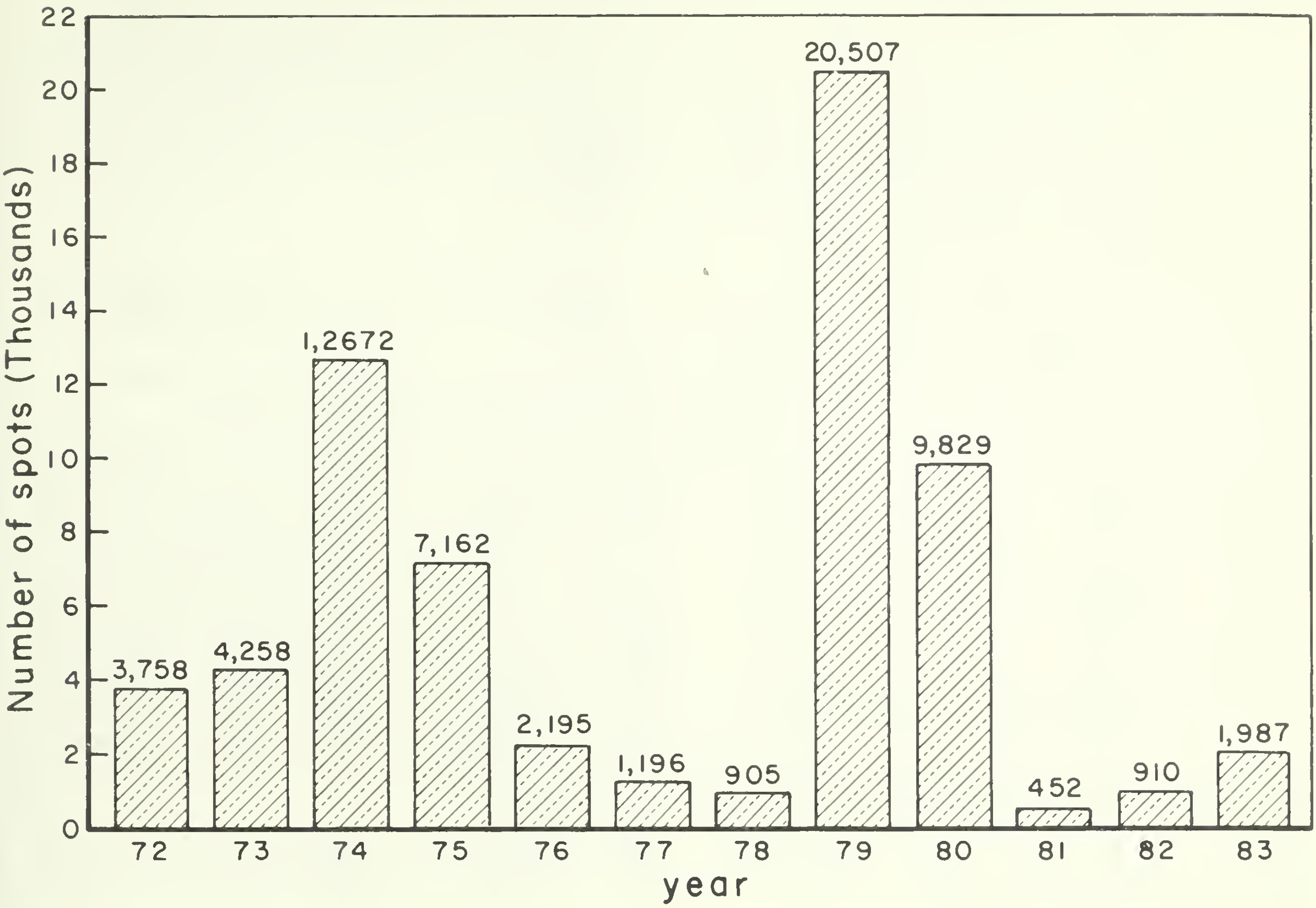

Figure 1—Number of southern pine beetle spots detected by aerial survey.

Table 1—*Southern pine beetle damage estimates in Georgia 1962, 1972–80*[1]

Calendar year[2]	Estimated volume salvaged[3] Cords	M fbm	Total volume killed Cords	M fbm	Stumpage values[4] Pulpwood $/cords	Sawtimber $/M fbm	Total value $
1962	0	0	1,785,240[5]	958	5.00	40	8,964,520
1972	13,976	10,532	35,836	11,627	6.00	65	970,771
1973	124,527	20,904	389,740	60,804	6.00	65	6,290,700
1974	179,736	22,386	402,254	43,700	10.00	70	7,081.540
1975	46,413	7,441	52,665	7,643	15.00	70	1,324,985
1976	15,609	3,446	21,677	4,221	15.00	70	620,625
1977	5,614	481	15,915	636	15.00	107	306,777
1978	1,682	180	6,487	582	16.00	118	172,468
1979	390,285	71,592	542,991	105,054	18.00	147	25,216,776
1980	384,194	57,169	528,316	78,575	21.00	110	19,737,886

[1] Information collected from State and Federal pest control specialists.
[2] Initial year based on available State records.
[3] Includes estimates on Federal, State, and private lands.
[4] Estimates from State pest specialists; same values assigned to timber salvaged.
[5] Actual volume of timber chemically treated plus estimated volume killed with no treatment.

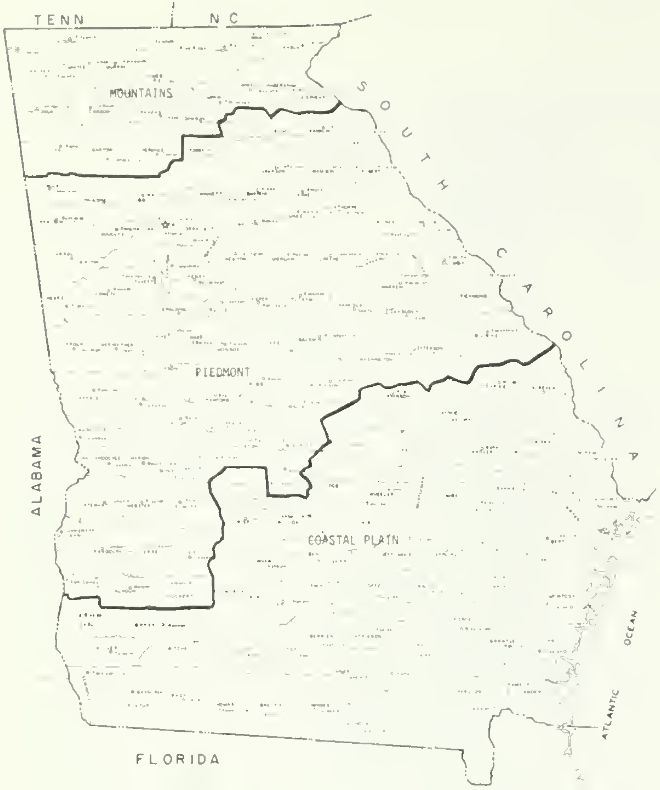

Figure 2—Broad geographic subregions in the State of Georgia.

category. However, the stands rated (whether moderate or high) needed to be thinned. The basal area prior to thinning averaged 131 square feet per acre in the 27 stands (range 80 to 200).

Packaging of Management Guidelines

A manual entitled "Guidelines for Managing Pine Bark Beetles in Georgia" was developed during the project (Karpinski and others 1984).

The manual provides guidelines for predicting, evaluating, and preventing bark beetle outbreaks, with the text outlined so that users can develop management strategies to suit their own particular forest conditions and management goals. Chapter 1 highlights the history of SPB activity in Georgia and correlates increases in beetle population levels with changes in forest structure. The chapters on aerial detection and ground evaluation provide information needed to set priorities for direct control. Procedures are given for ranking the susceptibility of stands to beetle attack. Silvicultural practices are recommended to lower the probability of attack in stands and reduce losses should attacks occur. The last chapter was designed specifically for industrial and large NIPL's to enable them to develop an integrated approach to managing pine bark beetles.

Other Technology Transfer Activities

Four panel exhibits (Expo System), seven training programs, three demonstrations, and a field trip were carried out during the project. Approximately 3,750 people attended SPB prevention thinning and hazard rating demonstration projects

Table 2—*Changes in commercial forest area, sawtimber volume, and growing stock from 1953 to 1982 in the Upper Piedmont*

Item	Change for the period—			
	1953–61	1961–72	1972–82	1953–82
	Percent			
Forest area				
Softwood	20	3	−17	4
Sawtimber volume				
Softwood	32	99	17	207
Growing stock volume				
Softwood	24	76	2	122

at various locations in the Piedmont. Several hundred pieces of literature were distributed at each meeting.

Two portable exhibits to be used as training aids were developed. One was a loblolly pine model (52 inches tall, 18 inches diameter) that was used to train resource managers in bark beetle identification. The tree was displayed in Atlanta for 2 days during Georgia-on-Parade activities. More than 1,000 people viewed the tree model, resulting in many inquiries. The other exhibit was a 4- by 2-foot scale model table display that illustrated an unmanaged loblolly/shortleaf pine stand and a well-managed loblolly pine stand. This exhibit was used for periods of several weeks at the Macon Museum of Arts and Sciences and elsewhere. Both of these exhibits will be available for future meetings and conferences throughout Georgia.

INFLUENCE OF DEMONSTRATIONS ON GEORGIA FORESTS

Those involved in this project found that demonstrations are a very important way to "sell" forest pest management techniques in Georgia. The project enabled the GFC to emphasize the identification and thinning of stands susceptible to SPB attack and spot growth. Although the effects of the thinnings may not be immediately evident, the stage has been set to further the proper management of pine stands and the reduction in beetle-caused losses in the State.

Immediate benefits of the project were:

1. GFC field foresters were exposed to the various hazard-rating systems during the early stages of the project and now consider stand hazard rating as part of the way they do business.
2. Public awareness has been increased, and landowners will now be alert to developing beetle problems.
3. Georgia landowners now know that clearcutting is not necessary to halt or prevent beetle outbreaks. Hopefully, the continuation of the project theme (thinning pine stands to reduce or prevent losses) will encourage them to consider future timber investments in the State.

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Table 3—*Individual stand data, Georgia thinning demonstration*

County	Acres	Stand type[1]	Hazard system		Species[2]	Age	Average pine BA	
			Piedmont	TX Hazard			Before	After
Baldwin	20	Natural	Moderate	Moderate	Lob/Shtlf	28	80	60
Baldwin	20	Natural	Moderate	Moderate	Lob/Shtlf	31	100	63
Banks	20	PP/Nat	Moderate	High	Lob	PP 30	PP 160	90
						Nat 33	Nat 120	80
Carroll	40	PP	Moderate	High	Lob	22	120	95
Coweta	35	Natural	High	High	Lob	31	166	96
Coweta	20	PP	Moderate	High	Lob	23	200	110
Coweta	60	PP	Low	Moderate	Lob	22	95	75
Coweta	20	Natural	Moderate	High	Lob	33	133	100
Forsyth	30	Natural	Moderate	High	Lob	37	146	85
Franklin	21	Natural	High	Very high	Lob	28	130	85
Gwinnett	45	PP	Moderate	High	Lob	27	160	80
Hart	20	PP	Moderate	Moderate	Lob	29	118	90
Hart	42	PP	Moderate	High	Lob	23	125	90
Heard	200	PP	Moderate	High	Lob	22	152	105
Heard	35	PP	Moderate	High	Lob	22	123	95
Henry	50	PP	Moderate	High	Lob	23	172	96
Jasper	225	Natural	Moderate	High	Lob/Shtlf	23	140	88
Jasper	40	PP	Moderate	Very high	Lob	22	120	80
Jasper	50	Natural	Moderate	High	Lob/Shtlf	33	144	85
Jones	70	Natural	Moderate	Moderate	Lob	31	92	82
Morgan	40	Natural	Moderate	Very high	Lob/Shtlf	46	123	82
Spalding	30	PP/Nat	High	High	Lob	PP 25	PP 170	94
						Nat 34	Nat 136	75
Spalding	40	Natural	Moderate	High	Lob	33	140	95
Spalding	40	Natural	Moderate	High	Lob	26	120	95
Talbot	99	Natural	Moderate	Moderate	Lob/Shtlf	42	90	77
Crawford	6	Natural	Low	Moderate	Lob	22	113	86
Crawford	36	Natural	Low	Moderate	Lob	19	116	95
Total	1,354	27						

[1] PP = planted pine stand
Nat = natural pine stand
[2] Lob = loblolly pine stand
Shtlf = shortlead pine

METHODS OF DETECTING, SUPPRESSING, AND PREVENTING SOUTHERN PINE BEETLE LOSSES IN MISSISSIPPI

William E. Lambert[1]

INTRODUCTION

The first recorded epidemic of the southern pine beetle (SPB) in Mississippi occurred in 1952 in the southwestern part of the State. An estimated 5 million cubic feet of timber worth $450,000 was destroyed. Since that time, the area affected by SPB has grown until all of the State supporting a loblolly/shortleaf pine host type has been infested at one time or another during the intervening 33 years.

The volume damaged since the first epidemic has often varied but the value of the timber has always increased (table 1). Today, a relatively small epidemic, in terms of area affected, can be costly. Although Mississippi has lost a total of $33.8 million dollars worth of timber to the SPB in that first and subsequent epidemics, there has been a tendency since to view this pest as an insect problem rather than a timber management problem.

This prevailing view has led to a crisis management approach to the SPB. During epidemic years, manpower, time, and money are extensively expended in "controlling the beetle." This only treats one symptom of a larger problem, and once that symptom subsides, the problem is forgotten until the next epidemic. During the years between outbreaks, when prevention activities should be stressed, the only reference to SPB is the question: "When do you think they'll be back?"

For all the recent research that has achieved a better understanding of the SPB, its management and prevention, little of this new knowledge and technology has been used. There has been a continuing need to make the resource forester, as well as the forest landowner, more aware of currently available information and technology and to demonstrate its usefulness.

A project to demonstrate recent developments in suppression and prevention tactics was begun by the Mississippi Forestry Commission in 1980. Project objectives were to: 1) Evaluate seven SPB hazard-rating systems and determine which one would be most applicable for use in Mississippi, 2) develop demonstrations of thinning as a means of reducing stand susceptibility to beetles, 3) demonstrate the utility of commonly available farm equipment in salvaging beetle-infested trees, 4) develop a series of videotapes with accompanying "how-to" type publications to educate landowners and forest resource personnel on SPB and appropriate forest management practices for preventing or reducing SPB-caused timber losses, 5) evaluate the usefulness of Agricultural Stabilization and Conservation Service (ASCS) 10- by 10-inch black-and-white contact prints for aerial detection surveys and hazard rating, and 6) demonstrate the value of LORAN-C navigation equipment in conducting aerial surveys.

APPROACHES TO MEETING THE OBJECTIVES

Hazard Rating Evaluation

Several hazard-rating systems have been developed for various parts of the Southeast. However, their effectiveness in more than one geographic area has not been demonstrated.

Table 1—*Southern pine beetle damage estimates in Mississippi, 1971–80*[1]

Calendar year[2]	Estimated volume salvaged[3] Cords	Estimated volume salvaged[3] M fbm	Total volume killed Cords	Total volume killed M fbm	Stumpage values[4] Pulpwood $/cords	Stumpage values[4] Sawtimber $/M fbm	Total value $
1971	0	3,000	0	3,000	0.00	50	150,000
1972	537	7,172	537	7,172	6.00	50	361,822
1973	579	7,229	579	7,229	8.00	50	366,082
1974	329	7,474	329	7,474	8.00	50	376,332
1975	488	9,600	488	9,600	8.00	60	579,904
1976	4,023	16,949	9,823	37,949	9.00	60	2,365,347
1977	8,597	8,651	13,409	15,670	8.00	115	1,909,322
1978	2,267	4,093	8,187	8,053	5.25	140	1,170,402
1979	40,246	13,799	108,540	29,784	9.00	155	5,593,380
1980	77,630	34,137	190,632	98,933	11.00	128	14,760,376

[1] Information collected from State and Federal pest control specialists.
[2] Initial year based on available State records.
[3] Includes estimates on Federal, State, and private lands.
[4] Estimates from State pest specialists; same values assigned to timber salvaged.

[1] Forest Entomologist, Mississippi Forestry Commission, Jackson, MS.

Consequently, 649 pine stands were hazard rated during the summers of 1981, 1982, and 1983 to determine the degree of effectiveness of 7 of these systems in Mississippi. One data collection point was taken every 5 acres. The rated stands were monitored by aerial photographs taken annually and these were examined for evidence of SPB activity. Activity discovered during the collection of the field data was noted on the data sheets.

The first and second summer's data from 511 stands were collected from the general population of pine stands of suitable host type. Other selection criteria were that a stand must have a minimum of 20 percent pine component and be in private nonindustrial ownership. Part of the second summer's data were taken in three counties in the northern, central, and southern regions of the State, respectively, that had experienced severe SPB problems in the past.

The third summer's data were taken from random stands that had SPB infestations present. Since the development of the other hazard-rating systems involved taking a data point from SPB infestations, an additional data collection point was taken at the origin of the spot in these infested stands. It was also thought that the conditions at the spot origin led (or contributed) to the spot initiation.

Seven hazard-rating systems were evaluated. These systems were 1) ARKANSAS HAZARD (Ku and others 1981), 2) COAST PROB (Hedden 1985), 3) Georgia (Belanger and others 1981)[2], 4) and 5) Kushmaul A and B (Kushmaul and others 1979), 6) Sader (Sader and Miller 1976), and 7) TEXAS HAZARD (Mason and others 1981). The ARKANSAS, COAST PROB, Georgia, Kushmaul A and Kushmaul B hazard systems were modified by Mississippi State University in order to make them more comparable. The interpretation of the discriminant scores was changed to include five hazard classes in those systems that did not have five classes. The "micaceous red clays" variable in the Georgia system was not used, since Mississippi does not have that soil type. Kushmaul A and B were designated "Mississippi Hazard A" and "Mississippi Hazard B."[3]

Nebeker and Honea[4] in their analysis of these data (table 2) found that of the seven systems evaluated, the ARKANSAS and Mississippi Hazard A and B worked best on infested stands and spots in Mississippi. Of these three systems, the Mississippi Hazard B performed better on infested stands than the ARKANSAS or Mississippi Hazard A and nearly as well on infested spots.

Mississippi Hazard B did place 2 percent fewer infested spots in the high-hazard category than either the ARKANSAS or Mississippi Hazard A system, rating 66 percent of the stands high hazard compared with 68 percent for both of the other systems. However, it also placed 3 percent fewer infested spots in the low-hazard category than Mississippi Hazard A and 2 percent fewer than ARKANSAS HAZARD. Mississippi Hazard B rated 3 percent low hazard, whereas Mississippi Hazard A and ARKANSAS rated 6 percent and 5 percent low hazard, respectively.

Table 2—*Percentage of infested stands and spots by hazard-rating systems and hazard-rating class in Mississippi*

Hazard-rating system	Hazard class[1]					
	High		Medium		Low	
Mississippi Hazard B	46	66	58	32	6	3
Mississippi Hazard A	42	68	45	26	13	6
ARKANSAS	39	68	36	27	15	5
TEXAS	30	47	45	38	25	15
Sader	27	51	23	23	50	25
COAST PROB	13	41	35	36	52	23
Georgia	15	28	31	32	54	40

[1] First column under each hazard class relates to percentage of infested stands; second column under each hazard class relates to percentage of infested spots at point of origin.

Because the Mississippi Hazard B system also has three of its five variables (total basal area, pine basal area, and number of stems per acre) capable of being manipulated to reduce a stand's hazard, it was selected for rating stands in Mississippi. The Mississippi Hazard A system has only one of two variables (pine basal area) that could be manipulated and the ARKANSAS HAZARD system has only two of four variables (total and hardwood basal area) with this capability.

The Mississippi Hazard B system has been developed for a simple computer program that will run on the Apple II and compatible microcomputers. With this capability, hazard rating will be included in the Commission's future forest management plans, which will also consider SPB control as well as other needed forest management practices.

General facts about hazard rating, what it is, how to use it, and examples of two rating systems, using Mississippi Hazard A and B, are explained in a videotape and an accompanying publication entitled "Applying a Southern Pine Beetle Rating System," released by the Mississippi Forestry Commission (see table 3).

Thinning Demonstrations

Although thinning (as a part of stand management) has been recognized as a means for reducing SPB susceptibility, many landowners are still reluctant to do any thinning on their properties. To encourage thinning as a management practice, several demonstrations were installed across the State in which stands were partially thinned. This resulted in a potential for comparison of thinned versus unthinned areas.

It was hoped that, in addition to the added benefits of more and faster growth, some beetle infestations would occur on these areas. If occurring in the unthinned portion, the preference of the beetles for denser, slower growing stands could be shown. If occurring in the thinned portion, the slower growth of the infestation and the correspondingly reduced damage could be demonstrated. Any SPB infestations that occurred could likely be salvaged using commonly available farm equipment. This would demonstrate to landowners that in many cases they would not necessarily be dependent on a

[2] This hazard system has been replaced by the PIEDMONT RISK system for use in Georgia.

[3] Nebeker and Honea; personal communication.

[4] See footnote 3.

Table 3—*Videotapes and publications developed for technology transfer in the Mississippi demonstration project*

Videotape title	Companion publication	Subject
Forestry is Good Business	Cultural Practices Are Good Business	Costs/benefits of management practices
Leave Tree Marking of Susceptible Pine Stands	Leave Tree Marking of Susceptible Pine Stands	Thinning and competition concepts and methodology
Removing Competing Hardwoods	Removing Competing Hardwoods From Pine Stands	Thinning techniques
Detecting and Preventing the Southern Pine Beetle	Detecting and Preventing the Spread of the Southern Pine Beetle	Identifying susceptible stands, spot detection and location, setting control priorities, selecting treatment
Applying a Hazard System for the Southern Pine Beetle	Applying a Southern Pine Beetle Rating System	Stand hazard rating

pulpwood cutter or logger for salvage but could do the work themselves. Even if the landowner did not want to go to the trouble of hauling the wood to a yard, it could be skidded to a roadside or other easily accessible point and sold from there. In this way, the smaller or more inaccessible infestations not ordinarily salvaged would be more likely to be controlled.

Because many landowners were unwilling to "tie up" their property for the project's duration or did not want to be involved, only a few properties located in accessible or visible areas were available for use in this phase of the project. Of these, only two were actually thinned due to poor market conditions. No infestations occurred in either area, but infestations in other stands were salvaged using farm equipment. In these demonstrations, infested trees were cut and bucked into manageable log lengths, then skidded to a roadside or accessible loading point with logging chains and hooks or logging tongs attached to a farm tractor drawbar. Ford 4110 rubber-tired farm tractors were used for skidding.

A great deal of landowner interest was generated in the salvage demonstrations, and, on the whole, this part of the project was a success.

Landowner Education and Technology Transfer

Much of the current knowledge on SPB management and control has not been widely used. Thus, to educate landowners and forest resource personnel and present the information gained from this project, a series of five videotapes (table 3) was produced. This series, entitled "Forest Management Practices," covered in each tape an aspect of forest management tied to SPB management, prevention, or control.

The lead-in tape for the series was "Forestry Is Good Business." This program was intended to set the stage for the rest of the series by introducing landowners to various management practices, demonstrating their need, and pointing out how they would be economically beneficial in the long run with more monetary gain prior to and at harvest. Another benefit was fewer beetle problems.

Thinning and competition were covered in "Leave Tree Marking of Susceptible Pine Stands" and "Removing Competing Hardwoods." "Detecting and Preventing the Southern Pine Beetle" dealt with identifying susceptible stands, detecting and confirming the presence of southern pine beetles, evaluating infestations, setting control priorities, and choosing a treatment method. The final tape in the series, "Applying a Hazard System for the Southern Pine Beetle," covered hazard rating, what it is, how to take measurements needed to get a rating, and two examples of stand rating using two different systems.

Each videotape was accompanied by a "how-to" type publication (table 3). These corresponded to the tapes and served as a reference for the viewer. All of these videotapes may be purchased from the Mississippi State Cooperative Extension Service.

Aerial Detection Using ASCS Photography

The use of aerial photos in detection surveys and in hazard rating large areas has immense potential benefits in SPB management. Aerial photos can increase the accuracy of infestation plotting and thereby save time in ground location. In the Mississippi project, hazard rating of large areas could only be efficiently accomplished using aerial photos due to the time and expense involved. This delineates the areas with the greatest potential for infestations to occur, allowing the concentration of survey efforts and other resources in areas where benefits would be greatest.

This phase of the project attempted to accomplish its objective using photography that was generally available. Black-and-white contact prints from the Agricultural Stabilization and Conservation Service were selected. For aerial detection work, these photos were excellent. In comparison with standard sketch-mapping techniques that use 1/2-inch- to 1-mile-scale highway maps, the ASCS photos made it much easier to keep track of a position and reorient should an observer become lost. Since the photos conformed to natural terrain features, accurate plotting was possible. This, coupled with photo use in ground checking, avoided a great deal of lost time locating inaccurately plotted infestations and orienting locations plotted in map sections with few or no landmarks available.

The ASCS photos were taken for uses other than interpretive analysis and their resolution is poorer than that of mapping-quality photography, often resulting in a certain amount of blur or fuzziness under magnification. Hence, their usefulness in hazard-rating work proved to be limited, since the intent was to take as much information from photos as was normally taken from ground work. The relatively small scale used in the ASCS photos, 1/40,000 and 1/58,000, made measurements error prone and interpretation difficult. This was further compounded by the fact that the photos were not always taken during leaf-off condition, which is essential for accurate distinction between pine and hardwood stands.

Two of the hazard-rating systems compared in this project were originally intended to be used in conjunction with aerial photos to acquire stand information. However, neither of these systems proved to be accurate enough for use in Mississippi. (A system using gross measurements or stand features could possibly be developed, but this was neither the intent nor the purpose of this project).

Electronic Navigation for Aerial Surveys

A LORAN-C electronic navigation unit was acquired during the project to demonstrate the value of such equipment in increasing aerial survey accuracy (Dull 1980). It made possible the reflying of the same flight lines, permitting a more reliable evaluation of the progress of spot growth. In situations where the pilot also had to act as an observer and the LORAN was tied into the autopilot, attention could be concentrated more on plotting rather than being divided between plotting and staying on flight lines. When detection surveys were undertaken in remote areas and infestation levels were low, the latitude and longitude of spots were determined with the LORAN unit rather than by positions plotted on highway maps or photos. Exact locations could thus be determined.

Some areas of the State that were surveyed under Spanish land grants are nearly a jigsaw puzzle in the way the sections are arranged in townships. These sections are of varying shapes such as circular, triangular, or other nonsymmetrical designs. In some cases, more than 50 to 60 sections exist per township. In these areas, the use of a navigation unit like the LORAN was the only way to establish flight lines that the pilot could fly or refly.

Other Project Activities

Other activities of the Mississippi demonstration project included use of the videotapes in training or other presentations. Although their use was somewhat limited due to delays in receiving the accompanying publications, 12 sessions involving field day presentations, county forestry committees, field personnel training, civic groups, and group displays were presented. The audience attending these sessions totaled 498. Further use of these tapes and publications for landowner meetings and field personnel training is in the planning stage.

INFLUENCE OF THE DEMONSTRATION PROJECT ON MISSISSIPPI FORESTS

Although some of the objectives of the project were not fully met, as a whole, they served to redirect the emphasis of our program in some areas and refine efforts in others. Mississippi is now moving toward incorporating SPB hazard rating in forest management plans. Whenever a timber stand is cruised and evaluated for a management plan, information on its susceptibility to SPB will also be considered. Our insect and disease report form is being revised so that an area containing reported beetle infestations can be hazard rated and that information made available to the landowner. Information on hazard rating, SPB, forest management practices, and their benefits relative to both SPB prevention and financial goals is available to landowners and forest resource personnel in the form of videotapes and publications. Improvements in aerial survey techniques have been incorporated into our annual and presuppression surveys.

The present and continued use of the knowledge gained in identifying stands susceptible to SPB, informing landowners of beetle prevention and control tactics, and emphasizing the value of sound forest management practices and improved survey techniques will be of immense benefit to the State in the future. These results will constitute an important step in the direction of integrated pest management and away from pest control.

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INCORPORATING PEST MANAGEMENT TECHNOLOGY INTO LAND MANAGEMENT DECISIONMAKING: HOLLY SPRINGS NATIONAL FOREST, MISSISSIPPI

M. D. Connor, D. A. Starkey, W. A. Nettleton, J. Fort, S. Weaver, R. J. Uhler, and M. N. White[1]

INTRODUCTION

The Holly Springs Ranger District (RD) of the Holly Springs National Forest (NF) consists of 128,300 acres. The District experienced its first southern pine beetle (SPB) outbreak in 1979, which resulted in a total of 2,680 M fbm of pulpwood and sawtimber being salvaged on an SPB suppression project implemented in fiscal year 1980. There is also a history of annosus root rot (ARR) in the area; however, its total impact is yet unknown. These circumstances, together with the expressed interest of Holly Springs personnel, created an opportunity to demonstrate the incorporation of new pest management technology into National Forest management practices.

To be extensively utilized, new pest management information must be readily accessible. Available information, heretofore, had not been in a simple, easy-to-access package for National Forest resource managers. Information such as SPB spot data or the hazard rating of a particular stand had to be requested through the Forest Pest Management (FPM) field offices of the Forest Service's State and Private Forestry organization. Control and prevention recommendations for one pest sometimes conflicted with those for another (e.g., thinning stands to discourage SPB buildup could lead to annosus root rot problems), causing confusion and requiring interpretation before a decision could be made. In addition, Southern Region National Forest computerized stand data, the Continuous Inventory of Stand Conditions (CISC), had to be requested through the Forest Supervisor's office, thus preventing a District Forester from easily combining resource information with pest management information. Consequently, many forest management decisions had to be made without utilizing all the pest management information available.

The objective of the Holly Springs project was to demonstrate the feasibility of incorporating existing and new pest management technologies into National Forest land management decisionmaking. Forest pest management technology was to be made readily available through automatic data-processing equipment, which would result in its more rapid, expanded utilization.

APPROACH TO MEETING OBJECTIVES

Interactive Data Processing

At the beginning of the demonstration project, a microcomputer was purchased for the FPM Field Office in Pineville, LA. SPB recordkeeping systems, SPB spot growth models, the IPM Decision Key (Anderson and others 1985), and economic models for various pests were placed on this computer and made available in an interactive format known as the FPM System (fig. 1). A portable computer terminal was placed on the Holly Springs NF so that District personnel could access these programs. They were also trained to access the USDA Forest Service computer in Fort Collins, CO, to directly obtain CISC data.

An employee trained in both forestry and pest management and knowledgeable in computer use was placed in the District office at Holly Springs to enhance communication between District personnel and FPM. In addition, an effort was made to include district personnel in all discussions that required either forestry information or data collection for making a pest management decision.

```
 0. FINISHED

SPB INFORMATION SYSTEM

 1. SPBIS DATA ENTRY
 2. SPBIS SUMMARY
 3. SPBIS SPOT PRIORITY

MISCELLANEOUS PROGRAMS

10. PRE-B/C ANALYSIS
11. B/C WITH AND W/O A PROJECT
12. TFS SPOT GROWTH MODEL
13. MESSAGE SENDER--NOT FOR GENERAL USE
14. LIST A FILE
15. EDITOR

INTEGRATED PEST MANAGEMENT-DECISION KEY

20. FOR THE MAJOR SOUTHERN PINES (WITH HAZARD RATING OPTION)
21. FOR THE MAJOR SOUTHERN PINES (WITHOUT HAZARD RATING OPTION)
22. FOR SOUTHERN HARDWOODS
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Figure 1—Menu for the FPM System interactive microcomputer programs.

[1] Respectively, Entomologist, Plant Pathologist, and Entomologist, USDA Forest Service, Southern Region, Forest Pest Management, Pineville, LA; Timber Management Assistant, USDA Forest Service, Southern Region, Holly Springs National Forest, Holly Springs, MS; Computer Specialist, USDA Forest Service, Southern Region, Forest Pest Management, Atlanta, GA; and former Biological Technician, USDA Forest Service, Southern Region, Forest Pest Management, Pineville, LA, (currently County Forester, Texas Forest Service, Pittsburg, TX).

The authors gratefully acknowledge the Forest Supervisor and staff, National Forests in Mississippi, and the staff of the Holly Springs NF for support and assistance during this project. Special thanks are extended to Clint Floyd, District Ranger; Art O'Farrell, formerly District Soil Scientist; and Brent Botts, Forester. Their interest, enthusiasm, and support were major reasons for the project's success.

SPB risk rating.—Studies of bark beetle/site/host interrelationships across the South have led to identification of certain site/stand characteristics consistently associated with SPB infestations (Coster and Searcy 1981). Based on this knowledge, predictive techniques (stand risk ratings) have been developed to rate forest stand susceptibility to SPB attack.

Lorio and Sommers (1981) developed a two-phase SPB stand risk-rating system for the Kisatchie NF in Louisiana that utilizes CISC data. The system is called NF RISK. The system was tested and then implemented on the Holly Springs NF in 1979.

The first version of the NF RISK system uses a FORTRAN computer program, RISK, which accesses the CISC information at the USDA Forest Service Computer Center. It searches five data fields—forest type, stand condition class, method of cut, operability, and site index—and prints out a listing of high-, medium-, and low-risk stands for an entire National Forest Ranger District. Because CISC does not include data on basal area, method of cut and operability were used as general indicators of stand density.

An improvement in the NF RISK system permitted National Forest personnel to include individual stand basal areas in the risk rating, as well as to update CISC stand risk ratings, as new silvicultural prescriptions were completed. Thus, an entire Ranger District could be risk rated over a 10-year period using actual field-collected data.

NF RISK was judged to be the best SPB hazard/risk rating system for implementation on the Holly Springs RD because of three factors: 1) It was designed for National Forests, 2) it required no additional data collection, and 3) the Holly Springs NF has forest stand conditions similar to the Kisatchie NF.

Summary program results comparing the CISC data for Holly Springs and the Kisatchie revealed that while forest type, age distribution, and stand condition classes were similar, there was a significant difference in average site index for loblolly and shortleaf pine. Therefore, the site index parameters in the NF RISK program were lowered. The resulting list of high-and medium-risk stands seemed to accurately reflect the areas where significant resource loss would take place if SPB infestations were to occur. Respectively, 13, 17, and 70 percent of the stands on the Holly Springs NF were rated as high, medium, and low risk (fig. 2). This information was used to update the CISC data. The improved version of NF RISK was also implemented. A supplement to the "Compartment Prescription Handbook for the National Forests in Mississippi" was written to allow inclusion of pine basal area and SPB risk rating based on field data on the CISC forms. These risk codes serve as constant reminders of potential SPB problems in these stands.

SPB Information System (SPBIS).—A computerized record-keeping system had already been developed and revised several times for use on National Forest Ranger Districts with SPB suppression projects. The purpose of the system was to provide information on individual SPB infestations for historical use and documentation of suppression costs. These records had heretofore been maintained on the Forest Service computer at Fort Collins and were difficult to access. Records were provided to FPM only after a spot was controlled and offered little benefit to the District.

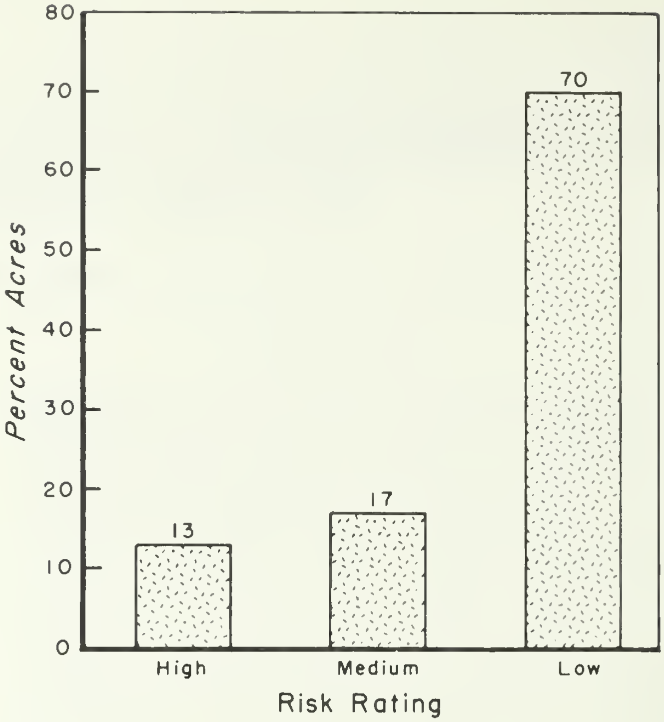

Figure 2—Percentage of total regulated acres on the Holly Springs National Forest by SPB risk class, as classified by NF RISK, February 1985.

After consultation with District personnel, an improved information system (SPBIS) was devised for the microcomputer. Some time-consuming data collection was deleted and information added that would set priorities for spot control and generate summary reports required by Supervisor's Offices. This system, in combination with the terminal in the District Office, allowed foresters to input and have immediate access to their SPB data (fig. 3).

SPBIS was initially field-tested on the Holly Springs, but a 1983 SPB outbreak in Texas allowed the first field testing of the system under epidemic conditions. Because only minor portions of the data were valuable to the Districts, SPBIS was further modified so the records could be accessed with a data-base management program (written by Robert Uhler, USDA Forest Service, Southern Region). This allowed the Districts to sort data and get totals on any information contained in their records. It also enhanced user acceptance of the system since information could be retrieved by location, spot size, control date, control treatment, or other criteria, and included volume totals. Since RECORD KEEPER[2] can be used to analyze the data in different combinations of spot size, control treatments, and elapsed time for different control activities by spot priority, problem areas can be detected without actually visiting spots. During technical assistance trips, time can be spent discussing and visiting suspected problem areas without having to rely on their accidental discovery in the field.

[2] A computerized spread sheet program to be used with SPBIS.

---LOCATION------			-----SURVEY--------			---------GROUND CHECK------------						-------SALE PREP------			-------SUPPRESSION------				-----SECONDARY TRT----		
SPOT	COMP	STAND	DATE	TYPE	GR.IN TREES	DATE	INF	# INF TREES	TBA	PBA	P/S	DATE	SAW VOLUME	PULP VOLUME	DATE	PRIM TRT	# OF TREES	SUP TRT	DATE	SAW VOLUME	PULP VOLUME
2001	0085	00	841001	A		841002	Y	25	90	70	S	841022	68	0	841106	S					
2002	0051	00	841001	A	15	841002	Y	15	90	70	S	841023	87	0							
2003	0072	00	841001	A	8	841003	N	2	110	80	S	841003	0	0	841003	D					
2004	0072	00	841001	A	3	841003	N	0	110	80	S	841003	0	0	841003	0					
2005	0021	00	841001	A	10	841003	Y	18	90	90	S	841023	19	0	841106	S					
2006	0010	00	841001	A	4	841003	Y	55	80	70	S	841023	97	0	841105	S					
2007	0012	00	841001	A	8	841005	N	0	90	90	S	841005	0	0	841005	0					
2008	0023	00	841001	A	6	841004	N	0	80	80	S	841004	0	0	841004	0					
2009	0011	00	841001	A	2	841009	N	0	80	70	S	841009	0	0	841009	0					
2010	0011	00	841001	A	4	841009	N	0	100	100	S	841009	0	0	841009	0					

Figure 3—Example of data listing from the Southern Pine Beetle Information System (SPBIS).

SPB priority program.—In conjunction with SPBIS, another computer program was written that accessed the District's ground check data and assigned a control priority. This program was based on work by Billings and Pase (1979) and was also field tested in Texas, especially on the Sam Houston National Forest. It provides information on the number of additional trees that will be killed in 30 days and the number that will be actively infected in 30 days (Billings and Hynum 1980) (fig. 4). This allows the District to concentrate on spots that are most likely to grow.

SPB summary program.—During SPB outbreaks, the National Forest Supervisor's Offices often need data on either the status of control efforts or the volume of timber removed. This information can be obtained by utilizing a program that reads the necessary information from SPBIS and then summarizes data for the report. Most Supervisor's Offices have a terminal or computer capable of accessing the FPM microcomputer in Pineville, LA, so a status report can be obtained at any time (fig. 5).

Management Approaches for Annosus Root Rot

ARR hazard rating.—Hazard rating for ARR using soil characteristics has been of interest since a southwide survey found higher levels of ARR damage in thinned stands with sandy soils than in those with loamy or clayey soils (Powers and Verrall 1962). A workable hazard-rating method based on a survey of thinned plantations in Virginia was developed by Morris and Frazier (1966) and further substantiated by other researchers (Alexander and others 1975; Froelich and others 1966). Survey work by the Southern and Southeastern Forest Experiment Stations (Froelich and others 1977; Kuhlman and others 1976) identified a number of soil series that often sustained severe ARR infections.

To utilize this soils information, a list of mapped soil series on the Holly Springs RD was prepared using Soil Conservation Service soil series descriptions. Series were placed in a generally decreasing order of sand content and increasing clay content. Hazard rating was done according to methods detailed in the research cited above (table 1). While the method of hazard rating by soil series of Froelich and others (1977) initially was judged best for the Holly Springs, the hazard-rating method was later modified to designate silt loam soils as moderate hazard and add Smithdale as high hazard (Mistretta and others 1983). Mylar overlays of district soils maps were color coded to indicate high- and moderate-hazard soil series and the maps bound in a notebook (for District use) that included a detailed explanation of the hazard ratings and guidelines for using them (fig. 6). These mylar hazard maps can be directly overlaid on stand maps during future prescription processes and will be particularly useful because SPB hazard from CISC files or the prescription process can be easily coded on stand maps, and hazard of both SPB and ARR directly compared. A composite map of the District showing both SPB risk and ARR hazard was made for use in planning. During the hazard-rating process, District personnel were shown the various hazard classes of soils in the field.

Disease status.—A survey of 23 thinned loblolly, shortleaf, and mixed stands was made to provide the District with information about the abundance, distribution, and impact of ARR. The disease was found to be widespread and common in loblolly stands (table 2) with damage mostly moderate. Less than 10 percent of the shortleaf pine stands had evidence of root rot. Fifty percent of the stands with both loblolly and shortleaf had root rot. Survey results indicate that the disease is most likely to cause problems in loblolly plantations; however, as more shortleaf plantations are established and thinned, ARR problems may increase for this species.

Annosus sampling procedure (ASP).—To provide the District with more specific information about root rot, a cooperative arrangement was made with Dr. Sam Alexander of Virginia Polytechnic Institute and State University (VPI&SU) to field test the annosus sampling procedure. Four thinned loblolly pine plantations were selected for sampling and 20 plots of four trees were established in each. Trees were measured for height, d.b.h., radial growth, and live crown ratio, and a 1-foot-square by 1-foot-deep hole was dug at 10 sample points and the pine roots removed and inspected for symptoms of ARR. Percentage of infection was then calculated for the plantations, utilizing root counts from all 10 samples (Alexander and others 1985) (table 3).

NATIONAL FOREST-13 RANGER DISTRICT-1

HIGH PRIORITY

SPOT NO.	COMP	STAND	RISK SCORE	30 ATK	DAYS TRA
0081	0051	00	100	49	62
0073	0050	00	90	102	130
0074	0058	00	90	57	71
0080	0094	00	90	38	50
0075	0046	00	90	33	43
0077	0034	00	80	17	23
0076	0005	00	70	23	31
0079	0041	00	70	18	25
2096	0094	00	70	9	13

MEDIUM PRIORITY

SPOT NO.	COMP	STAND	RISK SCORE	30 ATK	DAYS TRA
0230	0002	10	60	15	21
0078	0082	75	60	4	7
2094	0099	00	60	0	1
0045	0073	00	50	8	12
0046	0022	00	50	7	11
0013	32		50	2	6
2002	0051	00	50	2	5
2099	0099	00	50	0	1
2103	0094	00	50	0	1
2051	0093	00	50	0	1
0083	0071	00	50	0	1
2100	0068	00	50	0	1
2052	0022	00	50	0	1
2087	0010	00	50	0	1
2082	0010	00	50	0	1
2053	0009	00	50	0	1
2088	0008	00	50	0	1
2067	0099	00	50	0	0
2085	0069	00	50	0	0
2066	0067	00	50	0	0
2065	0067	00	50	0	0
0059	0081	00	40	0	1
2054	0008	00	40	0	1

LOW PRIORITY

SPOT NO.	COMP	STAND	SCORE	30 ATK	DAYS TRA
0056	0037	00	30	0	0
2095	0099	00	20	0	1
2069	0071	00	20	0	1
2097	0069	00	10	0	0
2098	0068	00	10	0	0
0008	23		0	0	1

ATK = ADDITIONAL TREES KILLED
TRA = TREES REMAINING ACTIVE

Figure 4—Example of computer output showing a priority listing for spots that need to be controlled.

NATIONAL FOREST-13 RANGER DISTRICT-1
REPORTING PERIOD: 84/10/01 TO 85/12/31

TOTAL PULPWOOD MARKED. 9
TOTAL SAWTIMBER MARKED 1965
NUMBER OF SPOTS MARKED 48

PULPWOOD SALVAGED. 0
SAWTIMBER SALVAGED 1861
SPOTS SALVAGED 21
SPOTS TREATED (CUT/LEAVE). 23
TREES TREATED (CUT/LEAVE). 3745
SPOTS GONE INACTIVE. 20
SPOTS TREATED (TOTAL). 74

PULPWD MARKED BUT NOT TRT. 8
SAWTBR MARKED BUT NOT TRT. 97
SPOTS MARKED BUT NOT TRT. 2

DATE OF LAST FLIGHT. 85/02/26
SPOTS OBSERVED-LAST FLIGHT 0
TOTAL NUMBER OF NEW SPOTS. 87

Figure 5—Summary of southern pine beetle control data obtained from SPBIS.

To help validate this method, three 1/20-acre plots were established in each plantation and all the trees pulled out with a bulldozer. Each plot tree was measured and percentage of root infection calculated from an examination of the totally exposed root systems. These data, together with similar data from all over the South, were used to develop the growth and yield model GY-ANNOSUS (Hokans and Alexander 1985), described below.

GY-ANNOSUS model.—To utilize the stand and ARR infection data, researchers at VPI&SU modified a growth and yield model for thinned loblolly pine plantations and designated the modification GY-ANNOSUS (Hokans and others 1985). The model predicts the cubic foot yield loss due to root disease at specified points in the future (fig. 7). Infection percentage and stand parameters obtained in the ASP were used to drive the computerized growth and yield model.

Projected yield losses for the four plantations at the next thinning (10 years after thinning) ranged from 5 to 15 percent (table 3). Infection levels in these plantations ranged from 17 to 33 percent. All four plantations were on silt loam soils (Lexington and Providence) that had initially been rated as high hazard. Based on this level of infection and yield loss, the hazard rating of silt loam in this area was reduced to intermediate, as previously mentioned.

Economics of borax treatment.—To demonstrate the use of the computer model "Economic Analysis of Borax Treatment" (available as a separate program on the IPM Decision

Table 1—*Annosus root rot hazard for soils series on the Holly Springs National Forest according to various workers and as used in the Integrated Pest Management Demonstration Project*

Soil series	Morris and Frazier 1966	Froelich et. al. 1966 Alexander et. al. 1975	Kuhlman et. al. 1976 Froelich et. al. 1977	Mistretta et. al. 1983	Hazard rating applied[1]	As modified or interpreted[2]
Eustis	High	High	High	—	High	High
Lucy	High	High	High	—	High	High
Troup	High	High	High	—	High	High
McLaurin	High	High	High	—	High	High
Smithdale	High	High	—	High[3]	High	High
Ruston	High	High	High	—	High	High
Jena	Low	Low	—	—	Low	Low
Bibb	Low	Low	—	—	Low	Low
Ochlockonee	Low	Low	—	—	Low	Low
Maben	Low	Low	—	—	Low	Low
Mantachie	Low	Low	—	—	Low	Low
Oaklimiter	Low	Low	—	—	Low	Low
Sweatman	Low	Low	—	—	Low	Low
Tippah	Low	Low	—	—	Low	Low
Lexington (loess)	Intermed.	Low	High	—	High	Intermed.
Chenneby	Low	Low	—	—	Low	Low
Dulac (loess)	Intermed.	Low	High	—	High	Intermed.
Bude	Low	Low	—	—	Low	Low
Calloway	Low	Low	—	—	Low	Low
Cascilla	Intermed.	Low	High	—	High	Intermed.
Providence	Intermed.	Low	High	—	High	Intermed.
Grenada	Intermed.	Low	—	—	Low	Low
Loring (loess)	Intermed.	Low	High	—	High	Intermed.
Gillsburg	Low	Low	—	—	Low	Low
Falaya (loess)	Low	Low	High	—	High	Intermed.
Arkabutla	Low	Low	—	—	Low	Low

[1] This scheme was used as a starting point and soil hazard maps were coded accordingly.
[2] Based on our field surveys, we feel this more accurately represents the hazard.
[3] Based on a report (Mistretta and others 1983) of damage in 4 of 5 stands surveyed on this soil on the Bankhead National Forest, Alabama.

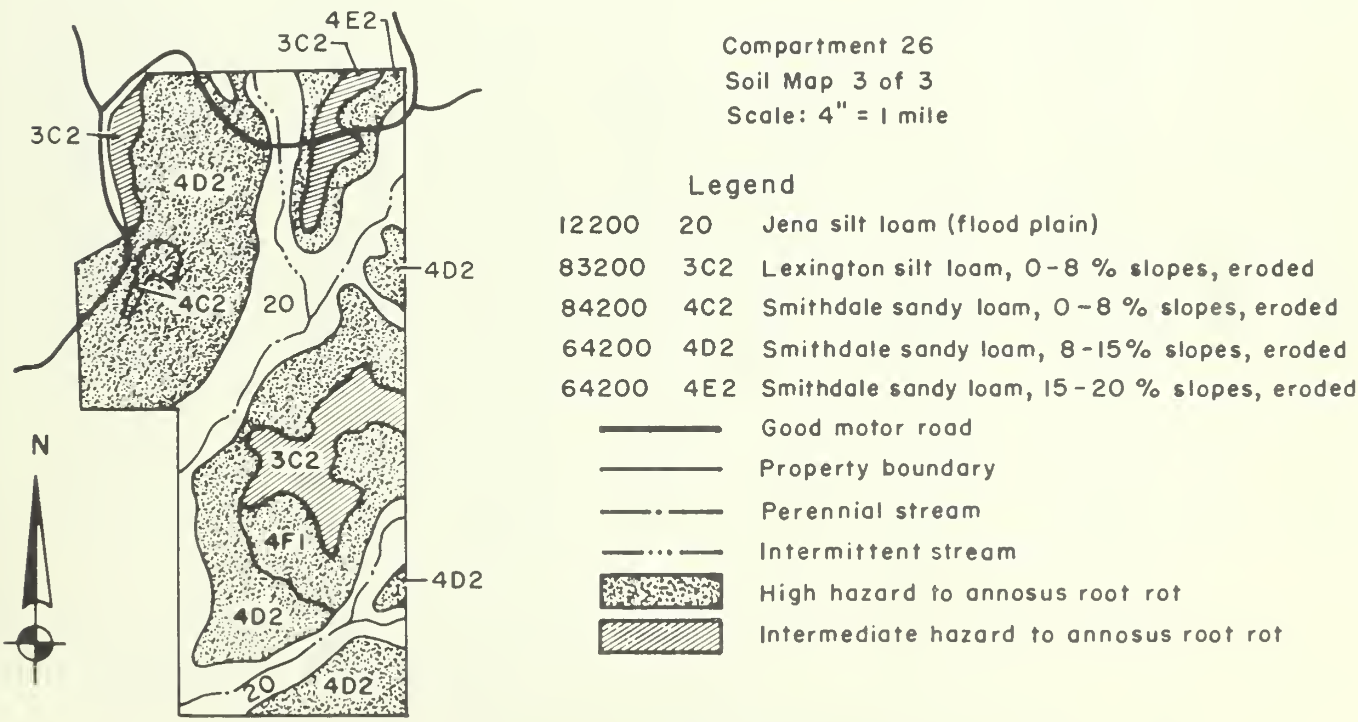

Figure 6—Annosus root rot hazard map.

Key), data were collected from four loblolly stands marked for their first thinning. After stand parameter input, the model predicts a percent return on investment (in borax treatment) after taxes (table 4). Utilizing yield-loss percentages generated by GY-ANNOSUS results in a relatively accurate reading of the output table (fig. 8).

Other Approaches

IPM Decision Key.—The IPM Decision Key, written by a team of entomologists and pathologists and a silviculturist, is an interactive program designed for a microcomputer. Questions are asked that require forest stand data and short-term management plans. A list of management recommendations is then provided for SPB, pales weevil, fusiform rust, ARR, pitch canker, and littleleaf disease.

This program was already developed at the time the Holly Springs demonstration project was initiated. The project objective was to determine how applicable the Decision Key was to National Forests. The major concern of field foresters was that, for use in compartment prescription writing, more specific information was needed. For instance, one recommendation on high-hazard annosus sites is to increase spacing in the next plantation. Specific information is needed in the compartment prescription on the required spacing for planting. In some cases (such as this one), research information is not available, but, if this option is chosen, the District foresters

CUBIC-FOOT VOLUME PROJECTIONS FOR THINNED LOBLOLLY PINE PLANTATIONS
ON HIGH ANNOSUS HAZARD SITES. (VERSION 1.0)

STAND IDENTIFIER : HS-28-1
SITE INDEX (BASE AGE 25) : 55 FEET
ANNOSUS INCIDENCE : 19 PERCENT

ANALYST : STARKEY
DATE : 3-21-85

	INCIDENCE = 19 %			NO DISEASE			DIFFERENCE		
AGE	BASAL AREA (SQFT)	OB VOL TO 4IN TOP (CUFT)	VOL YIELD (CUFT)	BASAL AREA (SQFT)	OB VOL TO 4IN TOP (CUFT)	VOL YIELD (CUFT)	OB VOL TO 4IN TOP (CUFT)	VOL YIELD (CUFT)	YIELD LOSS (%)
30	88	1991	----	88	1991	----	0	----	----
31	91	2114	----	91	2124	----	10	----	----
32	93	2236	----	94	2257	----	20	----	----
33	96	2358	----	97	2389	----	31	----	----
34	98	2478	----	99	2521	----	42	----	----
35	100	2597	----	102	2651	----	54	----	----
36	102	2715	----	105	2781	----	66	----	----
36	80	2016	699	80	2016	765	0	66	8.6
37	82	2119	----	82	2127	----	8	----	----
38	84	2222	----	85	2239	----	17	----	----
39	86	2324	----	87	2350	----	26	----	----
40	88	2425	----	90	2460	----	35	----	----
41	90	2526	----	92	2571	----	45	----	----
42	92	2625	----	94	2680	----	55	----	----
43	94	2724	----	96	2789	----	65	----	----
44	96	2822	----	98	2896	----	75	----	----
45	98	2918	----	100	3003	----	85	----	----
46	100	3013	----	102	3109	----	96	----	----
47	101	3108	----	104	3214	----	107	----	----
48	103	3201	----	106	3318	----	117	----	----
49	105	3293	----	108	3421	----	128	----	----
50	106	3383	----	110	3523	----	139	----	----
50	0	0	3383	0	0	3523	0	140	4
TOTALS			4082			4288		206	

Figure 7—Output table from GY-ANNOSUS.

ECONOMIC ANALYSIS OF BORAX TREATMENT

LOB, SLASH, SHORT, OR LONG.. LOB
STAND AGE.................. 26
STEMS/ACRE.................. 380
SITE INDEX (BASE AGE 50).... 93
AVERAGE DBH................. 8.7

AVERAGE HEIGHT.............. 60
% STEMS THINNED............ 43
HRLY RATE OF CHAINSAW OPER.. 10
COST/100 LBS. OF BORAX...... 33.60
HARVEST AGE................ 36

PULP OR SAW HARVEST (P/S)... P
PRESENT PRICE/CORDS......... 10
MARGINAL INCOME TAX (%)..... 20
INFLATION RATE (%)......... 4

BEFORE TAXES AT HARVEST

MORTALITY DUE TO ANNOSUS %	WITH TREATMENT VOLUME (CRDS)	WITH TREATMENT VALUE $	WITHOUT TREATMENT VOLUME (CRDS)	WITHOUT TREATMENT VALUE $	LOSSES AVERTED $	RETURN ON COST OF TREATMENT %
5	43.12	705.12	40.97	669.87	35.26	4.74
10	43.12	705.12	38.81	634.61	70.51	12.26
15	43.12	705.12	36.66	599.35	105.77	16.90
20	43.12	705.12	34.50	564.10	141.02	20.32
25	43.12	705.12	32.34	528.84	176.28	23.03
30	43.12	705.12	30.19	493.59	211.54	25.29
35	43.12	705.12	28.03	458.33	246.79	27.24
40	43.12	705.12	25.87	423.07	282.05	28.95
45	43.12	705.12	23.72	387.82	317.30	30.48
50	43.12	705.12	21.56	352.56	352.56	31.86

AFTER TAXES AT HARVEST

MORTALITY DUE TO ANNOSUS %	WITH TREATMENT VOLUME (CRDS)	WITH TREATMENT VALUE $	WITHOUT TREATMENT VOLUME (CRDS)	WITHOUT TREATMENT VALUE $	LOSSES AVERTED $	RETURN ON COST OF TREATMENT %
5	43.12	648.71	40.97	616.28	32.44	6.22
10	43.12	648.71	38.81	583.84	64.87	13.84
15	43.12	648.71	36.66	551.41	97.31	18.55
20	43.12	648.71	34.50	518.97	129.74	22.01
25	43.12	648.71	32.34	486.53	162.18	24.76
30	43.12	648.71	30.19	454.10	194.61	27.06
35	43.12	648.71	28.03	421.66	227.05	29.03
40	43.12	648.71	25.87	389.23	259.48	30.77
45	43.12	648.71	23.72	356.79	291.92	32.32
50	43.12	648.71	21.56	324.36	324.36	33.72

ESTIMATED FUTURE PRICE = $ 16.35/CORDS
ESTIMATED ANNUAL GROWTH RATE = 3.56%
ESTIMATED COST OF TREATMENT = $ 22.19/ACRE

Figure 8—Output table from economic analysis of borax treatment.

Table 2—*Characteristics of thinned stands surveyed for annosus root rot on the Holly Springs National Forest*

Compartment/stand	Species	Approx. years since thinning	ARR	Conks Windthrow Mortality Stringy rot	Damage[1] level	Approx. soil texture
8/18	Loblolly	5	Yes	X X X O	Moderate	Silt loam
29/15	Loblolly	4	?	O X X O	Light	Silt loam
72/7	Loblolly	5	No	O O O O	None	Silt loam
99/2	Loblolly	5	No	O O O O	None	Silt loam
00/1	Loblolly	4	Yes	X X X O	Moderate	Silt loam
14/19	Loblolly	6	Yes	X X X X	Moderate	Silt loam
28/1	Loblolly	5	Yes	X X X X	Moderate	Silt loam
29/22	Loblolly	5	Yes	X X X X	Moderate	Silt loam
10/14	Shortleaf	5	No	O O O O	None	Silt loam
12/12	Shortleaf	7	No	O O O O	None	Sandy loam
14/21	Shortleaf	7	Yes	O X X O	Moderate	Sandy loam
19/5	Shortleaf	5	No	O O O O	None	Silt loam
46/22	Shortleaf	9	No	O O O O	None	Silt loam
59/10	Shortleaf	4	No	O O O O	None	Silt loam
77/1	Shortleaf	7	No	O O O O	None	Silt loam
77/24	Shortleaf	7	No	O O O O	None	Clay loam
89/10	Shortleaf	9	No	O O O O	None	Silt loam
106/12	Shortleaf	7	No	O O O O	None	Sandy loam
106/20	Shortleaf	5	No	O O O O	None	Silt loam
10/19	Mix	6&1	Yes	X X X O	Moderate	Silt loam
13/10	Mix	7	?	O X X O	Light	Sandy
13/20	Mix	7	?	O X X O	Light	Sandy
44/2	Mix	10	Yes	X X X X	Moderate	Silt loam/sand

[1] None = no noticeable damage from ARR.
Light = little evidence of ARR: a few dead trees present
Moderate = A few to several infection centers of 1-3 trees; occasional windthrows and/or broken stems on ground.
Severe = several to many infection centers with >3 trees; many windthrows and/or broken stems on ground.

must decide on planting density and include it in the prescription.

Thinning priority program.—This computer program was developed for the microcomputer (by forester Brent Botts of the Holly Springs RD) to determine commercial thinning priority for work not completed during the scheduled year. The program considers the following stand variables: basal area, average stand d.b.h., volume, age, site index, access, method of harvest, and ARR hazard. Each variable is then weighed based on its importance in determining the thinning priority. The implementation of this method resulted in an estimated savings of $570 to the District and also improved use of personnel. Since the program concept was developed by a forester, it provides an excellent example of the acceptance and integration of pest management considerations along with forest stand conditions in the decisionmaking process.

TECHNOLOGY TRANSFER TO OTHER NATIONAL FORESTS

As previously described, the computerized system of recording (SPBIS) and tracking SPB spots was field tested on the National Forests in Texas. It has since been implemented on all seven Districts in the State, on three Districts of the Kisatchie NF, and on three Districts of the National Forests in Mississippi. Before the end of 1985, SPBIS will probably be implemented on at least four more National Forest Districts in Louisiana and Mississippi. Two noticeable advantages of

Table 3—*Stand parameters, percent infection, and percent yield loss (predicted by GY-ANNOSUS) of thinned loblolly pine plantations on the Holly Springs National Forest infected with annosus root rot.*

Compartment/stand	Age	Basal area	Mean d.b.h.	Mean height	Site index base age 25	Percent infected	Yield loss (%) 10 yrs. after first thinning
8/18	30	86	9.8	62	56	33	15
14/19	33	120	10.0	62	53	5	5
28/1	30	88	9.8	61	55	19	9
29/22	26	82	10.4	58	57	17	10

Table 4—*Estimated percent return on investment in borax treatment at the next harvest for four loblolly pine stands on the Holly Springs National Forest, assuming infection with annosus root rot occurs at previously measured levels.*

Compartment pay unit	Age	Stems/ acre	Mean d.b.h.	Mean height	Site index base age 50	Percent stems marked for removal	Percent return (harvest in 10 yrs.) after taxes (5-15% yield loss)	
							Pulp	*Saw*
120/2	26	380	8.7	60	93	43	6-18	31-46
82/5A	28	340	8.8	57	95	41	6-19	32-41
82/5B	29	300	9.6	76	114	57	4-12	24-38
66/19	19	540	8.5	58	127	56	2-14	26-41

the computerized SPBIS are: 1) It has been well received on all of the Forests, and 2) the data appear to be more accurate than is the case with previous data-collection systems.

Prior to this project, only the Kisatchie NF had implemented risk rating. Since this project's initiation, NF RISK has been implemented on National Forests in Mississippi, Texas, and Alabama (Nettleton 1983).

The annosus sampling technique and GY-ANNOSUS appear to be useful tools for providing information to the land manager on infection levels and potential growth loss due to this disease. In addition, they complement the program "Economic Analysis of Borax Treatment" by providing estimates of yield loss. This technique, used with success on private land in Alabama and on Federal land in South Carolina, will soon be implemented on other National Forests in Mississippi and on the Bankhead National Forest in Alabama. ARR hazard rating has been accomplished for both the Bankhead NF in Alabama and the Sam Houston NF in Texas and is being implemented on other Mississippi National Forests. Efforts are underway to make this new technology available through a fact sheet and an annosus root rot slide-tape program that includes the annosus sampling procedure. Plans are underway to incorporate GY-ANNOSUS in FPM's interactive computer system to make it easily available to land managers.

INFLUENCE OF THE DEMONSTRATION PROJECT ON THE NATIONAL FORESTS IN MISSISSIPPI

The Holly Springs NF demonstration project was highly successful in incorporating forest pest management practices in forest management decisionmaking. SPB and ARR hazard rating have been included in the compartment silvicultural prescription process, which allows pest management considerations to be applied at the time when stand management is planned for the next 10-year period.

Implementation of technology important in managing pest outbreaks was also successful. Guidelines for determining priorities were implemented for the removal of SPB spots during a severe epidemic, and the SPBIS program was modified to fit the needs of the Holly Springs NF. New techniques for evaluating ARR and predicting damage were field-tested and demonstrated to district personnel.

Technology found applicable on the Holly Springs project was subsequently implemented on National Forest land in Texas, Louisiana, Mississippi, and Alabama and on Federal land in South Carolina. Expanded implementation is planned for Mississippi and Alabama National Forests. Support and acceptance of the technology were a direct result of the exposure provided by this project. Important to its success were: 1) Establishment of a close working relationship with District personnel, 2) presentation of information in a format useful to the practitioner, and 3) easy access to the information needed to make resource management decisions. Future technology transfer efforts in the Southern Region will continue to build on these elements and the relationships developed during this demonstration project.

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DEMONSTRATING THE EFFICACY OF THINNING FOR REDUCING SOUTHERN PINE BEETLE IMPACTS IN NORTH CAROLINA

Coleman Doggett[1]

INTRODUCTION

Epidemics of the southern pine beetle (SPB) have been known to occur at irregular intervals in North Carolina since the mid-1700's (Price and Doggett 1978). During the most recent epidemic, which occurred between 1960–76, an estimated 1,340,914 cords of pulpwood and 606,850 M fbm sawtimber valued at nearly $39 million was killed by the beetle (table 1).

Around 19.5 million acres of North Carolina is in commercial timberland, or approximately 63 percent of the State's total acreage. Of this, over 6.5 million acres is in pine type susceptible to SPB attack. The ownership pattern of this resource is of interest. About 5.2 percent of North Carolina's commercial forest land is contained in the National Forest System; 10.9 percent is owned by forest industry; 3.8 percent is owned by other public agencies; and a sizable 80.1 percent is owned by some 250,000 private individuals.

The variety of interests, abilities, and assets of private owners makes a unified, well-coordinated approach to pest management difficult. Experience has shown that while these landowners are certainly more interested in SPB control during outbreak periods, they are not willing to adopt measures to alleviate future outbreaks. Consequently, private nonindustrial landowners were the targeted audience for a demonstration on how SPB incidence and impact can be reduced through application of current technology.

Analysis of current technology reveals that the impact of SPB is influenced by a number of factors, most of which the landowner cannot control. For instance, soil type, species, and stand density have been identified as factors influencing beetle activity (Hicks 1980). The land manager, however,

Table 1--*Southern pine beetle damage estimates in North Carolina, 1960–80*[1]

Calendar	Estimated volume salvaged[3]		Total volume killed		Stumpage values[4]		Total
					Pulpwood	Sawtimber	value
year[2]	Cords	M fbm	Cords	M fbm	$/cords	$/M fbm	$
1960	0	0	0	200	5.00	35	7,000
1961	0	0	0	5	5.00	35	175
1962	10,000	5,000	20,000	10,000	5.00	35	450,000
1963	20,408	10,121	24,008	11,921	5.00	35	537,275
1964	5,565	47,740	6,565	5,740	5.00	35	233,725
1965	28,108	19,281	43,108	31,281	5.00	40	1,466,780
1966	28,758	26,485	32,758	29,485	5.00	40	1,343,190
1967	2,876	2,008	4,876	3,508	5.00	40	164,700
1968	26,037	10,776	56,037	20,776	5.00	40	1,111,225
1969	35,867	15,197	65,867	30,197	5.00	40	1,537,215
1970	26,579	16,558	51,579	31,558	5.00	40	1,520,215
1971	6,388	600	7,388	610	5.00	45	64,390
1972	31,415	8,622	32,615	11,122	6.00	80	1,085,450
1973	79,414	41,573	138,614	73,573	6.00	80	6,717,524
1974	198,331	82,949	353,331	147,949	6.00	50	9,517,436
1975	213,004	92,160	401,004	164,160	6.00	50	10,614,024
1976	77,615	26,248	103,164	34,771	6.00	50	2,357,534
1977	53,665	6,169	78,740	9,195	7.35	100	1,498,239
1978	37	0	537	20	7.25	97	5,833
1979	1,578	589	64,416	38,919	7.50	140	5,931,780
1980	5,815	1,354	241,822	58,766	7.50	105	7,984,095

[1] Information collected from State and Federal pest control specialists.
[2] Initial year based on available State records.
[3] Includes estimates on Federal, State, and private lands.
[4] Estimates from State pest specialists; same values assigned to timber salvaged.

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cannot practically change the soil type on his property, and, in most instances, must work with tree species already established. The major factor that may be effectively manipulated by the landowner or manager is stand density, which may be controlled by thinning. In North Carolina, thinning is usually accomplished by commercial operators who utilize the thinned material for pulpwood or sawtimber. Thus, we set as our project's objective the demonstration of the practicality and efficacy of commerical thinning to reduce SPB damage in the State.

APPROACHES TO MEETING THE OBJECTIVES

Upon determination that commercial thinning was the most practical option for reducing SPB impact, it was necessary to conduct a survey to evaluate whether commercial thinning could be done on a statewide basis. Consequently, a questionnaire was prepared and sent to all county offices to determine the availability of thinning operations. The questionnaire asked county personnel to classify thinning opportunities in their counties as 1) readily available, 2) usually available, 3) difficult, or 4) not available. The results of this survey revealed that in only 30 of the State's 100 counties was commercial pulpwood thinning readily available. In another 23 counties, commercial thinning was usually available, while in the remaining 47, it was difficult or impossible to obtain thinning contractors (fig. 1). Obviously, it was important to concentrate our demonstration areas in those counties where thinning opportunities were greatest.

The next part of our project focused on selecting those counties where SPB had traditionally been a problem. This was done by determining the number of years that showed SPB activity during the 1960–76 outbreak period (fig. 2).

Based on thinning opportunity and past SPB incidence, four counties were selected for demonstration projects. These were Vance, Davidson, Cleveland, and Polk Counties (fig. 3).

Technicians were hired in the selected counties with the sole responsibility of carrying out thinning operations in pulpwood-size stands. These technicians contacted local landowners, explained the program, and offered to make timber examinations. During the examination, a form was completed that detailed stand conditions (fig. 4). The form was developed in cooperation with Dr. Fred Hain, an SPB researcher affiliated with North Carolina State University. The form served the dual function of determining appropriate management recommendations and forming the basis for research analysis in future outbreaks. Data collected on the form included stand species, age, height of dominants, diameter range, basal area, soil type, bark thickness, proportion of live crown, and radial growth rate.

If the timber examination indicated the need for thinning, a brochure (North Carolina Forest Service 1982) explaining the value of thinning as an SPB mitigation measure was given to the landowner. If the landowner agreed to have timberland thinned, the technician marked the crooked, diseased, and suppressed trees for removal with the goal of reducing stand density to a basal area of 80 to 90 square feet. After marking the trees, the technician gave the landowner a list of timber buyers in the area. When actual cutting began, the technician made frequent checks to be sure that the stand was cut as marked and that no undue damage occurred to the residual trees. Following this procedure, some 125 different tracts containing over 1,500 acres were marked and thinned.

DISCUSSION AND CONCLUSIONS

Commercial thinning is an excellent approach to controlling stand density. Research indicates that the less dense stands resulting from thinning should have fewer SPB problems and, when problems do occur, their impact will be less than in dense stands. Although approximately half of the State of North Carolina has little or no thinning operations available commercially, the Piedmont region, traditionally

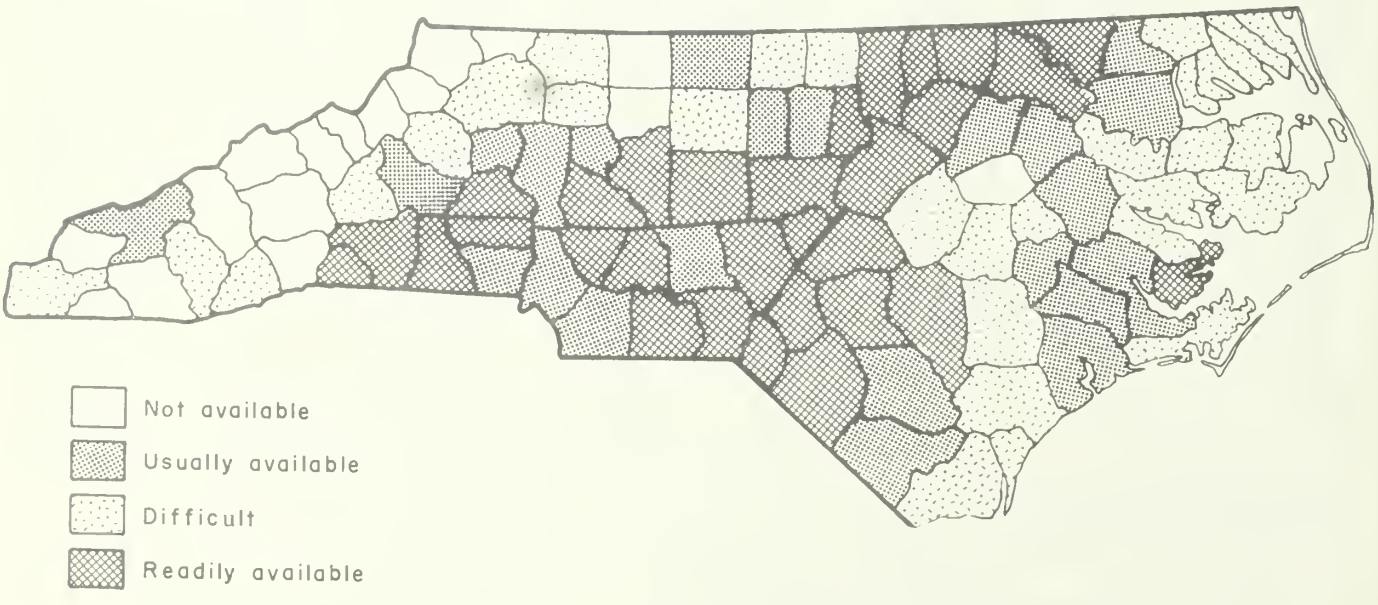

Figure 1—Pine pulpwood thinning operations commercially available in North Carolina, 1982.

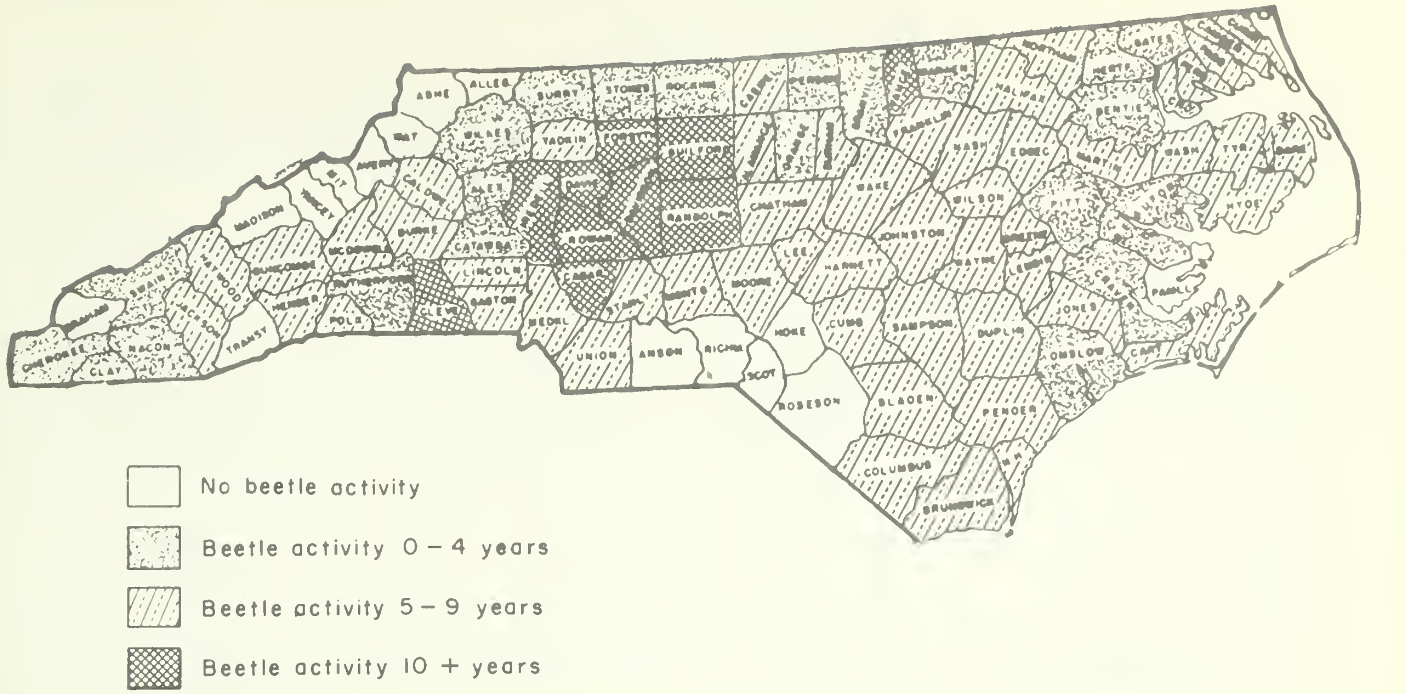

Figure 2—Southern pine beetle occurrence in North Carolina, 1960-76.

the worst SPB problem area, offers the best commercial thinning opportunities.

A thinning demonstration project conducted in North Carolina from 1980–83 indicates that if an effort is made to contact landowners and provide a complete thinning job (e.g., marking and cutting supervision), landowners are receptive to utilizing the operation as an SPB mitigation tool. Although no severe SPB outbreak has occurred since the thinning project ended, when the next outbreak does occur, the project's results will enable us to compare the thinned stands with nearby unthinned stands to demonstrate the technique's effectiveness in reducing SPB damage.

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Figure 3–Counties where SPB thinning projects were located, North Carolina Demonstration Project.

SPB THINNING PROJECT

Landowner____________________ B____ S____ P____

Address____________________

____________________ County

TRACT #					
Acres					
Species (by %)					
Age					
Height of dominants					
Diameter Range					
BA pine					
BA other overstory spp.					
BA to cut					
Soil					
Year last cut					
Date marked					
Date thinned					
Cords per acre removed					
Bark thickness (5 random trees)					
Proportion of live crown					
Radial growth (# rings per last inch)					

If a thinned stand is attacked, redo this form for the attacked plot. Take one bark thickness sample per five trees - maximum of 20 sample trees.

Data taken by:

Figure 4—Stand condition form developed for North Carolina thinning projects.

DEMONSTRATING INTEGRATED PEST MANAGEMENT ON NATIONAL FORESTS IN SOUTH CAROLINA AND GEORGIA

William H. Hoffard and Steven W. Oak[1]

INTRODUCTION

Forest pests have always been major problems on the Tyger and Enoree Districts of the Sumter National Forest (South Carolina) and the Chattooga and Oconee Districts of the Chattahoochee–Oconee National Forest (Georgia). With the exception of the northern third of the Chattooga District (an area located within the Southern Appalachian Mountains), the Districts are entirely on the Piedmont plateau, where decades of land abuse have eroded much of what once was productive topsoil. On the poor soils that remain, tree growth is often slow, and the area's forest cover is susceptible to two of the most significant pests of southern pine: southern pine beetle (SPB) and littleleaf disease (LLD).

During the latest SPB outbreak (1979–80), millions of cubic feet of timber were killed by the beetle on National Forest Ranger Districts in the area described earlier. Likewise, LLD impact within these areas has been enormous. Southwide, at least 15 million acres have been affected by this disease, and damage has been serious enough to affect management on some 5 million acres.

Because of this grim history, these Districts were selected for an Integrated Pest Management (IPM) demonstration project. The project had four primary objectives.

1) Identify existing IPM technologies for the management of pine pests on National Forests.
2) Communicate the IPM technology to Forest Service land managers.
3) Illustrate how the IPM technologies can work to maximize use of National Forest lands for different objectives.
4) Coordinate the work on the Sumter National Forest with the companion demonstration project on State and private land being conducted by Clemson University and the South Carolina Forestry Commission.

APPROACHES TO MEETING THE OBJECTIVES

Identifying Existing IPM Technologies: Objective 1

Several survey and evaluation methods were screened and the ones found most appropriate for the demonstration area (fig. 1) were selected following consultation with area land managers. The techniques chosen were easy to apply and required a minimum of fieldwork for implementation.

While LLD and SPB were of principal concern, fusiform rust, annosus root rot (ARR), and pales weevil were also considered.

Fusiform rust.—Land managers were supplied with a hazard map for fusiform rust generated from an earlier survey of the Sumter National Forest. In the demonstration area, rust is a management concern in limited areas or individual stands. Computer programs for economic analysis of some rust management strategies are part of the IPM Decision Key (Anderson and others 1982; Redmond 1985) and were provided to assist decisionmakers.

Annosus root rot.—As with fusiform rust, ARR is not a major concern within the demonstration area. Nevertheless, high incidence may occur in individual stands, causing severe damage. A root-sampling technique (Alexander 1984) was used in the demonstration area to assess disease incidence and growth loss in individual stands. Further, economic analyses for stump treatments with borax following thinnings were provided through the IPM Decision Key.

Pales weevil.—For this pest, land managers were supplied with the latest management information, as well as an economic analysis computer program. Similar to the fusiform rust management economic model, this program helps land managers determine whether chemical treatment of seedlings or a delay in planting provides the most economical protection against weevil attacks on trees planted in recently cut forests.

Littleleaf disease.—Littleleaf is the most significant disease in the demonstration area. Efforts, therefore, were concentrated on hazard mapping. Methods for predicting LLD damage in shortleaf and loblolly pine stands were developed from intensive research in the Piedmont during the 1940's and 1950's. Investigations were centered in the heart of the demonstration area on the Calhoun Experimental Forest, Sumter National Forest, making the results directly applicable to project needs.

Individual stand hazard was determined by using a rating scale that assigned point values for the critical soil factors—erosion class, soil consistency, depth to zone of greatly reduced permeability, and subsoil mottling (Campbell and Copeland 1954). Though quite accurate, the system requires onsite soil evaluation. Instead, soil series were placed in one of three damage classes based on the close association between risk and the internal drainage characteristics of the soil series (Campbell and Copeland 1954). This approach can be applied without costly, labor-intensive fieldwork.

We interpreted the damage classes as disease-hazard classes and summarized (from published Soil Conservation Service (SCS) County Survey Reports) the internal drainage characteristics critical to the point prediction system of the 20 soil series already grouped by Campbell and Copeland for the area (1954, table 1). We then evaluated the same characteristics for the previously unclassified soil series and assigned them to the appropriate hazard class (table 2). These hazard classes were the foundation from which individual stand haz-

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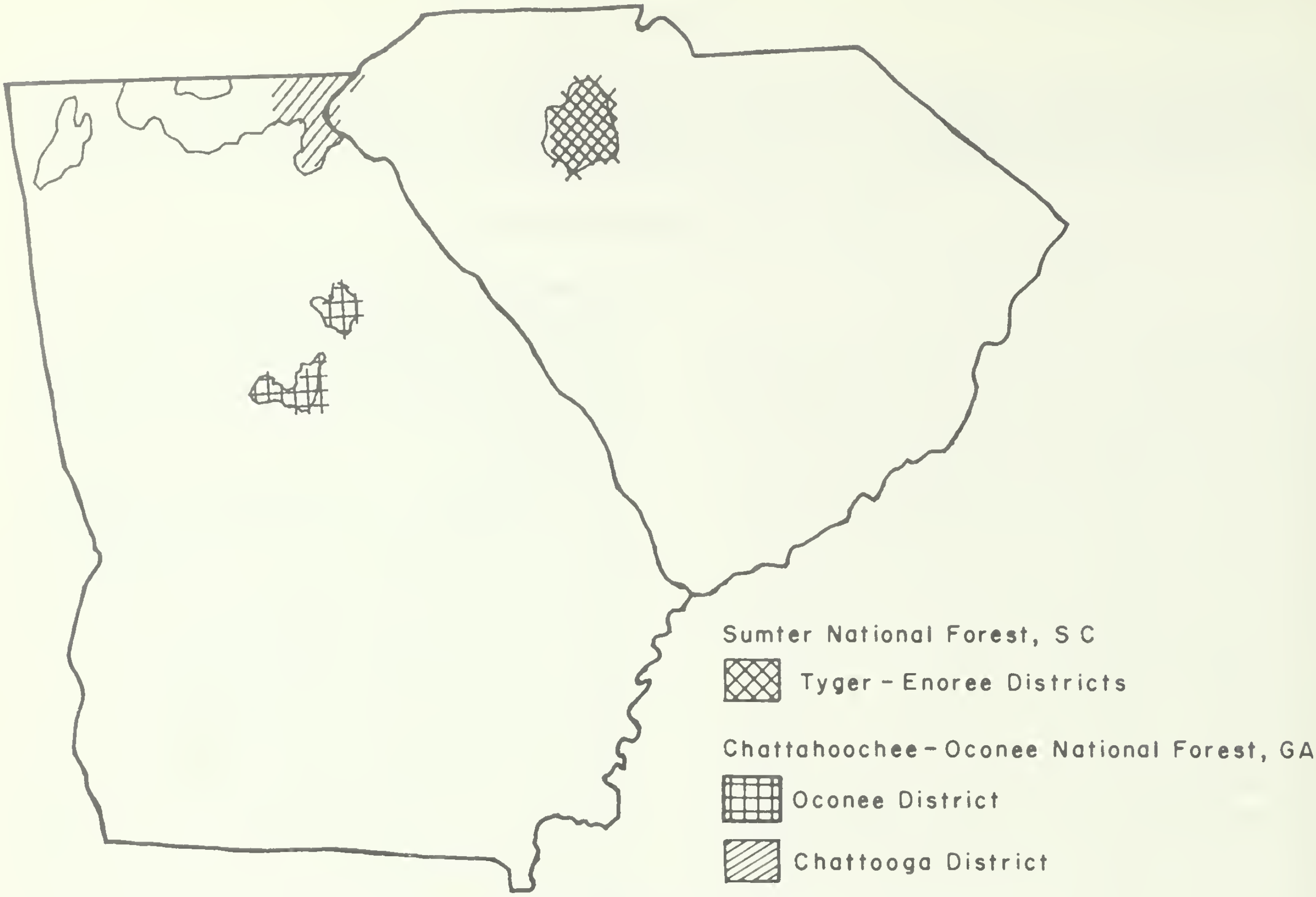


Figure 1—Regional map showing location of districts in demonstration area.

Table 1—*Internal drainage characteristics of soil series in the Sumter National Forest with known relationships to little-leaf damage classes*

	Internal drainage characteristics[1]			
Soil series[2]	Damage class[2]	Subsoil	Permeability	Mottles
Wilkes, Vance, Orange, Catawba, Mecklenburg, Herndon, Tatum, Manteo	High	Mostly clay	Slow to moderately slow with marked reduction at 12 inches or less. *exception:* Herndon	Present within 18–24 inches
Louisa, Madison, Appling, Helena	Inter-mediate	Mostly clay	Moderate to moderately slow without marked change. *exception:* Helena	Usually greater than 24 inches
Lloyd, Nason, Durham, Lockhart, Cecil, Georgeville, Davidson, Alamance	Low	Loamy clay or coarser	Moderate without marked change.	Usually greater than 36 inches

[1] In: Camp and others 1975; Camp and others 1960; Hardee 1982.
[2] Association of soil series with damage class. In: Campbell and Copeland 1954.

Table 2—*Soil series found within the Sumter and Oconee-Chattahoochee National Forests classified for littleleaf disease risk according to internal drainage characteristics of previously classified soils (ref. table 1)*

High	Intermediate	Low		
Winnsboro	Vaucluse	Worsham	Tirzah	Buncombe
Iredell	Colfax	Wickham	Rion	Armenia
Goldston		Wehadkee	Pacolet	Chewacla
Efland		Wateree-Rion	Louisburg	Blanton
Enon		Toccoa	Hiwassee	Altavista
Susquehanna		Enoree	Congaree	Red Bay
		Ailey	Lakeland	Starr
		Orangeburg	Eston	Gwinnett
		Norfolk		

ard classes were determined. Clearly, SCS County soil survey maps were essential to hazard mapping.

Southern pine beetle.—As with LLD, emphasis on SPB was on implementation of stand risk-rating systems and combining the systems with other technology.

Table 3 shows the risk-rating systems used. All systems, with the exception of the LLD system, are products of either the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP) or the Integrated Pest Management Research, Development, and Applications Program for Bark Beetles of Southern Pines (IPM). A more detailed explanation of each SPB rating system follows:

PIEDMONT RISK (Hedden 1985b): This system uses three variables to rate stands for SPB risk: 1) Slope, 2) clay component of soil, and 3) shortleaf pine component of the stand. Table 4 shows how these variables are considered in determining whether risk of SPB attack is high, medium, or low. Since all this information is available through SCS maps and stand records, the ratings can be assigned without onsite visits.

P HAZARD GA (Belanger and others 1981): This system was developed for the Georgia portion of the demonstration area. Four variables (soil surface depth to "A" horizon, radial growth of dominant and codominant trees for the last 5 years, average live crown ratio for all pines, and percentage of loblolly in the total pine component) are used to develop a discriminant score. In turn, this score determines relative susceptibility to SPB as very high, high, medium, or low. This system was not used in the demonstration area, except as a means of validating NF RISK (see below).

Table 3—*Risk-rating systems employed in South Carolina–Georgia IPM demonstration area*

Rating system	District			
	Tyger	Enoree	Oconee	Chattooga
LITTLELEAF	X	X	X	
PIEDMONT RISK	X	X		
NF RISK			X	X
MTN RISK				X
P HAZARD GA[1]			X	

[1] Used to validate NF RISK modification

Table 4—*PIEDMONT RISK system for southern pine beetle*

Shortleaf pine:	*Score*
Yes — more than 50 percent of the pine is shortleaf	1
No — less than 50 percent of the pine is shortleaf	0
Steep slope:	
Yes — slopes are greater than 10 percent	1
No — slopes are less than 10 percent	0
Clay soil:	
Yes — clay loam, clay, silty clay (>28 percent clay)	1
No — sandy loam, sandy clay loam, loam (< 28 percent clay)	0

Risk class	*Risk value* (total score)
high	3
moderate	2
low	1

NF RISK (Lorio and Sommers 1981): NF (National Forest) RISK uses existing computer-based data stored in CISC (Continuous Inventory of Stand Conditions), the program and file the National Forest System uses to describe the changing status of its forest stands. The system has been successfully used to rate for SPB risk on the Kisatchie National Forest in Louisiana. Through confirmation with historical records, it was found that certain CISC data, such as "Stand Condition Class" (e.g., "immature sawtimber"), could be reliably associated with SPB risk. With the assistance of Roger P. Belanger of the Southeastern Forest Experiment Station, the system was modified for conditions on the Oconee and southern Chattooga (Piedmont section) Districts in Georgia. Modifications for the Georgia Piedmont principally reflected site index differences and Piedmont littleleaf influences as they relate to SPB risk. Figure 2 shows the modified flowchart sequence for the Georgia Piedmont.

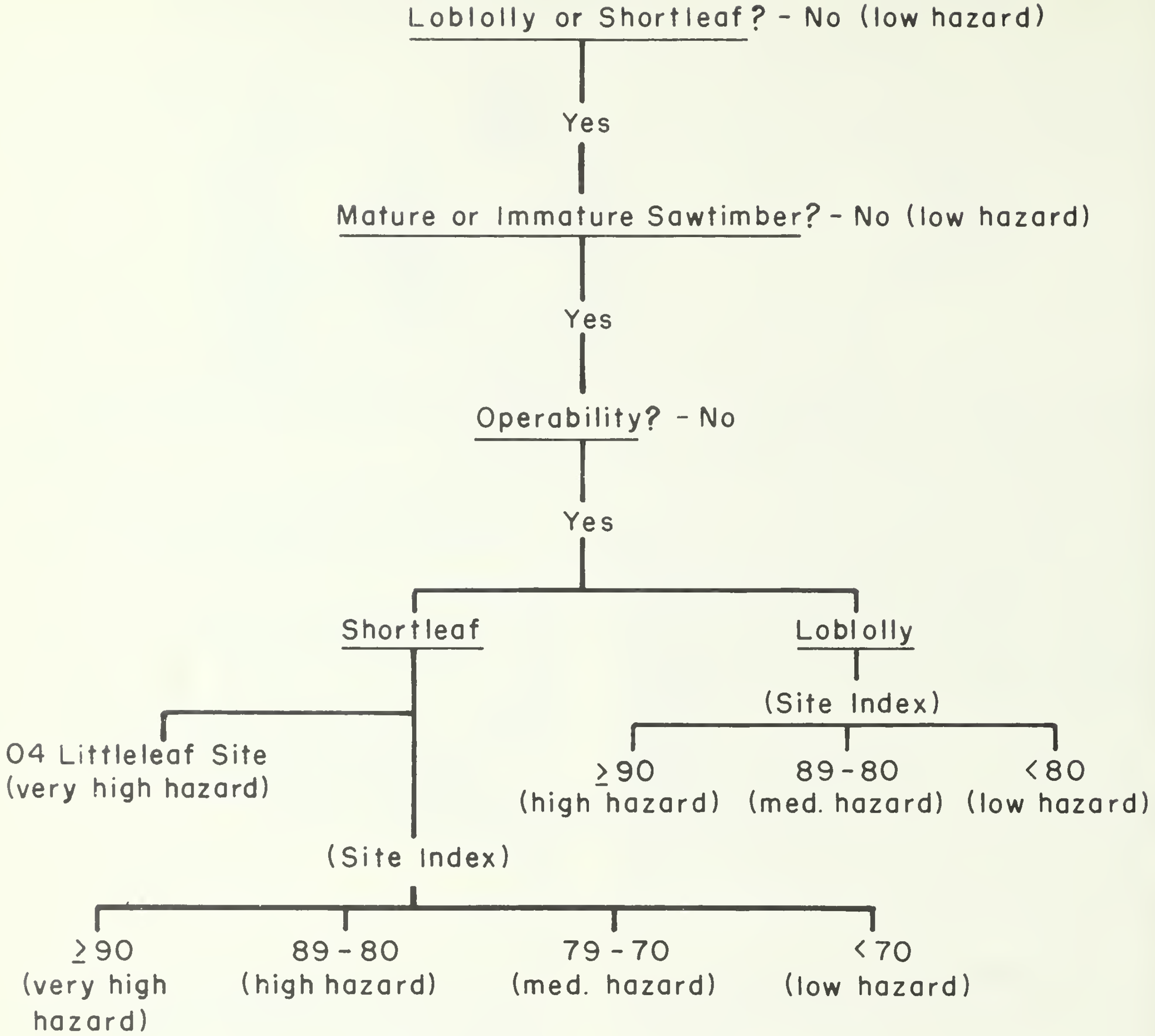


Figure 2—NF RISK flowchart modified for the Oconee National Forest.

Figure 3 shows the percentage of very high, high, medium, and low risk stands on the Oconee and Piedmont regions of the Chattooga District.

MOUNTAIN RISK (Hedden 1985a). This system reliably projects SPB risk in mountain stands where shortleaf, Virginia, pitch, and Table Mountain pines are a significant component of the forest cover. The system was developed within the demonstration area and, when applied in a larger area, correctly rated more than 80 percent of the stands.

Communicating IPM Technology to Land Managers: Objective 2

Assimilation and continued application of IPM technology require that the products of hazard rating (hazard maps) be provided in a form that is compatible with current management methods. Maps were prepared to aid in the compartment prescription process at the Ranger District level.

Three distinct phases were involved in providing information and involving land managers in the application of hazard rating. The first phase made them aware of the procedures used in rating stands for SPB and LLD and in developing hazard maps. Project personnel converted SCS maps to the scale of currently used compartment maps, color-coded soil types according to hazard, set criteria for determining individual stand hazard, and manually produced hazard maps.

In a second phase, only the essential information (SCS soil maps at the appropriate scale, with hazard classes coded) was provided to land managers. This gave them the flexibility of developing their own criteria for hazard rating stands. For example, one manager might rate a stand high hazard if 50 percent of its acreage was on high-hazard soil, while another might consider any high-hazard soil as sufficient reason for a high rating.

The final phase supplemented this flexibility by computerizing the mapping process for increased speed and accuracy in data retrieval and map reproduction, long-term data storage, and use of information developed for pest management for other resource management situations. This was accomplished

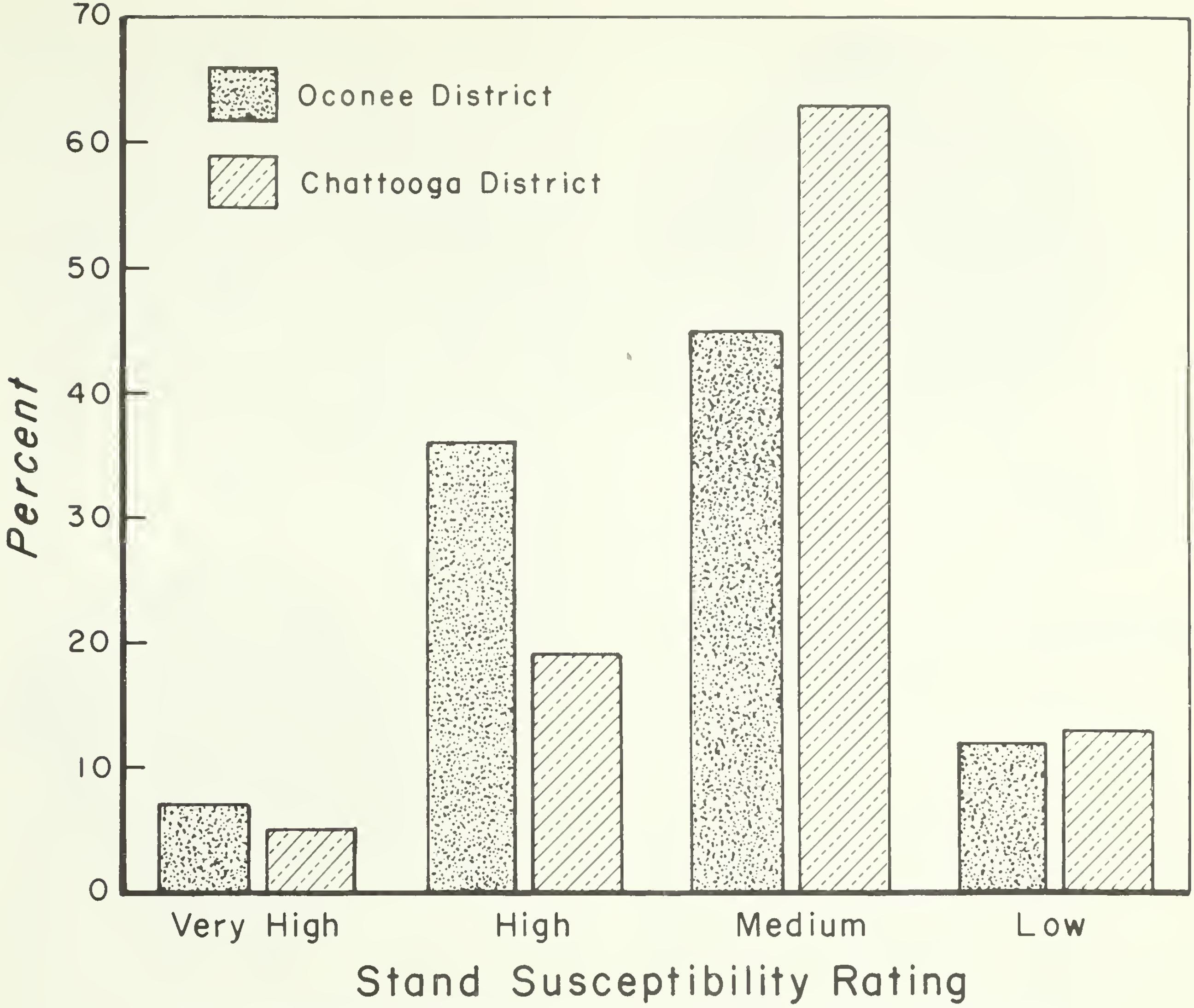


Figure 3—Percentage of total acreage susceptible to southern pine beetle as classified by NF RISK (Piedmont region only).

by using a computerized Geographic Information System (GIS) developed by R.L. Beveridge of the USDA Forest Service, Region 4, Boise, Idaho (Beveridge and Knapp 1984). This GIS consists of programs prefixed PEST and was originally developed to assist in summarizing and mapping forest pest data collected during aerial surveys of 13.5 million acres of forest land in the West. It allows entry of point data (e.g., beetle spots) or polygon data (e.g., an area of high-hazard soil), data summary and editing, map plotting, and the overlaying of data files to determine areas of commonality (e.g., overlaying soil hazard with forest type—fig. 4).

PEST programs were originally developed to store and edit plot data over a large geographic area (half of a 7.5-minute quad map or about 110 mi^2) using a Hewlett-Packard desktop computer, digitizer, and plotter. Modification was needed to run the programs on our equipment and process information for a much smaller area (about 4 mi^2). While losing the capability of generating larger area maps (e.g., showing LLD hazard soils on an entire District or Forest), it did allow for the production of hazard maps for individual compartments at the same scale as maps currently in use on the Ranger Districts.

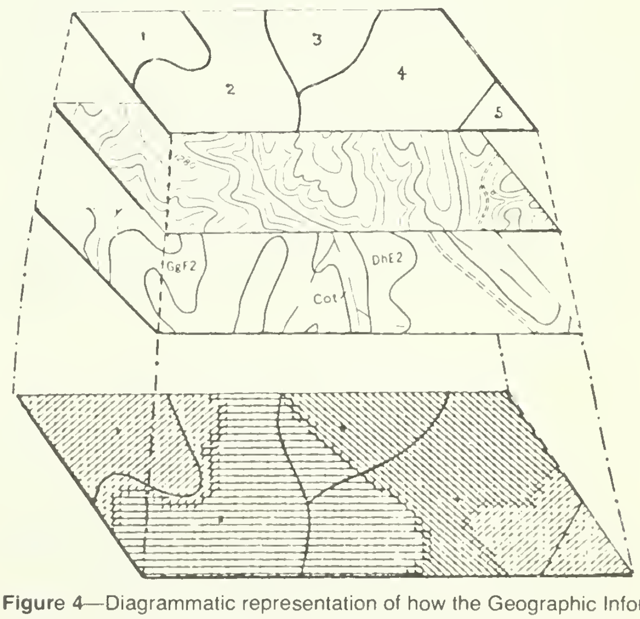


Figure 4—Diagrammatic representation of how the Geographic Information System compares various strata. Digitized map (*bottom*) is based on "stacking" data from three strata (in this case, stand, topographic, and soils information).

The steps involved in generating maps similar to hazard maps with PEST programs are described in Beveridge and Knapp (1984).

A stand boundary map can be plotted on a transparency film and directly overlayed onto the LLD soil hazard map to assist land managers in locating relative positions of various hazard class soils within existing stands (figs. 5 and 6). When combined with the tabular summary of acreage by hazard class for each stand, these maps allow informed decisions to be made about hazard rating of existing stands. Further, they can be used in monitoring high-hazard areas during pest outbreaks, in decisionmaking for intermediate cultural treatments (e.g., preventive or salvage thinning), and in lowering the pathological rotation age.

Illustrating How IPM Technologies Work on National Forest Lands: Objective 3

The third objective of the project was accomplished in four steps:

1) Demonstration of computerized decisionmaking aids.
2) Incorporation of hazard-rating and decisionmaking aids into the compartment prescription process.
3) Survey of previously undocumented losses from LLD in loblolly stands.
4) Field demonstrations of the assessment techniques and applications.

Demonstration of computerized decisionmaking aids. —Miniterm computer terminals were placed on the Tyger and Enoree Districts in South Carolina. These terminals provide access to technology available on the Forest Pest Management host computer in Doraville, GA. Programs available to the Districts included the Integrated Pest Management Decision Key, which considers a variety of variables in formulating pest management recommendations for specific site-stand-pest conditions, and several economic models that permit a detailed financial analysis of pest management alternatives. These economic models dealt with such pests as fusiform rust, ARR, SPB, and pales weevil.

Additional technology was also transferred to District personnel through training sessions, publications, and close work with individual professionals.

Incorporation of hazard-rating and decisionmaking aids into the compartment prescription process.—The hazard-rating maps were placed in compartment prescription files for continuing reference. They will be used for 10 years, after which the areas will be reexamined and management options reevaluated.

The maps and tables will influence silvicultural prescriptions, including thinning, species selection, and stand conversion. This information helps to ensure that pest management is considered in formulating silvicultural strategies.

Survey of previously undocumented losses from LLD in loblolly stands.—A survey of LLD in loblolly pine stands was carried out on the Tyger and Enoree Districts cooperatively with Clemson University (Dr. Frank Tainter) and Sumter National Forest personnel. The survey was conducted in response to concerns by Forest Service foresters that loblolly was sustaining noticeable damage in many areas and management guidelines for such stands were not available. Symptoms included yellow foliage, foliage dwarfing and tufting, branch dieback, and reduced annual increment. Land managers also reported "negative growth" over 10-year measurement periods in some damaged stands due to the combined effects of tree mortality and very poor growth.

We illustrated the losses by surveying damaged stands and determining: a) Incidence of damage, b) growth reduction due to LLD, and c) inception of growth reduction relative to expression of crown symptoms. It is hoped that results of the survey will be useful in determining pathological rotation ages on different hazard sites, scheduling presalvage thinnings, and determining the need for stand conversion to hardwoods.

Preliminary analyses indicate that: 1) Trees with light and severe crown symptoms (impacted trees) grow significantly less than healthy trees but do not differ from each other; 2) growth of impacted trees culminated between age 30 and 4O but had not culminated in healthy trees by age 50, 3) incidence of impacted trees averaged 15 percent on high- and intermediate-hazard soils and 5 percent on low-hazard soils.

Further analysis is needed to determine: 1) The relationship between the onset of crown symptoms and growth reduction (this will aid in survey and damage assessment), and 2) specific guidelines on stand management (the level of reduction that warrants action).

Field demonstration of the assessment techniques and applications.—The ARR sampling technique was demonstrated on the Savannah River Plant and on four National Forest Ranger Districts outside the Piedmont demonstration area. This disease can cause mortality or growth reduction and can be a significant constraint to management in thinned pine stands. Until recently, evaluation of ARR losses was limited to mortality. With the new ARR sampling system, growth reduction can also be determined. Root samples are systematically taken in thinned pine stands, the percentage of infected roots discovered, and the growth loss quantified through a computer growth and yield simulator called GY-ANNOSUS (Hokans and Alexander 1985).

The need to reinstate ARR preventive stump treatment was demonstrated after the sampling system was applied in four thinned but untreated pine stands on the Savannah River Plant. High disease incidence was also present in thinned stands outside the traditional ARR high-hazard area.

Coordination With South Carolina's Companion Demonstration Project on State and Private Land: Objective 4

The companion projects conducted in concert with the Forest Service-funded project by Clemson University and the South Carolina Forestry Commission had significantly different objectives, emphases, and client groups, but addressed the same issue— the implementation of current IPM technologies to reduce pest-caused losses in South Carolina. Close coordination and cooperation were needed not only to avoid duplication of effort but also to bring the results of the individual projects to as many groups as possible. Efforts ranged from extensive collaboration on specific projects to more limited roles as sources for information about other project

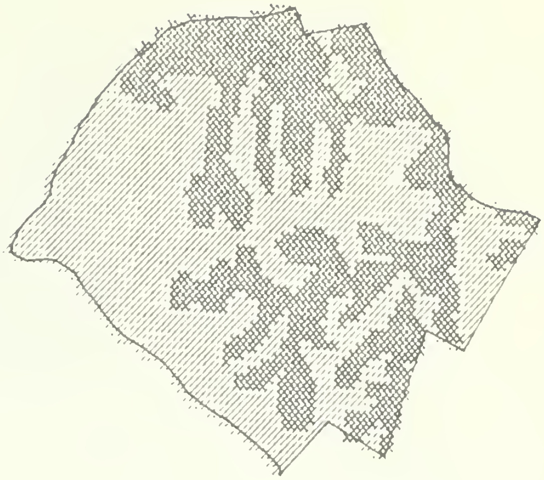
Littleleaf soil hazard
Compartment 101
Enoree Ranger District
Sumter National Forest, SC

Hazard	L	M	H
Strata	1	2	3

STAND	STRATA 1	STRATA	STRATA 3
1	25.26	8.36	159.13
2	14.77	9.33	26.74
3	34.49	29.95	197.37
4	0.00	.76	45.22
5	.54	2.31	16.04
6	17.91	0.00	9.26
7	6.49	12.83	12.61
8	0.00	0.00	12.36
9	0.00	0.00	25.30
10	12.76	6.70	6.63
11	6.81	6.02	38.38
12	[illegible]	0.00	16.76
13	[illegible].42	11.96	119.06
14	3.03	0.00	16.90
15	1[illegible].14	10.95	4.50
16	[illegible]1.69	26.63	18.45
17	0.00	.22	[illegible]2.77
18	0.00	0.00	4[illegible].36
19	1.15	18.70	23.46
	4.76	6.41	7.35
TOTAL	249.22	151.13	81[illegible].65

COMPARTMENT 101
SUMTER NATIONAL FOREST,
ENOREE RANGER DISTRICT
ACREAGE OF LITTLELEAF BY
HAZARD CLASSES (STRATA)
AND STANDS

Figure 5—Littleleaf disease hazard map produced by GIS with tabular output. Stand map (*top*) is electronically overlayed on soils map (*middle*). The accompanying computer program (*bottom*) tabulates stand acreage by hazard class. Stand and soil hazard maps can be manually overlayed by plotting one map on a transparency.



SPB hazard
Compartment 101
Enoree Ranger District
Sumter National Forest, SC

Hazard	L	M	H
Strata	1	2	3

STAND	STRATA 1	STRATA 1	STRATA
1	66.49	42.03	83.73
2	29.04	0.00	14.54
3	77.65	90.88	104.91
4	11.44	35.35	.61
5	15.42	.51	3.17
6	0.00	3.64	22.64
7	24.12	3.10	0.00
8	0.00	10.96	1.52
9	0.00	19.23	7.89
10	6.27	6.21	11.94
11	5.63	33.40	11.17
12	0.00	14.27	4.76
13	47.29	59.71	38.86
14	14.88	1.75	2.83
15	10.26	0.00	14.64
16	57.28	64.30	19.84
17	2.36	0.00	20.17
18	21.35	1.92	20.38
19	17.51	5.33	20.75
20	15.08	0.00	0.00
TOTAL	422.07	39[illegible].59	404.33

COMPARTMENT 101
Sumter N.F., ENOREE [illegible]
ACREAGE OF SOUTHERN PINE
BEETLE BY HAZARD CLASSES
(STRATA) AND STAND.

Figure 6—Southern pine beetle soil risk map produced by electronically resorting soil series according to criteria identified in the PIEDMONT RISK system. Soil hazard is one of three components that determine SPB risk.

Figure 7—Stand risk for southern pine beetle on Compartment 154, Oconee National Forest, as determined with modified NF RISK.

activities. For example, the survey of LLD occurrence and losses in loblolly pine on the Sumter National Forest involved collaborative planning, field data collection, and data analysis with the Clemson project. Similarly, a slide-tape on LLD and its effective management was jointly developed by Clemson and USDA Forest Service investigators.

LLD hazard-rating methods were taught at formal workshops organized by Clemson University. Combined participation of all projects in informal status reporting sessions for different client groups served the objectives of all. Finally, USDA Forest Service land managers were informed through workshops and field demonstrations of the portable sawmill (South Carolina Forestry Commission), the ARR management system and sampling method, the IPM Decision Key, and other pest management software available to foresters (Clemson), and the Clemson Pest Management Information Center.

CONCLUSION

The South Carolina—Georgia project demonstrated the importance of considering pests in forest resource management. With the latest technology (much of it developed through ESPBRAP and the IPM Program), foresters and technicians can accurately rate LLD and SPB risks. Computer programs like the Integrated Pest Management Decision Key and economics models help foresters devise prescriptions for management of LLD, fusiform rust, ARR, SPB, and pales weevil that are practical and cost effective. Computerized technology is now in a form that is easy to understand and adapt to existing conditions.

The demonstration project concentrated on the specific needs of the Federal forester. Efforts were made to ensure that the appropriate technology was adapted to the Southern Region's existing specifications and formats. Examples include digitizing hazard maps to the same scale as USDA Forest Service compartment prescription maps and modifying the CISC system to project SPB hazard with existing site/stand data.

One important element of technology transfer is continued application. Since compartment data are reevaluated and updated at 10-year intervals, the maps and other information provided by this project for each compartment file will be used by foresters for at least a decade.

Throughout the project, work was coordinated with the companion South Carolina demonstration project to prevent duplication of effort and ensure a more comprehensive approach.

In the years to come, Forest Pest Management in the Southern Region will continue to monitor District use of the technology to verify its validity and consider the incorporation of new information as it becomes available.

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SOUTHERN PINE BEETLE PREVENTION AND CONTROL MEASURES FOR NONINDUSTRIAL PRIVATE LANDOWNERS IN SOUTH CAROLINA

Michael C. Remion and Andrew J. Boone[1]

INTRODUCTION

Southern pine beetle (SPB) has become an increasingly important pest of pine forests in South Carolina. As early as 1804, General Charles Pinckney described the severity of the SPB problem when he reported the loss of 5,000 acres in a 7,000-acre pine plantation 26 miles north of Charleston. In a recent outbreak (1972–74), over 781,000 cords and 251,000 M fbm of pine were killed by the insect (table 1).

In October 1982, a cooperative Federal–State–university demonstration project was implemented in South Carolina. This project involved the cooperative interaction of the South Carolina Forestry Commission (SCFC), Clemson University, and the USDA Forest Service. The overall goal of the State project was to provide nonindustrial private forest (NIPF) landowners with small holdings with effective control and prevention measures to reduce current and potential timber losses caused by the SPB. The objectives were to:

1. Develop educational displays for the identification, prevention, and suppression of SPB infestations.
2. Develop a training program for SCFC personnel to improve and standardize SPB aerial and ground detection and suppression approaches.
3. Demonstrate the use of aerial photography and radio navigation aids in locating spots.
4. Develop and demonstrate a stand hazard-rating system for SPB in the Piedmont Region of South Carolina.
5. Develop leaflets and public service announcements relating to SPB identification, timber utilization, prediction, prevention, and suppression.
6. Demonstrate silvicultural practices to reduce stand susceptibility to SPB attack.
7. Conduct portable sawmill (Mobile Dimension Saw®) demonstrations.

Work on objectives 4 to 6 was contracted to the Clemson University Department of Forestry (CUDF) by the Commission.

APPROACHES TO MEETING THE OBJECTIVES

Educational Displays

This approach was designed to educate and inform NIPF owners and forest managers of the proper techniques of identifying, preventing, and suppressing SPB spots. To achieve this goal, the SCFC constructed permanent, modular display units complete with lighting systems for each of its seven districts. Two copies each of three photographic transparency sets and graphics were developed for these display units. These visual aids displayed information on the identification of the SPB and the damage it causes, recognition of SPB high-hazard stands, and the use of forest management practices to prevent or reduce losses, and the proper application of effective control methods. The displays were used at large landowner association meetings, State fairs, and farm-city week festivals.

SPB slide-tape programs and projectors were provided to all SCFC districts. These programs were used by Commission foresters to transfer the latest technology concerning SPB identification, hazard rating, prevention, and control to forest landowner associations and related groups. Forty-five presentations were made involving approximately 1,350 landowners, foresters, and forestry technicians.

Training for SCFC Foresters

The SCFC is responsible for detecting and suppressing forest pest outbreaks on both State and private lands in South Carolina. An urgent need existed to intensify training of SCFC personnel involved in SPB aerial and ground detection and suppression operations. Accordingly, 18 training sessions were conducted for 124 SCFC personnel using techniques such as slides and maps to achieve the level of awareness desired.

Personnel involved as observers in aerial detection and suppression surveys were shown aerial slides of SPB infestations of known size. From these slides, the size (number of trees) of the spots was estimated and recorded. Instructors then compared each observer's estimate with the known number of trees in each infestation to determine accuracy in estimating infestation size. Training continued until all observers reached 90 percent accuracy in estimating spot size.

Training was also conducted in the field with personnel involved in SPB suppression activities. This training included locating spots using aerial photographs, delineating spot boundaries for control, and laying out roads for access to spots that were to be salvaged.

Use of Aerial Photographs

This effort focused on demonstrating the use of aerial photographs as an aid in locating SPB infestations for suppression. In 1981–82, the SCFC joined with the USDA FS Aerial Survey Team from Doraville, GA, to cooperatively test an

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Table 1—*Southern pine beetle damage estimates in South Carolina 1960–80*[1]

Calendar year[2]	Estimated volume salvaged[3]		Total volume killed		Stumpage values[4]		Total value
					Pulpwood	Sawtimber	
	Cords	M fbm	Cords	M fbm	$/cords	$/M fbm	$
1960	0	390	0	3,900	0.00	32	124,800
1961	0	221	0	2,210	0.00	34	75,140
1962	11,400	400	43,000	90,000	5.00	36	3,455,000
1963	250	324	1,650	2,162	7.00	32	80,734
1964	50	46	360	455	7.00	32	17,080
1967	834	701	8,340	7,009	7.00	37	317,713
1968	1,352	1,009	13,517	10,093	7.00	40	498,339
1969	1,604	629	16,044	6,292	6.00	35	316,484
1971	400	30	1,470	142	6.00	30	13,080
1972	15,500	7,918	250,000	12,218	7.00	52	2,385,336
1973	120,135	7,640	284,335	124,440	8.00	89	13,349,840
1974	193,310	16,911	247,310	114,541	7.00	70	9,749,040
1975	85,214	10,606	85,214	31,235	7.00	60	2,470,598
1976	19,274	510	19,274	510	7.00	60	165,518
1977	236	25	393	42	7.00	54	5,000
1978	0	0	0	0	0.00	0	0
1979	41,800	6,722	46,815	28,010	12.00	160	5,043,380
1980	173,095	1,474	184,099	23,586	13.00	106	4,893,403

[1] Information collected from State and Federal pest control specialists.
[2] Initial year based on available State records.
[3] Includes estimates on Federal, State, and private lands.
[4] Estimates from State pest specialists; same values assigned to timber salvaged.

aerial sampling method for measuring timber mortality caused by bark beetles over a large area of mixed ownership in South Carolina. Aerial color infrared negatives resulting from this test were used to make photographic prints for the demonstration project.

Prints for all of the forested area in 31 counties were provided to SCFC project foresters in the respective districts. A full set of these same photographs was retained by SCFC's Insect and Disease Section. Ten training sessions were offered to 45 SCFC foresters to instruct them in the use and interpretation of new photography. The photographs provided the SCFC with an initial baseline record for a continuous recordkeeping system of SPB infestations throughout the State. They were also being used by project foresters for hazard-rating stands for management plans, suppression activities, thinnings aimed at reducing stand SPB hazard, and maintaining healthy forests.

The SCFC established an aerial photography cooperative committee to make prints of the new photography available to landowners. Committee members included representatives from the SCFC, consulting foresters, and industrial foresters. Through this committee, 3,600 prints were provided at cost to some 84 landowners throughout the State.

In years to come, this newly acquired photography will be used to prepare SPB occurrence and severity maps for each county affected by SPB and ultimately to validate SPB hazard-rating systems.

Development of a Stand Hazard-Rating System

To develop an SPB hazard-rating system in the Piedmont Region of South Carolina, Clemson University and the Commission collected data on more than 50 SPB spots. SPB losses in the Piedmont were found to be closely related to stand density, soil, and host tree characteristics. Using data collected during the project and logistic models (Reed and others 1980) developed in other States relative to probability of SPB occurrence, Clemson developed an SPB hazard-rating system for the Piedmont Region. This system addressed both SPB spot incidence and spread. The newly developed system was field tested by SCFC foresters and found to correctly rate stands 82 percent of the time.

This system's methodology was later published (in leaflet form) (fig. 1) under the IPM Demonstration Project (Hedden

Figure 1—Hazard-rating and prediction leaflets for the southern pine beetle in the South Carolina Piedmont.

and Karpinski 1983; Karpinski and others 1984). Twelve training sessions involving 84 SCFC foresters and industrial foresters were conducted to train them in the use of the system.

SCFC project foresters are currently using this system in woodland examinations and incorporating the results into management plans.

Leaflets and Other Educational Materials

This effort was designed to develop educational materials relating to the identification, prevention, and control of SPB. The material developed by Clemson was targeted at the nonindustrial, private landowner. Leaflets prepared and distributed by Clemson's Department of Forestry and Cooperative Extension Service and the SCFC are tabulated in table 1.

These publications were developed to meet the needs of the NIPF owners in South Carolina and an estimated 10-year supply was printed. During the 1984 SPB outbreak, approximately 5,000 copies of each publication were distributed to forest landowners and industrial forest managers who have CFM programs.

In addition to these publications, three 30-second public service announcements (PSA's) for television were prepared (table 2). These announcements addressed the identification of SPB infestations, the prevention of SPB spots through forest management practices, and the control of SPB spots.

Table 2—*Summary of leaflets, fact sheets, and public service announcements prepared for use in the South Carolina demonstration project*

Project	Prepared by	Media	Title (description)
Educational material	Clemson University Cooperative Extension Service and Department of Forestry	Forest Leaflet 5	Identifying the southern pine beetle
		Forest Leaflet 6	Salvage removal, a method for controlling SPB infestations
		Forest Leaflet 7	Cut and leave, a method for controlling SPB infestations
		Forest Leaflet 8	Estimating potential loss from the southern pine beetle
		Forest Leaflet 11	Predicting potential loss to southern pine beetle in natural stands in the Piedmont
		TV PSA	30-second announcement on SPB infestation identification
		TV PSA	20-second announcement on SPB prevention
		TV PSA	30-second announcement on SPB control
Portable sawmill	Clemson University Cooperative Extension Service and Department of Forestry	Forest Leaflet 9	Portable sawmill operators in South Carolina
		Forest Leaflet 10	So . . . you want to buy a portable sawmill!
		Forest Leaflet 12	Don't leave your trees to rot in the woods . . utilize them!
	SCFC	Fact sheets	Integrated pest management project in SC
			Portable sawmill lease demonstration conducted by the SCFC (two fact sheets)

They were targeted at landowners to inform them of approaches for dealing with the SPB problem in South Carolina.

Copies of the three PSA's were provided to all TV stations within the State and also those in adjoining States that telecast to South Carolina. Copies of the spots were also provided to the Information and Education Section of the Commission for further use.

Illustrating the Feasibility of Silvicultural Practices

This effort was initiated by Clemson to demonstrate the compatibility of silvicultural practices for reducing stand hazard to SPB with the diverse management objectives of the NIPF owners. To achieve this goal, demonstration areas on NIPF lands were established to illustrate to consulting foresters, SCFC foresters, extension workers, and landowners with small holdings the feasibility of using silvicultural practices to alter stand conditions favorable to SPB attack.

Seven demonstration areas were established in the Piedmont of South Carolina, and management plans were prepared for each tract based on the landowner's objectives. Silvicultural prescriptions to reduce stand hazard were included in each plan and the practices implemented on each tract. Following treatment of the demonstration areas, a monitoring program was initiated to document effectiveness of the practices in reducing SPB losses over the years.

To date, approximately 10 visits have been made to each of the demonstration areas for "show-me" trips. Complete slide series have been developed for each tract showing "before and after" silvicultural treatments. Additional pictures will be taken in future years to document the actual effects of the various treatments in reducing and/or preventing losses due to SPB.

Demonstration and Use of the Portable Sawmill

The sawmill demonstration work in the South Carolina project (fig. 2) has involved three phases: Phase I was concerned with planning, purchase, and training; Phase II involved demonstrations in the Piedmont Region of South Carolina; and Phase III involved demonstrations in the Sandhills and Coastal Plains Regions of South Carolina.

Three methods were used: 1) Public demonstrations, 2) lease demonstrations, and 3) sawmill study demonstrations. (See table 3 for a summary.)

Public demonstrations.—Public demonstrations were organized and targeted to reach the nonindustrial, private landowner. Each public demonstration was scheduled for a single day, and the public was invited to attend by means of radio-television announcements and news releases. SCFC personnel organized the meetings and demonstrated the sawmill, and Clemson Extension personnel presented educational programs at each session.

Landowners involved in the demonstrations were required to cut and deck their own logs and provide two individuals to assist SCFC personnel during the demonstration. Landowners retained the lumber sawed during the demonstrations for their own personal use at no charge.

Through December 1984, some 30 demonstrations had been conducted in 17 different counties, reaching a total of 16,234 people. In 1985, an additional 15 public demonstrations are scheduled.

Lease demonstrations.—Lease demonstrations were offered for small, private landownerships on the following priority basis: 1) Landowners with active beetle infestations, 2) landowners with beetle-killed (inactive) timber, and 3) landowners with thinning operations scheduled to reduce SPB hazards.

Under a lease demonstration agreement, landowners were required to cut and deck their own logs, provide at least two individuals to assist SCFC personnel in loading logs and stacking lumber, and pay $10 per board foot of lumber sawed and a one-time $20 "setup" fee. In cases where less than 1,000 board feet was sawed, a minimum fee of $120 was incurred by the landowner.

The maximum time allowed for each lease agreement was 2 weeks or 40 working mill hours, whichever occurred first. Under terms of the agreement, the SCFC leased the mill and two operators to maintain and physically operate the mill. Lumber sawed during these demonstrations was retained by the landowner. Lease demonstrations were open to the general public at the landowner's discretion.

Through December 1984, a total of 16 lease demonstrations had been conducted in six different counties reaching 163 people. An additional 10 lease demonstrations are planned during 1985.

Sawmill studies.—Seven sawmill studies were conducted during Phase II. These involved the collection of data to prepare a brochure on cost analysis, efficiency, and effectiveness of the Mobile Dimension portable sawmill.

Table 3—*Summary of portable sawmill demonstrations in South Carolina for the period August 1983–December 1984*

Type of demonstration[1]	Demonstrations	Counties covered	Total visitors	Mill operation	Total sawed
	Number			*Hours*	*Board feet*
Public	30	17	16,234	216	46,021
Lease	16	6	163	217	46,780
Sawmill study	7	5	151	95	15,383
Totals	53	--	16,548	528	108,184

[1] Educational programs were presented at all public demonstrations by the South Carolina Forestry Commission and or the Clemson University Cooperative Extension Service.

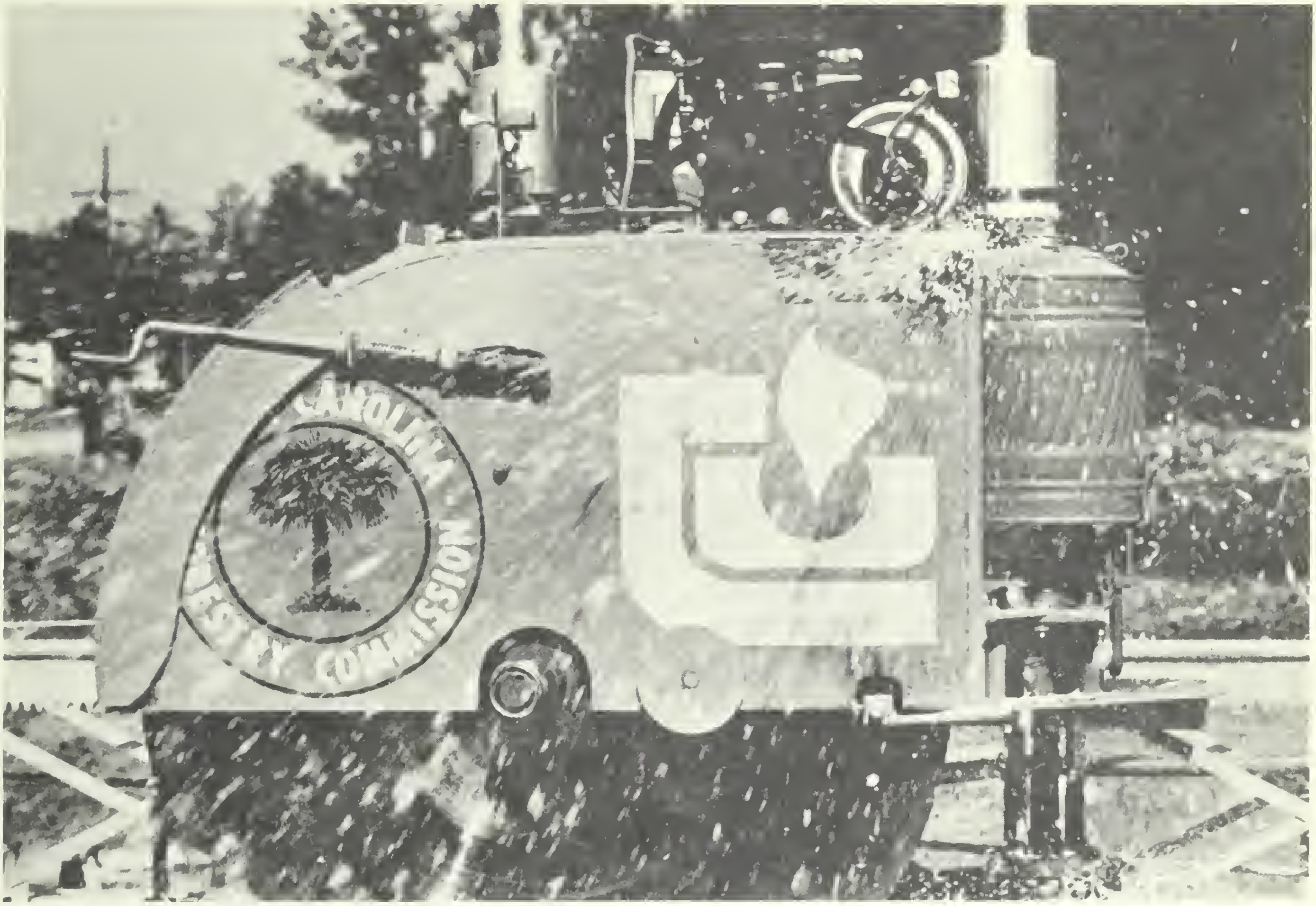

Figure 2—Use of portable sawmill process for beetle-killed sawlogs on nonindustrial private lands.

Variance in lumber thickness and width was measured on boards at the ends and midpoints. Also, logs were scaled prior to sawing and lumber scaled following sawing to determine the waste factor. Detailed fixed and variable costs were recorded to determine actual costs per 1,000 board feet of lumber produced.

During Phase III of the sawmill demonstration, the Commission plans to develop and print a pamphlet on air drying and stacking of lumber and a manual on cost analysis and efficiency of the Mobile Dimension portable sawmill. Leaflets and fact sheets prepared and distributed during this project are also tabulated in table 1.

The SCFC constructed a portable display on IPM and an appropriate sign to accompany the sawmill demonstrations. A video program was also developed by the SCFC for use at public demonstrations when only the mill was on display. This program was effectively used with the sawmill at the South Carolina State Fair in October 1983. An estimated 12,500 people visited the exhibit.

Ongoing training sessions with project foresters, conducted by the SCFC Insect and Disease Staff, focus on new IPM technologies to encourage and stress the importance of incorporating IPM practices in management plans on State and private forest lands.

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INTEGRATED FOREST PEST MANAGEMENT PRACTICES IN SOUTH CAROLINA

D. L. Ham, C. Karpinski, F. H. Tainter, and R. L. Hedden[1]

INTRODUCTION

In South Carolina, losses caused by forest pests have been unnecessarily high, especially on nonindustrial private ownerships, which comprise over 70 percent of the commercial forest land in the State. Southern pine beetle (SPB), littleleaf disease, fusiform rust, annosus root rot (ARR), as well as other pests, cause mortality and growth losses conservatively estimated to have exceeded $8 million each year during the 1970's (Anderson and others 1981; Price and Doggett 1982). Historically, convincing farmers and other landowners to implement sound forest management practices, which would include pest management, has been very difficult.

Private landowners (as well as many professional foresters) lack a real understanding of the value and compatibility of forest/pest management practices with various ownership objectives. As a result, pest management has often been left to chance, and serious losses have occurred when landowners have had to respond to crisis situations.

A demonstration project involving the cooperative efforts of Clemson University, the South Carolina Forestry Commission, and the USDA Forest Service appeared to be the best way of increasing implementation of the latest pest management approaches. Because of the extensive forest acreage owned by nonindustrial private individuals, we believed that there was primarily a need to address this ownership group. Although considerable attention was focused on this audience, cooperative interaction with professional resource managers and Extension specialists also enhanced efforts to reach the principal users, the nonindustrial landowners. Cooperative Extension Service personnel and agency, industry, and consulting foresters had the personnel network and local contacts to make technology transfer effective. By receiving training, materials, and information through the Integrated Pest Management (IPM) project, these professionals also increased our ability to disseminate information and, in all cases, participated in a true cooperative spirit.

Our ultimate goal was to provide the most up-to-date technology on forest pest management and to present and demonstrate it in a manner that would convince landowners of its value and applicability to their specific situations. This approach was in keeping with our philosophy throughout the project that technology transfer must go beyond simply packaging information. It must interpret results and information while educating the user about its value and applicability.

The project focused on the major pest problems in South Carolina, the SPB/littleleaf problem in the Piedmont and fusiform rust and annosus root rot in the Coastal Plain. Specific emphasis was placed on: 1) Rating stand susceptibility to pest attack, 2) encouraging cultural or management practices to prevent or reduce pest losses, 3) recommending direct control tactics, and 4) utilizing damaged pines.

APPROACH TO MEETING THE OBJECTIVES

IPM Technology Evaluation

Initial activities involved evaluating existing pest management technology and determining its potential for use in South Carolina. Suitable existing materials were either used in their original form or modified for local needs. SPB risk/hazard rating systems were reviewed to determine which ones landowners could use to identify stands that needed cultural treatment. Particular emphasis was given to the Coastal Probability and Piedmont Probability systems (Hedden 1985a, 1985b). Computer software was also evaluated and, if found to be suitable, incorporated in the project. Specific software included CLEMBEETLE (Hedden 1985c), IPM Decision Key (Anderson and others 1982), FUSIFORM RUST—SLASH (Nance and others 1983), and YIELD, a timber yield forecasting and financial planning program (Hepp 1984).

Video materials and supplies of publications on the four pests were obtained and distributed (table 1). In addition, decisions were made concerning the development of new IPM printed and video material. Finally, different types of portable sawmills were compared. A Mobile Dimension Saw® (described by Remion and Boone in section II) was purchased, assembled, and transferred to the SC Forestry Commission to promote better utilization of pest-killed pine timber.

Developing New Materials and Techniques

As the project moved into the development phase, producing quality printed and videotaped material was a high priority. To accomplish this, a graduate assistant in graphic arts joined the project to help with photography; handle all aspects of publication layout, illustration, and typesetting; and help with design and printing of exhibit materials (table 1).

Project identification.—To focus attention on the IPM project, a logo was designed and used on all materials produced during the project (fig. 1). The logo was so well received that the Clemson University Cooperative Extension Service IPM Committee asked to use it on all Extension Service IPM-sponsored materials and programs in South Carolina. In addition, a similar (but different) logo was designed for 4-H Club IPM programs. The logo idea proved very effective in drawing attention to the project.

Both the Coastal Probability and the Piedmont Probability hazard-rating systems were modified to make them more useful to professional foresters and landowners without technical background. For each system, a card was printed for field use in stand ratings. A leaflet was also published to explain each

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Table 1—*Publications, movies, and videotapes produced by the South Carolina Demonstration Project*

Description	Title	Author	Date released
Leaflets			
Clemson Univ. Coop. Ext. Serv., For. Leafl. 5 (6 p.)	Identifying the southern pine beetle	Ham, D. L.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 6 (6 p.)	Salvage removal: a method for controlling southern pine beetle infestations	Ham, D. L.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 7 (6 p.)	Cut and leave: a method for controlling southern pine beetle infestations	Ham, D. L.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 8 (4 p.)	Estimating potential loss from the southern pine beetle	Hedden, R. L.; Karpinski, C.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 9 (6 p.)	Portable sawmill operators in South Carolina	Tainter, F. H.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 10 (8 p.)	So . . . you want to buy a portable sawmill!	Tainter, F. H.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 11 (6 p.)	Predicting potential loss to southern pine beetle in natural stands in the Piedmont	Karpinski, C.; Ham, D. L.; Hedden, R. L.	1984
Clemson Univ. Coop. Ext. Serv., For. Leafl. 12 (6 p.)	Don't leave your trees to rot . . . utilize them!	Tainter, F. H.	1983
Clemson Univ. Coop. Ext. Serv., For. Leafl. 13 (6 p.)	Predicting potential loss to southern pine beetle in the Coastal Plain	Karpinski, C.; Ham, D. L.; Hedden, R. L.	1984
Clemson Univ. Coop. Ext. Serv., For. Leafl. 14 (4 p.)	Estimating potential loss to southern pine beetle in the Coastal Plain	Karpinski, C.; Ham, D. L.; Hedden, R. L.	1984
Movies			
"The New Breed"	A 15-min. 16 mm film on portable sawmills as a tool in pest management.		
"Littleleaf"	A 15-min. 16 mm film on littleleaf disease history, cause, and impact.		
Videotapes			
"Identifying southern pine beetle attacks"	A 30-sec. videotaped public service announcement	S.C. For. Comm.	—
"Preventing southern pine beetle infestations"	A 30-sec. videotaped public service announcement	S.C. For. Comm.	—
"Direct control of southern pine beetle spots"	A 30-sec. videotaped public service announcement	S.C. For. Comm.	—

Figure 1—Logo for the Integrated Pest Management Demonstration Project in South Carolina.

system and use of the card. These publications, Forestry Leaflets Nos. 8, 11, 13, and 14, are listed in table 1.

Technology adaptation.—Another modification of existing technology was the conversion of the SPB management simulation model CLEMBEETLE from the mainframe computer to microcomputer versions. These were considered more accessible and would be more widely used by foresters in assisting landowners in pest management decisionmaking. CLEMBEETLE was converted to run on Radio Shack TRS 80 models II, 12, and 16, and on Apple II. The Radio Shack version was distributed to all county Extension offices where it would be readily accessible to Extension and South Carolina Forestry Commission personnel. The USDA Forest Service and other State forestry agencies with Apple II computers were primarily interested in the Apple version.

CLEMBEETLE and other decisionmaking models can illustrate the impact of pests under various site, stand, and pest conditions and, indirectly, indicate management practices to minimize pest impact. To maximize preventive efforts, however, the models should be used and stand treatments implemented when pest populations are at endemic levels.

Promotional materials.—Because of the impact and importance of the SPB in South Carolina, three additional Forestry Leaflets (Nos. 5, 6, and 7) were developed. Respectively, these dealt with identifying the southern pine beetle and its control using salvage removal and cut-and-leave methods. These leaflets have been widely used, including a request from the Louisiana Forestry Commission for 300 copies of each for distribution in that State. The Georgia Forestry Commission also requested that we make minor modifications (State name and logo changes) to Leaflets Nos. 6, 7, 8, and 11, and make them available for reprinting and distribution in Georgia.

To promote the increased utilization of pest-killed timber, three Forestry Leaflets (Nos. 9, 10, and 12) were published that dealt with the use of portable sawmills. In addition, posters or charts were developed that illustrated the financial returns possible from utilizing a portable sawmill onsite for landowner consumption of wood products rather than selling pest-killed timber for lower priced products (i.e., pulp). Other publications relative to portable sawmills and a study, "Economic and Operational Analysis of Portable Sawmill," are underway at this writing.

Exhibits featuring the overall IPM project as well as pest management computer applications were developed. The IPM Newsletter was started and is now published on a periodic basis. Considerable movie and videotape footage was taken. As a result, two 16 mm movies, "The New Breed," (dealing with the portable sawmill) and "Littleleaf," and three videotape public service announcements about the SPB were produced. In addition, videotapes about fusiform rust and annosus root rot are now being prepared. A slide-tape on littleleaf disease is also being provided, and the USDA Forest Service assisted in developing and implementing a littleleaf stand hazard-rating system for use on the Sumter National Forest in South Carolina (see related report by Hoffard and Oak, section II).

Computer applications.—The final area explored during the project was computer applications of IPM. This involved three distinct approaches. First of all, software service was provided to professional foresters and county Extension personnel in South Carolina. This included the distribution of pest management decisionmaking software. In addition, assistance was provided or the software actually run on both microcomputers and the mainframe computer at Clemson using data supplied by private landowners, agencies, and forest industry.

Second, electronic mail was used to quickly transmit IPM information to the field on a timely basis. The third area involved the use of an interactive call-in system. This technique disseminated information on pest status but was a more passive approach than electronic mail. Text information on various pests as well as a bulletin board for meetings or activities related to pest management were included in the interactive call-in system, which was designated as the Pest Management Information Center (PMIC) at Clemson University.

Clemson Extension Forestry maintained the PMIC on a TRS 80 model 16B microcomputer that was compatible with the statewide network of computers in each of the county Extension offices. Considerable time and effort were devoted to developing the software for handling the information on the host microcomputer as well as the communications software.

Disseminating IPM Information

Packaging and providing IPM information and management recommendations to foresters and landowners were rewarding aspects of the project. The portable sawmill demonstrations sponsored by the South Carolina Forestry Commission in cooperation with the local county Extension offices provided an excellent means of attracting landowners to field demonstrations and workshops. An educational program could then be presented that concentrated on local pest management problems and solutions as well as the economic justification for utilizing a portable sawmill. Various other county Extension-sponsored landowner meetings provided a similar opportunity to present IPM information.

IPM information was also presented to professional groups in South Carolina and elsewhere in the Southeast. Publications, exhibits, and computer demonstrations were often used to promote the project activities and philosophy. An Annosus Root Rot Workshop (Wedgefield, SC, May 23, 1984) that addressed the latest annosus sampling and management strategies and economic considerations was well received. The 1985 Clemson Forestry Forum (March 12, 1985) involved many IPM workers and covered most of the major pests. The project staff also participated in a statewide Extension IPM tour that provided an excellent opportunity to promote and gain support for forestry IPM programs with State and National Extension administrators.

Five tracts established during an earlier demonstration project were utilized. This involved working with five landowners with very different management objectives. The goal of the project was to demonstrate that pest management considerations could and should be incorporated during the early stages of the forest management plan preparation regardless of the landowners' management objectives. Consulting foresters cooperated in the project by assisting in the planning stages and implementing the silvicultural recommendations that included approaches to minimize the potential for SPB attack. These demonstration areas are now being used to illustrate this approach to other landowners in the State.

Publications, Movies, and Videotapes Produced

There were 10 publications, 2 feature films, and 3 videotapes produced during the demonstration project. These are summarized in table 1.

IMPACT OF DEMONSTRATION PROJECT ON SOUTH CAROLINA FORESTS

The guiding philosophy throughout the project was that successful persuasion of foresters and landowners to implement IPM strategies required presentation of the information in a professional, innovative manner. However, regardless of how good the information and materials, landowners must be motivated to implement them. A good return on an investment is one of the best motivators of all. With this logic foremost, every opportunity was used to emphasize the economic benefit of implementing pest management practices. Computer growth and yield software with financial analysis was especially helpful in making this a successful approach.

Stressing the economic impact of underutilizing pest-killed timber made the portable sawmill successful. For example, landowners were told that loggers seldom bought small volumes of timber because the high costs involved in moving equipment and personnel make it uneconomical. However, when a logger is willing to cut small volumes of salvageable sawtimber, landowners will normally have to accept a substantial reduction in price to compensate the logger for these additional costs. Figure 2 was used to illustrate that the price range paid for salvaged trees is consistently lower (usually pulpwood prices) than their potential value as sawtimber.

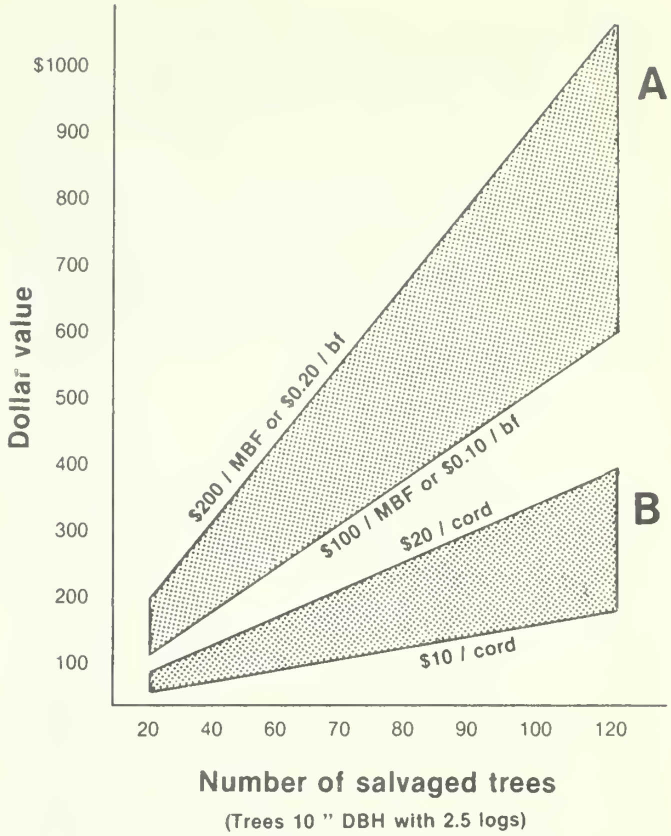

Figure 2—Price range for green sawtimber compared with price range for pulpwood that is commonly paid for small volumes of pest-killed timber.

Rather than sell pest-killed timber for pulpwood prices or let it go to waste, landowners can use portable sawmills to cut quality lumber at a cost well below market price.

Once the "dollar and cents" costs and returns from utilization had the attention of the audience, they were usually very receptive to considering other aspects of pest management. The economic approach also caught the attention of county Extension Service personnel. County agents routinely assist farmers and landowners with small holdings in the cost/benefit aspects of their agricultural operations. As a result, they have the confidence of that audience and can be very effective in disseminating forest pest management and economic information.

Initiation of three pest management projects by county Extension personnel is evidence of some of the IPM project impact on this audience. Two field projects to demonstrate the economic justification of thinning to reduce SPB losses are being installed. Another project to hazard rate pine stands in one county for annosus root rot and establish demonstration plots has also begun. These projects were initiated by county personnel using funding obtained through the Clemson University Cooperative Extension Service IPM Committee.

Many of the approaches used in the South Carolina Demonstration Project had a positive influence on other IPM programs in South Carolina. The Extension IPM Committee, aware of the magnitude and commitment of the project, supported and promoted many of its ideas and approaches. Some of these innovations, such as the IPM logo and computer communications software, have been adapted for IPM programs concerned with pests of other commodities in other university departments. Forestry interests will certainly be actively represented on the Extension IPM Committee in the future.

The Pest Management Information Center will continue to be maintained on the Radio Shack system or possibly in the future on a larger statewide computer communications system. Computer communications is a dynamic new area, and this demonstration project has been influential in initiating its use for pest management information dissemination in South Carolina.

CONCLUSIONS

The IPM project provided the Department of Forestry and the Cooperative Extension Service at Clemson University with the funding and flexibility to initiate a very ambitious pest management demonstration project. However, our responsibilities, attention, and work in integrated forest pest management will not stop with the termination of Federal funds. Activities during the IPM project have built an excellent foundation for future work and successful approaches have been developed that will continue to be used and improved. One of the important successes of the project was establishing the commitment of county Extension personnel to forest IPM. This will ensure the demand and continuing support for our forest pest management Extension work and dissemination of information.

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SOUTHERN PINE BEETLE TECHNOLOGY TRANSFER IN TEXAS

R. F. Billings, C. M. Bryant, V, H. A. Pase, III, K. A. Wilson, and C. Walker[1]

INTRODUCTION

Outbreaks of the southern pine beetle (SPB) have been notably persistent and severe in the 12 million acres of commercial forest lands in east Texas. In one continuous outbreak that lasted from 1958 to 1977, more than 58,000 multiple-tree infestations were detected on non-Federal lands, accounting for an estimated loss of 154 million cubic feet of pine timber. The threat of SPB infestations has been deemed one of the most serious restraints to improving forest productivity on both industrial and private nonindustrial lands in Texas.

In 1980, a 5-year cooperative project was initiated by the Texas Forest Service (TFS) to demonstrate, validate, and implement new technology for the integrated management of SPB and related pests within a two-county area of east Texas. The demonstration area corresponded to TFS administrative District 9, consisting of Polk and Tyler Counties in their entirety. These two counties consistently ranked among the more heavily infested counties during the 1958–77 SPB outbreak. Collectively, Polk and Tyler Counties contain over 1,100,000 acres of commercial forest lands of which 870,000 acres (77 percent) are in SPB host type (pine or oak-pine). The topography ranges from highly susceptible lowland sites to less susceptible rolling hills and uplands. Landownership is typical of southeast Texas counties, consisting of 76 percent industrial ownership, 23 percent nonindustrial, and 1 percent public lands (Kirby State Forest and the Beech Creek Unit of Big Thicket National Preserve).

The intended audience targeted by the East Texas Demonstration Project included the major forest industries in Texas, Texas Forest Service field foresters, and small, private landowners in the area. Major forest industries in Texas were involved directly in the project through the formation of a landowner advisory board (table 1). This nine-member board, consisting of one representative from each major company and the TFS Area Forester, met periodically with project personnel to review plans and accomplishments and to provide guidance in project activities.

Table 1—*Membership in landowner advisory board*

Name	Organization
Irwin Grillot	Champion International, Inc.
Wayne Foster	St. Regis Paper Company
Robert Larsh	Kirby Forest Industries, Inc.
Darwin Foster	Temple-Eastex Forests
Johnny Sutton	Wirt Davis Estate
Ronald Gresham	Owens-Illinois, Inc.
Herbert Branch	International Paper Company
Finis Prendergast	Louisiana Pacific
Gary Lacox	Texas Forest Service

The overall goal of the demonstration project was to acquaint concerned landowners, both industrial and private, with new technology available for the prediction, prevention, evaluation, and suppression of the SPB. Development, implementation, and validation of new SPB prediction and hazard-rating systems in Texas also were important features of this technology transfer effort.

APPROACH TO MEETING OBJECTIVES

SPB Hazard Maps

Research in recent years has documented that high basal area per acre, large-size trees, and poorly drained bottomland sites are associated with a high incidence of SPB infestation in east Texas. TX HAZARD, a hazard-rating system based on these factors (Mason and others 1981), was used to develop hazard maps for all pine stands greater than 10 acres in size in the two-county area (table 2). Stand data were obtained from 1978 color-infrared (CIR) print photography (scale = 1:20,000). Stand delineations were made and parameters of percent pine, percent crown closure, average d.b.h., pine basal area, and stand height were interpreted from the photos for each pine stand. Stand delineations were then transferred to acetate overlays for United States Geological Survey (USGS) orthophoto quadrangle maps (scale = 1:24,000), using a Kail reflective enlarger. Landform classifications, generated from USGS topographic maps, were combined with stand data to generate an SPB hazard classification (low, moderate, high, or extreme) for each stand (fig. 1).

An 85 percent correct classification of hazard was verified by visiting a 10 percent random sample of the stands in each quadrangle and measuring the actual hazard on the ground using the hazard-rating guide (TX HAZARD) shown in table 2. In the same manner, ca. 50 percent of all stands classified

[1] Respectively, Principal Entomologist and Entomologists, Texas Forest Service, Lufkin, TX; and District Forester, Texas Forest Service, Livingston, TX.

(Many Texas Forest Service personnel provided assistance in various aspects of this demonstration project, including Martha Johnson, Anita Weisenger, Charles Ware, Alan Smith, Steve Tracy, Davin Ivans, Mike Caughey, Carol Riggs, Elmer Freshour, Pat Bryant, Dan Mott, Elray Dominey, Tom Hartz, Ed Barron, and the District 9 field crews. We also thank Dr. Robert Maggio, Cathy Wilson, Ken Morris, and Russel Irons for their assistance with hazard map digitization, and Charles Palmer, Texas Natural Resource Information Service, for providing aerial photographs and generating the final grid block hazard map. Their efforts contributed greatly to the success of this project.)

Table 2—*Method of rating relative susceptibility of pine stands to SPB attack and timber loss in a two-county area in east Texas.*

	RIDGE			OTHER TERRAIN			BOTTOM		
	TREE HEIGHT (feet)			TREE HEIGHT (feet)			TREE HEIGHT (feet)		
Pine Basal Area (sq ft/acre)	<50	50-75	>75	<50	50-75	>75	<50	50-75	>75
<80	low	low	low	low	low	low	low	low	med
80-120	low	low	med	low	med	med	med	med	high
>120	low	med	med	med	high	high	med	high	high
	<6	6-12	>12	<6	6-12	>12	<6	6-12	>12
	TREE DIAMETER (inches)			TREE DIAMETER (inches)			TREE DIAMETER (inches)		

HAZARD

SOURCE: Mason, G.N. TX HAZARD. In: Mason, G.N.; Hertel, G.D.; Thatcher, R.C., compilers. Predicting southern pine beetle and disease trends. Pineville, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station and Southern Region Forest Pest Management; 1985:62-63. [Administrative training aid]

as high or extreme hazard were visited on the ground to confirm correct classification. High altitude CIR NASA positive transparencies taken in July 1980 and January 1981 were used to update the stand and hazard classifications of those stands that had been logged or thinned since 1978. The final hazard maps were reproduced in 5 mil chromatic film and later digitized by personnel of the Texas A&M University Department of Forest Science for permanent storage and subsequent updating. Acreages were computed for each hazard class and ownership category.

Copies of the SPB hazard maps pertaining to a given ownership were provided to each major forest industry with holdings in Polk and Tyler Counties. Also, a complete set of maps was provided to the TFS District 9 office in Livingston. To encourage hazard reduction, each company was also given a listing of all high- and extreme-hazard stands on their lands and asked to provide feedback to project personnel with regard to which stands were to be treated prior to 1985.

Many of the stands rated as high or extreme hazard are located on nonindustrial private lands. These landowners were contacted either in person by TFS district personnel or by mail to inform them of the situation and to encourage silvicultural treatments.

Of the 754,535 acres of current pine host type (> 10 years of age) in Polk and Tyler Counties in 1981, 57,038 acres (8 percent) and 29,739 acres (4 percent) consisted of stands rated as high and extreme hazard to SPB, respectively. Of the total acreage in high- and extreme-hazard stands, 56 percent belonged to forest industry, 39 percent to small private landowners, and the remainder (5 percent) to the Big Thicket National Preserve.

A survey was conducted in 1983 to document the extent to which high- and extreme-hazard stands had been treated since 1981 to reduce SPB hazard. A random sample representing 10 percent of all such stands on private lands and 13 percent on industrial lands was revisited during the summer and fall of 1983. Results revealed that during the 2-year interim, 24 percent of all high-hazard stands had been harvested on industrial lands, 33 percent had been thinned, and 43 percent had received no treatment. On small private holdings, the respective figures were 8 percent harvested, 13 percent thinned, and 79 percent no treatment.

With the return of high populations of SPB in 1983 and 1984, an opportunity was provided to validate these stand hazard maps. The locations of spots reported from detection flights (68 in 1983 and 232 in 1984) were correlated with stand hazard classifications. Results (fig. 2) served to validate the TX HAZARD system. More than three times as many infestations per 1,000 acres of hazard class occurred in stands rated as high or extreme hazard as in those rated as low hazard. Also, many of the spots reported in stands rated as low or moderate hazard were found to occur in "high hazard" pockets of dense timber. The reduced occurrence of spots in stands rated as extreme hazard in 1984 probably reflects the fact that a greater number of these stands have been thinned or harvested since 1981 compared with stands in the other hazard categories.

An unexpectedly high number of infestations was recorded in 5- to 14-year- old pine plantations, particularly during 1984 (fig. 2). This observation suggests that SPB is capable of expanding its range of hosts to include plantations as young as 5 years of age. Interestingly, of 106 infested stands ground checked by project personnel in the demonstration area in 1984, 98 percent had either never been thinned or had remained unthinned for at least the past 6 years. This testifies to the benefits of thinning as a preventive tool.

Areawide Hazard-Rating System for SPB

A practical system for mapping the abundance and distribution of suitable habitat for SPB was developed to quantify areawide hazard for all commercial pine forests in east Texas (Billings and Bryant 1983). The system was developed by comparing the frequency of SPB infestations per TFS grid block (18,000-acre unit) during the period 1973–77 to host conditions prevailing within the grid block at the time, the

Figure 1(a)—Project forester Charles Bryant delineates forest stands on color infrared stereo aerial photographs, one step in the process of developing southern pine beetle hazard maps. (All photos courtesy Texas Forest Service.)

latter information sampled from 1974 high-altitude aerial photography. To hazard rate a grid block with this system, 20 systematically distributed 30-acre circular photo plots are inventoried for the presence of pine host type, its density and percent coverage, and landform in a simple dichotomous (yes or no) sampling procedure. Values are then used in a hazard-rating equation to discriminate between high-hazard grid blocks and those in which the host conditions are insufficient to support outbreaks of the beetle. The final product is an areawide hazard map showing the distribution and abundance of pine host type and areas where severe beetle problems are most likely to occur.

To date, 656 grid blocks covering over 11,800,000 acres have been hazard rated using current 1980–83 aerial photography (scale = 1:120,000). Currently, 5 percent, 11 percent, and 84 percent of the grid blocks are rated high, moderate, and low hazard, respectively, in central and southeastern counties of east Texas. In a further application, the current hazard rating for each grid block was combined with the frequency of SPB infestations detected in 1982–83 in the same grid

Figure 1(b)—Example of final southern pine beetle hazard map for a portion of the two-county demonstration project.

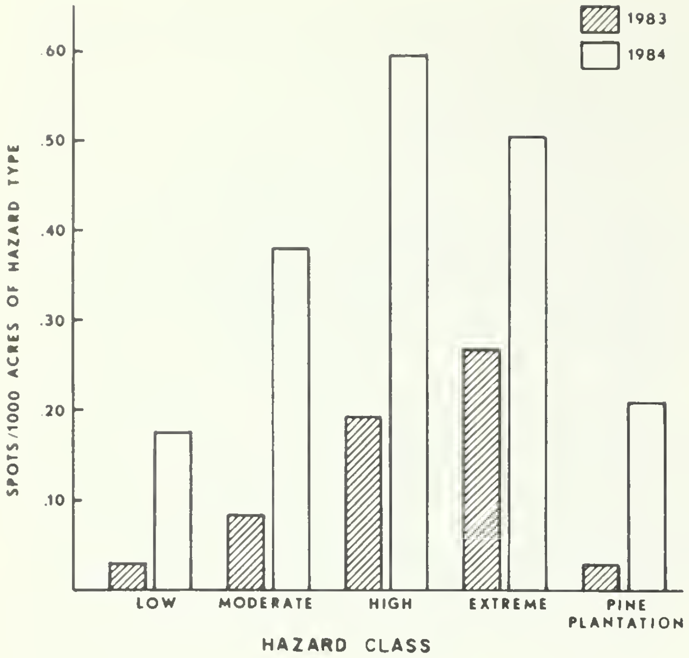

Figure 2—Average numbers of southern pine beetle infestations (10 or more trees) detected in Polk and Tyler Counties during 1983 and 1984 by stand hazard class.

block (table 3). The result was a risk classification or forecast of which specific grid blocks in east Texas would most likely suffer beetle outbreaks in 1984. Prior to the 1984 beetle season, a listing of extreme-, high-, moderate-, low-, and very low-risk grid blocks was distributed to forest industry and TFS field foresters. Other interested clients were notified through "Texas Forestry," the monthly publication of the Texas Forestry Association.

Records of 6,166 confirmed SPB infestations (spots) detected in east Texas within 504 grid blocks during 1982–1984 were compiled and summarized to validate the grid block hazard-rating system. Over the 3-year validation period, the average number of spots per grid block was 62.9 in high-hazard grid blocks, 20.7 in moderate-hazard grid blocks, and 6.6 in low-hazard grid blocks. Infestation levels by grid block hazard class for 1982–83 and 1984 are illustrated in figure 3.

A postseason evaluation of SPB risk classifications, based on 4,759 muliple-tree infestations detected in east Texas in 1984, revealed that the 10 grid blocks rated as extreme risk supported an average of 89.2 spots per grid block (ca. 5 spots per 1,000 acres). By contrast, those identified as high, moderate, low, and very low risk had an average of 40.1, 16.9, 11.1, and 3.6 spots per grid block, respectively. Clearly, the basic objective of the risk-rating system was met: 26 high- and extreme-risk grid blocks were identified prior to the 1984 beetle season. By the end of 1984, these grid blocks, representing only 5 percent of the outbreak area, had supported a disproportionate number (32 percent) of all new infestations. This risk-rating system is to be updated annually with the previous year's infestation records. A new list of grid blocks by risk category will be distributed to field personnel in preparation for each new beetle season.

Aerial Photo Missions and the Loran-C

From 1980–82, black-and-white stereo aerial photographs at a scale of 1:15,840 were obtained for 30 USGS 15-foot

Table 3—*Procedure used to assign 1984 risk classes to TFS grid blocks, based on hazard class and recent beetle infestation level*

Grid block hazard	SPB Infestation index (spots/grid block in 1982 and 1983) 0(0)**	1-10(1)	11-30(2)	>30(3)	
High hazard (3)*	Moderate	High	High	Extreme	R
Moderate hazard (1)	Low	Moderate	Moderate	High	I S
Low hazard (0)	Very Low	Low	Moderate	Moderate	K

Risk rating points = hazard points + population index points + proximity points***

Where 6 or 7 = Extreme risk of SPB infestations in 1984
4 or 5 = High risk
2 or 3 = Moderate risk
1 = Low risk
0 = Very low risk

* Hazard points
** Population index points
*** If grid block is located adjacent to a high-hazard grid block having >30 spots = 1 point.

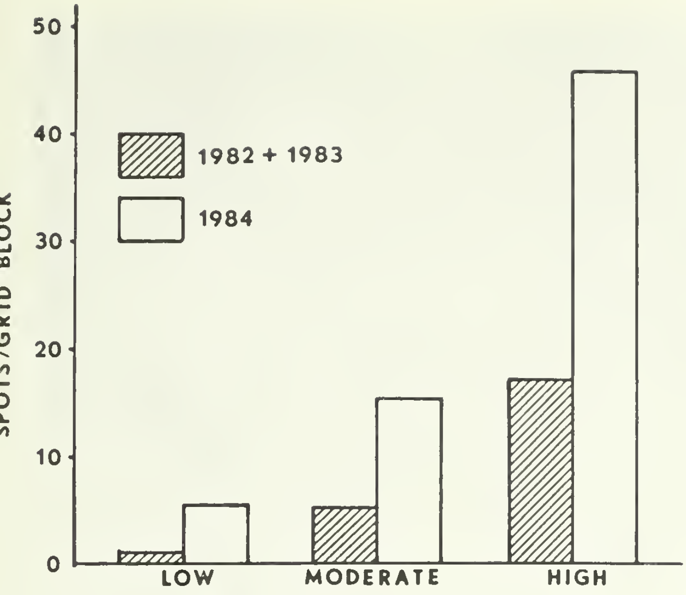

Figure 3—Average numbers of southern pine beetle infestations (10 or more trees) detected in Texas Forest Service grid blocks (18,000-acre units) during 1982-83 and 1984 by grid block hazard class.

quadrangles in east Texas, covering 4.9 million acres. These photo missions were flown with a Texas Forest Service De Havilland Beaver equipped with a Zeiss 9- by 9-inch format camera and a Loran-C radio navigation system. These missions provided an opportunity to test the Loran-C, a navigational system that has greatly aided aerial photography and SPB survey flights (Dull 1980). These tests revealed that the Loran-C operated well in most areas of east and central Texas, except near latitude N 30° 30′ where performance was erratic and unreliable. East Texas is located along the western fringe of the Southeast U.S. Loran-C Chain, which causes operational problems in certain areas.

The aerial photographs have been very beneficial to field foresters for forest and pest management work. Also, the photography has served as the foundation for updating quadrangle maps used by the TFS and forest industry for SPB and fire detection. A library of aerial photo negatives is maintained at the Pest Control Section office in Lufkin, where prints are available upon request to all interested parties.

SPB Decision Support System

A computer-based Southern Pine Beetle Decision Support System has been developed at Texas A&M University in cooperation with the East Texas Demonstration Project. A completed version is now available for use. The system is designed to help decisionmakers organize and use available information and technology to address SPB-related problems. Computer models used to project stand growth, predict SPB spot growth, evaluate economic impact, ascertain the costs and benefits of control efforts, evaluate utilization options, and hazard rate stands are linked by an interactive executive program. In addition, an information system provides SPB "fact sheet" recommendations for particular problems.

As a part of the demonstration project, the Pest Control Section is testing and implementing various components of the system. Several spot growth and damage prediction models have been compared with actual spot growth data. Modifications based on these tests have improved overall model performance. Approximately 30 infestations were monitored in 1982–83, and data from these spots have been used to further validate the models.

Microcomputers and IPM

An Apple III microcomputer and peripheral equipment were installed in Lufkin and contributed significantly to the quality and efficiency of Forest Pest Control Section operations as well as the integrated management of SPB. Word processing, statistical analysis, data transfer, data compilation, communications, and decision support are among the areas in which the microcomputer system has been used.

Additional microcomputer facilities were installed at Lufkin and the Texas Forest Service District 9 office in Livingston. These systems provide field foresters with access to available microcomputer technology for forestry and forest pest management and increase the efficiency of SPB operational data transfer.

Several SPB models were programmed for access on the Apple III microcomputer. These include the IPM Decision Key developed by the USDA Forest Service (Anderson and others 1982), stand hazard models (Mason and others 1981), TFS spot growth models (Billings and Hynum 1980), and annosus root rot management guidelines (Alexander and Anderson 1982). Advantages of having models on the microcomputer include ready accessibility (no phone lines required), low cost of operation, and the interactive mode. A major roadblock to the prompt transfer of computer-based SPB models, however, is the fact that most State and industrial field offices in Texas currently do not have access to computer hardware. This limitation should be overcome in time as the cost of microcomputer hardware declines and more field foresters gain access to such equipment.

Portable Sawmill

To increase the utilization of beetle-killed trees on small private holdings, the project purchased a Mobile Dimension Saw® in 1980 and installed it on a 22-foot trailer. Three TFS technicians were trained in sawmill operation and maintenance. The utility and availability of this portable sawmill were then advertised by means of demonstrations, folk festival parades, news releases, and television reports. The sawmill, together with a trained operator, has been leased to numerous landowners in Polk and Tyler Counties to convert green or beetle-killed trees to rough-cut dimension lumber (fig. 4). Although cost of operating the mill averaged $0.08 per board foot, productivity was found to vary with size and quality of logs, dimension of lumber sawed, and experience of mill operators. The largest job to date consisted of 14,000 board feet of beetle-killed trees sawed on the Alabama Coushatta Indian Reservation. The sawmill provides a practical alternative to those local landowners unable to sell their beetle-infested

Figure 4(a)—Portable sawmill used in the East Texas Demonstration Project to produce rough-cut dimension lumber from beetle-killed pines.

Figure 4(b)—Project coordinator Ron Billings demonstrates the portable sawmill as part of a landowner tour on the Kirby State Forest near Woodville, TX.

timber to salvage contractors. Since successful implementation of the portable sawmill in the east Texas demonstration project, other sawmill operations with similar equipment have been initiated in Texas, South Carolina, and other southern States to utilize beetle-killed trees.

Technology Transfer

Considerable effort was devoted to technology transfer throughout the duration of the demonstration project. Project plans and accomplishments, the availability of new pest management technology, and SPB status reports were communicated to east Texas landowners and to other interested parties by means of a newsletter entitled "Spotlight on Southern Pine Beetle." This single-page newsletter was prepared and distributed quarterly throughout the duration of the project. Plans are to expand this newsletter to include other pests of importance to Texas forestry and widen the distribution throughout east Texas. Accomplishments in the demonstration project also were the subject of other news releases, seminars, and landowner tours. Demonstrations of the portable sawmill served to increase attendance at numerous landowner meetings held to spread the word of project activities.

Field crews with TFS and forest industry were trained in new procedures for aerial detection, setting ground check priorities, direct control tactics, and beetle prevention (fig. 5). To communicate new technology available for detection, suppression, and prevention of SPB, two new publications were issued. One, a pocket-size booklet entitled "Southern Pine Beetle—Field Guide for Hazard Rating, Prevention and Control" (Texas Forest Service Circ. 259), has received wide acclaim, not only in Texas but across the South. The second publication, prepared in the format of a USDA Agriculture Handbook for distribution southwide as part of the IPM program's Integrated Pest Management Handbook series, is entitled "How to Conduct a Southern Pine Beetle Aerial Detection Survey" (Texas Forest Service Publ. 267). In addition, videotape training programs have been prepared on new aerial detection and ground check procedures. A complete list of publications and audio-visual materials produced by the East Texas Demonstration Project appears in table 4.

Members of the Landowner Advisory Board were encouraged to communicate project accomplishments to others within their respective organizations. Even after completion of the demonstration project, training aids, demonstrations, and publications will be used in a continuing effort to provide the Texas forestry community with the latest technology for integrated management of SPB.

Figure 5—Project entomologist Joe Pase conducts field training on improved methods for evaluating a southern pine beetle infestation and setting control priorities for the benefit of Texas Forest Service district crews.

Table 4—*Publications and audiovisual materials produced during the East Texas Demonstration Project, 1980–85*

Description	Title	Authors	Date released
Procedural guides			
Tex. For. Serv. Circ. 259, 10 p.	Southern pine beetle: field guide for hazard rating, prevention and control	Billings, R.F.; Bryant, C.M., V	1982
Tex. For. Serv. Circ. 267, 19 p.	How to conduct a southern pine beetle aerial detection survey	Billings, R.F.; Ward, J.D.	1984
Tex. Agric. Exp. Stn. MP-1518 24 p.	Procedural guide for using the interactive version of the TAMBEETLE model of southern pine beetle population and spot dynamics	Turnbow, R.H.; Coulson, R.N.; Hu, L.; Billings, R.F.	1982
Journal articles			
Z. angew. Entomol. 96:208-216	Developing a system for mapping the abundance and distribution of southern pine beetle habitats in east Texas	Billings, R.F.; Bryant, C.M., V	1983
Trade magazine articles			
J. Forestry 79:816	Texas project gets beetle when its down	Anonymous	1981
TF News 61:12-13	Have sawmill: will travel—portable sawmill aids beetle prevention program	Billings, R.F.	1982

Table 4—*Publications and audiovisual materials produced during the East Texas Demonstration Project, 1980–85 (continued)*

TF News 62:2-5	Southern pine beetle in Honduras: new approaches to an old problem	Billings, R.F.	1983
Tex. Forestry 24(5):1,6,7	New approach developed to forecast SPB outbreaks	Billings, R.F. Bryant, C.M.	1983
TF News 63:6-8	SPB hazard rating	Bryant, C.M.	1984
Tex. Forestry 22(7):2, 11, 12	Pine beetle demonstration project established in Polk and Tyler Counties	Tex. For. Serv.	1981
TFS Publ. 127: 11-17	Southern pine beetle demonstration project	Tex. For. Serv.	1982
Proceedings papers			
Proc. Society of Am. Foresters National Convention, Orlando, FL	Implementing new southern pine beetle technology in east Texas	Billings, R.F.	1982
Tex. Agric. Exp. Stn. MP-1553 p. 1-5	Forest pests in east Texas: past approaches, future challenges	Billings, R.F.	1984
Proc. Third Biennial Southern Silvic. Research Conf. 5 p.	Hazard-rating system aids southern pine beetle prevention in Texas	Bryant, C.M.	(In press)
Soc. Am. For. Publ. 82-05: 121-124	Microcomputers aid southern pine beetle management	Bryant, C.M.; Pase, H.A., III; Billings, R.F.	1982
TFS Publ. 136: 17-21	IPM demonstration project	Tex. For. Serv.	1984
Newsletters			
Distributed quarterly	Spotlight on southern pine beetle - progress report from the east Texas demonstration project		Since 1980
Audio/Visual Aids			

Videotape program on how to groundcheck southern pine beetle infestations and set control priorities.

Videotape program on SPB aerial detection surveys (In preparation)

IMPACT OF THE DEMONSTRATION PROJECT ON TEXAS FORESTS

This IPM demonstration project has proven to be a successful means for implementing new SPB technology within the State of Texas, where forest managers have long been plagued by beetle problems. The development, application, and validation of the TFS grid block hazard-rating system is considered a major contribution to new SPB technology. This grid block hazard-rating system provides a convenient, inexpensive, and practical means for monitoring the distribution and abundance of suitable host conditions on a regional basis. When combined with data on recent beetle activity to provide an annual risk classification for each grid block (table 3), the system provides reliable and timely SPB infestation predictions of value to all forest landowners and administrators in east Texas.

The preparation of hazard maps of all individual stands in Polk and Tyler Counties was a time-consuming task. But, coupled with cooperative efforts by forest industry to treat high-hazard areas, this effort is now paying dividends. Polk and Tyler Counties have a history of severe SPB problems.

Yet, during 1982 and 1983, no confirmed SPB infestations were detected in Polk County and only 74 spots (out of 1,407 statewide) were reported in Tyler County. Many of the latter were on ownerships where forest management is not practiced.

In 1984, despite the occurrence of 5,120 multiple-tree infestations statewide, only 77 and 130 new spots (> 10 trees) were reported in Polk and Tyler Counties, respectively. A ranking of counties by total numbers of 1984 spots reveals that 9 other counties had more infestations than Tyler County and 12 reported more than Polk County. This is a substantial improvement from the previous outbreak (1973–77) when Polk County ranked fifth and Tyler sixth. Although the reduced level of SPB activity in the demonstration area may be due partly to factors unrelated to our project efforts, the fact remains that Polk and Tyler Counties have escaped the severe SPB-caused losses that currently plague many nearby counties outside the demonstration area.

The return of SPB to east Texas provided an opportunity to validate the statewide grid block hazard- and risk-rating systems as well as stand hazard maps developed for Polk and Tyler Counties. Each system proved reliable in that the highest concentration of new SPB infestations occurred in grid blocks and in stands rated as high or extreme hazard (or risk).

CONCLUSIONS

As beetle populations increase again in east Texas, technology transfer efforts have become increasingly important. Numerous field foresters and technicians with little previous experience with SPB are being taught effective approaches to aerial detection, ground check evaluation, control, and prevention. As part of its pest management responsibilities, the Texas Forest Service will continue its technology transfer program in an effort to make landowners in other counties aware of the latest methods for dealing with the SPB problem in east Texas.

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DEMONSTRATING EFFECTIVE MANAGEMENT MEASURES FOR SOUTHERN PINE BEETLE IN VIRGINIA

Caleb L. Morris[1]

INTRODUCTION

The southern pine beetle has reached outbreak populations in Virginia at regular 10-year intervals since the mid-1950's. During these outbreaks, which have ranged from 2 to 4 years in duration, damage estimates averaged well over $1 million per year (table 1).

A major factor contributing to these periodic outbreaks is the presence of unmanaged, overmature stands of native pines, particularly in the Piedmont, which are highly vulnerable to beetle attack. Unthinned younger pine stands are rapidly increasing in number in Virginia and expected to contribute additional "beetle-fodder."

The limited availability of woods labor for thinning young pine stands remains a concern; more mechanized procedures must be developed if the thinning so vitally needed is to be accomplished. Education of landowners, consulting foresters, and forest industry in regard to the value of good silviculture is mandatory if the challenge of "beetle-proofing" Virginia's pine stands is to be met.

A major demonstration project funded by the USDA Forest Service was conducted during the calendar years 1982–84. This multifaceted project strongly emphasized education through demonstration of silvicultural techniques, equipment, photo technology, and economic studies.

A second demonstration project was instituted in 1979 with financial assistance from USDA Forest Service, Integrated Pest Management RD&A Program on a State forest in Piedmont Virginia. It consisted of an on-the-ground application of the IPM findings from the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP).

A summary of the results of successful efforts to meet the objectives of the 1982–84 demonstration project follows.

APPROACHES TO MEETING THE OBJECTIVES

First Objective

The project's first objective was to select five Piedmont counties and identify high-hazard pine stands in need of thinning or harvest (cooperatively with Virginia Polytechnic Institute and State University).

Standard ASCS 1:40,000 black and white photographs of five counties (Lunenburg, Nottoway, Halifax, Mecklenburg, and Prince Edward) were evaluated. In addition, the information was transferred in two counties (Lunenburg and Nottoway) to a county map, and actual measurements of the acreage in the different hazard categories were made by Virginia Polytechnic Institute and State University (VPI&SU). These photos were made available to the consulting foresters (involved

[1] Chief, Insect and Disease Investigations, Virginia Division of Forestry, Charlottesville, VA.

Table 1—*Southern pine beetle damage estimates in Virginia, 1960–80*[1]

Calendar year[2]	Estimated volume salvaged[3] Cords	Estimated volume salvaged[3] M fbm	Total volume killed Cords	Total volume killed M fbm	Stumpage values[4] Pulpwood $/cords	Stumpage values[4] Sawtimber $/M fbm	Total value $
1961	18,000	0	30,000	0	5.00	0	150,000
1964	63,000	0	90,000	0	6.00	0	540,000
1970	0	9,000	0	15,000	0.00	40	600,000
1972[5]	4,843	14,485	6,247	28,441	6.00	40	1,175,122
1973	4,843	14,485	6,247	28,441	6.00	40	1,175,122
1974	4,843	14,485	6,247	28,441	6.00	40	1,175,122
1975	4,843	14,485	6,247	28,441	6.00	40	1,175,122
1976	4,843	14,485	6,247	28,441	6.00	40	1,175,122
1977	159	0	265	0	6.79	0	1,800
1979	50	0	200	0	6.70	91	1,339
1980	90	0	389	0	8.25	69	3,209

[1] Information collected from State and Federal pest control specialists.
[2] Initial year based on available State records.
[3] Includes estimates on Federal, State, and private lands.
[4] Estimates from State pest specialists, same values assigned to timber salvaged.
[5] A total of 31,230 cords and 142,205 M fbm was reported killed from 1972–76. To provide uniformity within the table, these figures were divided by 5 years to show an average by year.

in Fourth Objective) for use in locating stands most in need of thinning. Maps and photos were then transferred to the individual county offices for use by Virginia Division of Forestry (VDF), industry, and consulting foresters working in those counties.

Second Objective

The second objective was to lease and demonstrate four promising, new pieces of equipment suitable for selective thinning in young pine stands and plantations.

The Division arranged 6-month equipment leases in cooperation with Chesapeake Corporation who secured reliable operators to evaluate the equipment's usefulness. We also conducted time/production evaluations on several of these pieces of equipment, which showed the MOR-BELL® Logger and the CASE UNILOADER® to be economical and effective in harvesting selectively thinned pine pulpwood.[2] Equipment demonstrated was: 1) Farmi winch, 2) MOR-BELL Logger, 3) MOR-BELL Shear, and 4) CASE UNILOADER 1845. During the lease period, numerous pulpwood yard operators, pulpwood crew supervisors, and industry foresters observed the equipment in field operations. All of the equipment demonstrated was sold to operators in Virginia and currently is being used for thinning.

Third Objective

The third objective was to arrange for equipment demonstrations. A 2-day working equipment demonstration was held in Essex County, VA, September 29–30, 1981. Fifteen pieces of logging equipment applicable to thinning operations were demonstrated. A total of 85 persons including consultants, industry, and Virginia Forestry Division foresters attended. A second, smaller, demonstration of the CASE UNILOADER was conducted over a 2-day period in the summer of 1982 with the cooperation of the Utilization Branch, VDF.

Fourth Objective

The project's fourth objective was to contract with consulting foresters to demonstrate the value of thinning in reducing future beetle outbreaks.

Contracts were made (by competitive bids) to thin 150 acres on private land in each of five southern Piedmont counties (Lunenburg, Halifax, Prince Edward, Louisa, and Mecklenburg). The consultant marked the stands for their first thinning, arranged for contractors (if requested), and supervised the cutting. A 30-acre limit per landowner was imposed. Twelve roadside signs calling attention to the thinning designed to reduce beetle damage were erected. Thinning operations have been completed on 90 percent of the selected tracts in the five counties; inspections have been conducted on 75 percent of the thinned tracts to date and will be completed in 1985.

[2] Grimm, Phil. Cost and production report on small mechanical thinning equipment. [Rep. dated September 1, 1982]. 5 p.

Fifth Objective

The fifth objective was to revise Division thinning publications and publish thinning guidelines.

A thorough review of VDF recommendations for thinning pine stands was completed, with some modifications and additions. A thinning pamphlet (5,000 copies) was developed and printed.

Sixth Objective

The sixth project objective was to determine ownership of pine stands in need of harvest or thinning, contact the involved landowners, apprise them of the high-hazard nature of these stands, and urge proper management.

Consequently, the Division mailed 50 letters to landowners of high-hazard stands in both Mecklenburg and Lunenburg Counties. Response was well above that expected: 45 to 50 responses per county were received requesting examination and recommendations. Assistance in servicing the requests was provided by the Insect and Disease Branch of VDF and Phil Grimm, Utilization Forester. (Additional letters were not mailed as anticipated due to lack of personnel to service responses.)

Seventh Objective

The seventh objective involved contracting with VPI&SU for a study to determine the economic value of various thinning regimes to reduce bark beetle damage.

This study (Burkhart and others 1984) incorporated the various available models of beetle populations, rates of spread, etc., with a population growth and yield model for Virginia developed by the VDF and by Dr. Harold Burkhart, VPI&SU. The results revealed the value of positive returns for all thinning regimes tested to reduce beetle attack over the 45-year rotation on the average to better sites. Values ranged from \$7.55 per acre on an average site at a rotation age of 45 (with one thinning to 80 ft^2 basal area at age 20, at two beetle spots per 1,000 acres of host type), to \$15.48 per acre where two thinnings had been done at age 20 to 35 under the same conditions; the better the site, the greater the gain.

Eighth Objective

The project's final objective was to illustrate the effectiveness of silvicultural control of the southern pine beetle.

The major goal was demonstrating the effectiveness of pine stand density manipulation to reduce beetle damage. All stands containing pine (ranging in age from 15 to 60 years) on a site called the Cole Tract were examined, marked, and harvested to reduce the basal area to 80 square feet. Periodic aerial surveys were conducted to compare beetle activity on the treated versus a nearby companion tract where management intensity was considerably lower. The results of those surveys are given in table 2. Beetle activity remained low until an outbreak occurred in 1983, when the first real occasion arose to evaluate the treatments.

To date, technology transfer has been limited to inclusion of the information on success in training meetings for VDF

Table 2—*Number of SPB spot infestations on treated (Cole) and untreated (Walker) tracts in the Virginia Piedmont*

	Number of beetle spots with red-topped trees	
Flight date	Cole	Walker
7/79	0	3
2/80	1	2
8/80	3	13
7/81	3 (singles)	3 (singles)
12/83	0	21 (16.3 acres total kill)

chief wardens, technicians, and foresters in 1983 and 1984. Plans for future information transfer will include a short magazine article for the Virginia Forestry Association.

INFLUENCE OF DEMONSTRATION PROJECTS ON VIRGINIA FORESTS

All of the objectives described above were designed to demonstrate the value of thinning to reduce beetle damage. Existing photo interpretation technology was applied to locate stands in need of thinning and harvest, and efforts to contact landowners with problem stands were instituted. The demonstration and evaluation of promising new equipment for selective thinning provided pulpwood producers a chance to view, observe, and evaluate. Thinning demonstrations on the State Forest and on private land in five Piedmont counties will provide a long-term testimony to the value of intermediate cuts in pine management. Consulting foresters under contract with the Division experienced firsthand the value of thinning. A bulletin on thinning benefits was widely distributed.

The results of the Demonstration Project provided additional information to support our arguments for better silvicultural management of our pine stands in Virginia. A series of meetings with forest industry in 1985 helped to present the case for better silvicultural management.

Publications generated by the projects included: "Evaluation of Thinning for Reduction of Losses from Southern Pine Beetle in Loblolly Pine Stands," by Burkhart and others 1985, submitted to *Southern Journal of Applied Forestry* (pending acceptance); "Thin Your Pines—It's Good Business" (a pamphlet), published by the Virginia Division of Forestry, 1983; "Identification of High-Hazard Stands for Control Measures of Southern Pine Beetle," by Smith and others 1981 (Remote Sensing Research Report 81−2, 14 p.).

LITERATURE CITED

Burkhart, H. E.; Haney, H. L., Jr.; Newberry, J. D.; Morris, C. L.; Reed, D. D. Evaluation of thinning for reduction of losses from southern pine beetle in loblolly pine stands. Southern Journal of Applied Forestry; 1985. [In press].

III. SUMMARY AND CONCLUSIONS

Technology transfer was a focal point of the Integrated Pest Management Research, Development and Applications Program for Bark Beetles of Southern Pines from the inception of the Program in 1980. The primary function of this activity was to develop, package, and transfer information in various forms to a diversity of users. To accomplish this, it was necessary to describe the information that would be transferred, to identify the audience(s), to determine what would be accomplished by providing the information, to organize an approach to transferring the technology, to determine the best way(s) to communicate the information, and to evaluate the outcome of the transfer effort.

To reach a broad and diverse spectrum of landowners and managers in 13 southern States required that the IPM Program and Southern Region specialists work through recognized regional or local forestry organizations and associations with established communications networks. Primary transfer agents included State and Private forestry staffs, State forestry organizations, Extension specialists, and larger industrial and forestry association organizations engaged in broadscale pest control activities. Representatives from these groups were continually involved in the planning and execution of work at the Program or project level throughout the life of the Program, and were in large part responsible for the success of its technology transfer efforts. Researchers engaged in more applied studies also contributed to this effort. The close working relationships among these diverse groups and individuals produced new ideas, made researchers aware of operational constraints, and assured that many end products would be of direct use to the ultimate consumers.

Projects to demonstrate improved technologies and "best management practices" were found to be a very effective means for transferring new information to forest industry, National Forests, consultants, and private nonindustrial landowners. By evaluating the results of technology transfer and providing feedback to the developers on a continuing basis, it was assured that the new technology would be more readily understood and accepted by its final users. This evaluation procedure covered not only the process (how things were done) but also the products (information and delivery systems) and the consequences (impact) of the transfer efforts.

Feedback on the demonstration project approach to technology transfer was very positive. Improved, standardized approaches to detection, evaluation, prevention, prediction, and suppression were implemented by many organizations. Procedures were validated under operational conditions or improved for field application as a result of user feedback. Each organization involved shared the results within its own organization and with others with whom they customarily worked. This approach reached the greatest numbers of people and utilized the most qualified transfer agents. It also offered the opportunity for the ultimate user to get involved, provided a means for foresters and landowners (working hand-in-hand with specialists) to observe and discover the application of new technology on their own land, and to work on their own problems within the limits of their own management objective(s) and forest and economic conditions.

IV. APPENDIXES

APPENDIX I—SCIENTIFIC NAMES OF SPECIES MENTIONED IN THIS PUBLICATION

nsect species

lack turpentine beetle	*Dendroctonus terebrans* (Oliv.)
os engraver beetles	*Ips avulsus* (Eichh.)
	Ips grandicollis (Eichh.)
	Ips calligraphus (Germ.)
'ales weevil	*Hylobius pales* (Herbst)
outhern pine beetle	*Dendroctonus frontalis* Zimm.

isease species

nnosus root rot	*Heterobasidion annosum* (Fr.) Bref.
usiform rust	*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*
ittleleaf disease	*Phytophthora cinnamomi* Rands
'itch canker	*Fusarium moniliforme* Sheld. var. *subglutinans* Wollenw. and Reink.

ree species

lash pine	*Pinus elliottii* Engelm. var. *elliottii*
oblolly	*Pinus taeda* L.
hortleaf	*Pinus echinata* Mill.

)ther organisms

lue stain	*Ceratocystis minor* Hedgc. (Hunt)
ompetitive fungus	*Phlebia gigantea*

APPENDIX II—TECHNOLOGY TRANSFER GOALS, OUTPUTS AND PARTICIPANTS DURING THE IPM PROGRAM, 1981–8

Item 1—*Targets and outputs of the Integrated Pest Management Program for Bark Beetles of Southern Pines*

Targets	Outputs
Methods for measuring and predicting impacts for making control decisions.	Procedures for measuring bark beetle and disease impacts. Procedures for predicting bark beetle and disease impacts. Models for southern pine beetle (SPB), fusiform rust, and annosus root rot impacts. Benefit/costs of management strategies.
Increased utilization of beetle-killed timber.	Sawmill decision model. Field procedures for determining utilization potential of beetle-killed timber.
Measurement and roles of biological and environmental factors affecting beetle populations.	Sampling techniques for SPB (in standing trees) and *Ips* populations (in standing trees and logging residue). Description of beetle, fungal, and microenvironmental interactions.
Methods for measuring and predicting host susceptibility to beetle attack.	Identification of host and environmental conditions favoring beetle attack and brood development. Models for describing and predicting host susceptibility to beetle attack.
Suppression and prevention tactics for bark beetles.	Management guidelines to reduce pest losses in natural and planted stands. Identification of harvesting and thinning practices contributing to bark beetle- and tree pathogen-caused losses. Bark beetle behavioral chemical (attractant) formulations and deployment strategies. Registration of Dursban® and/or Sumithion® for *Ips* spp. and/or black turpentine beetle control. Determinations of efficacy and safety of additional chemicals for bark beetle control.
Development and incorporation of pest management strategies into forest management programs.	Development of pest management systems for SPB-*Ips* complex. Pest management approaches incorporated into forest management programs.

Item 2—*Technology transfer teams formed during ESPBRAP and IPM Programs*

Technology transfer team	Team leader and affiliation	Program involvement
Silvicultural practices and stand-rating systems	Roger P. Belanger USDA Forest Service Southeastern Forest Experiment Station	ESPBRAP
	Roger Dennington USDA Forest Service Southern Region	IPM
Guidelines for utilizing beetle-killed timber	Robert F. Westbrook USDA Forest Service Southern Region	ESPBRAP
Socioeconomic guidelines	Joseph Lewis USDA Forest Service Southern Region	ESPBRAP
New insecticides and improved spray systems	John W. Taylor USDA Forest Service Southern Region	ESPBRAP
Sampling methods and predictive models	Fred M. Stephen University of Arkansas	ESPBRAP
Aerial survey and navigation systems	J. G. Denny Ward USDA Forest Service Southern Region	ESPBRAP
Behavioral chemicals	Thomas L. Payne Texas A&M University	ESPBRAP
Host/pest interactions	T. Evan Nebeker Mississippi State University	IPM
Integrated pest management strategies—decision support system	Robert N. Coulson Texas A&M University	ESPBRAP
	Michael D. Connor USDA Forest Service Southern Region	IPM

Item 3—*Approaches for preparation, packaging, and delivery of written and audiovisual materials*

A. ESPBRAP/IPM Program-supported communications

1. USDA Agriculture Handbooks, Technical Bulletins, and Agriculture Information Bulletins.
2. USDA Forest Service General Technical Reports and special reports.
3. Feature articles in professional and trade magazines.
4. Training/education aids: slide-tapes, management guidelines, portable displays, hands-on microcomputer demonstrations, training sessions for Federal and State pest management specialists.
5. Program newsletters

B. Investigator-generated communications

1. Technical or semipopular articles in domestic and foreign journals, government publication series, university series, and industry or association magazines.
2. Computerized information on mainframes, minicomputers and microcomputers.
3. Training/awareness workshops for Federal, State, industry, nonindustrial landowners and managers, and consultants.
4. Training aids: slide-tapes, movies, videotapes, public service announcements.
5. Fact sheets, leaflets, and circulars.
6. Project newsletters (Texas Forest Service Spotlight on Southern Pine Beetle; Clemson University Integrated Pest Management Newsletter).
7. Portable displays.

C. Communications through other organizations

1. Feature articles in professional and trade magazines.
2. Presentations at regional, national, and international symposia, work conferences, and meetings.
3. Sale of slide-tapes through SOUTHFORNET.
4. Highlight statements in professional society (Entomological Society of America, Society of American Foresters), association, Cooperative Extension Service, and Forest Service newsletters.
5. Participation in continuing education courses at universities.
6. Sale of videotapes through Mississippi State Cooperative Extension Service.

Item 4—*Expanded Southern Pine Beetle R&D Program, Integrated Pest Management RD&A Program, USDA Forest Service, Southern Region, and State forestry organization publications and audiovisual aids*

Series, title, and publication year	Series no.
USDA Agriculture Handbooks	
Southern Pine Beetles Can Kill Your Ornamental Pine (10/78; reprinted 1980)	H&GB 226
A Mill Operator's Guide to Profit on Beetle-Killed Southern Pine (4/79)	AH 555
A Field Guide for Ground Checking SPB Spots (11/79; reprinted 7/80, 8/83)	AH 558
An Aerial Observer's Guide to Recognizing and Reporting SPB Spots (4/80)	AH 560
How to Identify Common Insect Associates of the SPB (7/80; reprinted 10/81)	AH 563
Woodpeckers and the SPB (7/80; reprinted)	AH 564
Loran-C Radio Navigation Systems as an Aid to SPB Surveys (11/80)	AH 567
A Guide for Using Beetle-Killed Pine Based on Tree Appearance (3/81)	AH 572
Direct Control Methods for the SPB (3/81; reprinted 8/83)	AH 575
Silviculture Can Reduce Losses from the SPB (12/80)	AH 576
How to Interpret Radiographs of Bark Samples from Beetle-Infested Pines (3/81)	AH 577
How to Conduct a SPB Aerial Detection Survey (6/84)	TFS Circ. 267
Identification and Biology of Southern Pine Bark Beetles (3/85)	AH 634
Rating the Susceptibility of Stands to SPB Attack (4/85)	AH 645
Distinguishing Immatures of Insect Associates of Southern Pine Bark Beetles (12/85)	AH 641
SAMTAM—A Guide to Sawmill Profitability for Green and Beetle-Killed Timber (In press)	AH 648
Managing Piedmont Forests to Reduce Losses From the Littleleaf Disease-Southern Pine Beetle Complex (In press)	AH 649
Integrated Pest Management in Southern Pine Forests (In press)	AH 650
Use of an Attractant to Disrupt SPB Spot Growth (In preparation)	AH ____
USDA Forest Service Technical Bulletins and General Technical Reports	
Site, Stand and Host Characteristics of SPB Infestations (1981)	TB 1612
Evaluating Control Tactics for SPB (11/79)	TB 1613
Modeling SPB Populations (11/80)	TB 1630
The Southern Pine Beetle (10/80)	TB 1631
Field and Laboratory Evaluations of Insecticides for SPB Control (11/81)	GTR SE-21
Utilization of Beetle-Killed Southern Pine (12/85)	GTR WO-47
Thinning Practices in Southern Pines—With Pest Management Recommendations (12/85)	TB 1703
Technology Transfer in Integrated Forest Pest Management in the South (12/85)	GTR SE-34
USDA Agriculture Information Bulletins	
Southern Pine Beetle Program Accomplishments Report (1/81)	AIB 438
Integrated Pest Management in the South—Highlights of a 5-Year Program (11/85)	AIB 491
USDA Forest Service Southern Region Forest Pest Management Technology Update—Southern Pine Beetle Fact Sheets	
Use of beetle-killed timber for lumber (10/79)	1
Use of beetle-killed timber for pulp, plywood, and paneling (10/79)	2
Setting control priorities for the SPB (10/79; reprinted 4/84)	3
An aerial observer's guide to recognizing and reporting SPB spots (4/80)	4
Insecticides for the SPB (10/79; reprinted 3/83, 4/84)	5

Series, title, and publication year	Series No.
Woodpeckers can help control the SPB (5/80)	6
PTAEDA: A loblolly pine growth model (6/80)	7
FRONSIM, a computer program model (6/80)	8
Use of behavioral chemicals for SPB suppression—a research update (7/80)	9
Rating the susceptibility of pine stands to SPB attack (10/80)	10
The ESPBRAP site-stand data file (10/80)	11
Loran-C navigation (12/80)	12
Use of beetle-killed timber for particleboard and hardboard (12/80)	13
TBAP-Timber benefits analysis program (12/80)	14
Salvage removal (1/81)	15
Cut-and-leave (1/81)	16
Chemical control (1/81; reprinted 2/84)	17
Pile-and-burn (1/81; reprinted 7/84)	18
A method for assessing the impact of SPB damage on esthetic values (5/81)	19
Economic impact of the SPB on recreation—one approach (5/81)	20
Silviculture: A means of preventing losses from the SPB (6/81; reprinted 4/84)	21
Setting control priorities using emergence: attack ratios—a research update (9/81)	22
DAMBUGS—A case study (9/81)	23
Buffer strip (5/82; reprinted 7/84)	24
Utilization of beetle-killed southern pine based on tree appearance (5/82)	25
Use of computer simulation models to predict expected tree mortality and monetary loss from SPB spots—a research update (1/83)	26
A research update: FERRET—the question analysis routine for the SPB decision support system (1/83)	27
Texas hazard-rating guide (4/83)	28
A computerized literature retrieval system for the SPB (5/84)	29
SAMTAM: Sawmill analysis model for green and beetle-killed southern pine timber (2/85)	30
Utilization guides for green and beetle-killed timber (Submitted 6/83)	
CLEMBEETLE*	
TAMBEETLE*	
TFS spot growth*	
Arkansas SPB*	
PIEDMONT RISK*	
SPB COMP*	
Fusiform rust yield—slash*	
GY-ANNOSUS*	
SPB decision support system*	
MS Hazard B*	
NF RISK*	
TFS GRID HAZARD*	
AR HAZARD*	
MOUNTAIN RISK*	
IPM Decision Key*	

Series, title, and publication year	Series No.
Aerial GA*	
Borax for annosus prevention*	
Estimating the severity of annosus root rot in loblolly pine stands*	
Slide-tapes	
The biology and identification of the SPB. (46 slides, 7-minute tape)	
Insects associated with the SPB. (79 slides, 14-minute tape)	
Building among the pines. (121 slides, 19-minute tape)	
Control methods for the SPB. (80 slides, 16-minute tape)	
Silviculture can reduce SPB losses. (65 slides, 9-minute tape)	
Chemical control of SPB. (50 slides, 9-minute tape)	
Applying integrated pest management in southern forests. (80 slides, 14-minute tape)	
Fusiform rust (In preparation)	
Annosus root rot: management strategies to minimize damage (In preparation)	
Littleleaf management strategies (In preparation)	
Portable displays	
Hazard rating for SPB, annosus root rot, fusiform rust, and littleleaf disease	
Utilization of beetle-killed wood	
Integrated forest pest management	
Professional journal articles	
The Southern Lumberman (Applefield 1983; Westbrook and others 1981)	
Southern Journal of Applied Forestry (Thatcher and others 1982)	
Forest Farmer (Belanger and others 1983; Thatcher 1984, 1985)	
The Consultant (Hertel and others 1983)	
Forests and People (Branham 1984; Branham and Nettleton 1985)	

* All of these fact sheets were submitted in 1984 or/ 1985 and will have been issued by the time this publication goes to press.

Item 5—*Models used in training pest management specialists in predicting southern pine beetle and disease trends, tree mortality, and econon losses*

Models	Purpose
Hazard rating	
TFS Grid Hazard	To rate susceptibility of Texas Forest Service 18,000-acre grid blocks to SPB infestation.
AR Hazard	To estimate relative susceptibility of Arkansas pine stands to SPB attack.
MS Hazard B	To determine the relative hazard of timber stands to SPB attack in Mississippi and Alabama.
TX Hazard	To rate relative susceptibility of pine stands to SPB attack and timber loss in Gulf Coastal Plain.
NF Risk	To rate relative risk of pine stands to SPB attack on National Forests in the South.
Piedmont Risk	To determine the risk of natural stands suffering loss due to SPB attack in the Piedmont.
Mountain Risk	To evaluate forest stands in the southern Appalachians for susceptibility to SPB infestation.
Trend models	
SPB Comp	To predict a change in SPB-infested area from the previous year for specified multicounty climatic districts.
Aerial GA	To predict the number of SPB spots per acre in a given year for the Piedmont of Georgia.
Southeast Surveil	To project the percentage of the southeastern U.S. with SPB activity in current year based upon SPB acti in a subsample of the region.
Southeast Predict	To predict SPB infestation coverage over the Southeast for next year based upon SPB activity in the curr year in a subsample of the region.
Spot growth models	
TAMBEETLE	To predict short-term (30 to 90 days) growth potential of existing SPB spots, tree mortality, and economic loss in currently infested planted and natural stands.
Arkansas SPB	To predict short-term (30 to 90 days) SPB population growth, tree mortality, and economic loss in currently fested loblolly and/or shortleaf pine stands.
TFS Spot Growth	To predict tree mortality and economic losses caused by SPB infestations over next 30 days during summe months.
E/A Ratio	To predict the relative increase in number of SPB-infested trees on a spot-by-spot basis during next 3 to 6 mont
Management simulation	
CLEMBEETLE	To simulate the probability of spot occurrence and expected loss caused by SPB in single or multiple loblolly shortleaf pine stands for periods as short as a year or as long as a rotation.
ITEMS (Integrated Timber/Economics Management Simulator)	To simulate the performance of one or more pine stands under varied management regimes and levels of S activity over a period of years.
Management information and decision support systems	
SPB Decision Support System	To help forest and pest managers analyze questions regarding southern forest and SPB pest management anc provide the latest technology available for management decisionmaking.
IPM-DK (Integrated Pest Management Decision Key)	To provide a listing of currently recommended management options for preventing or reducing losses caused insects and diseases in a variety of management situations.
Other	
SPBEEP (Southern Pine Beetle Economic Evaluation Procedure)	A computerized procedure for analyzing the economic benefits and costs associated with SPB control projects volving salvage removal.
Fusiform Rust Yield—Slash	To predict yields by diameter class at rotation age from unthinned slash pine plantations infected with fusifo rust.
Stump Treatment with Borax	To provide an economic analysis of the use of borax stump treatment during thinning of pine stands on hig hazard annosus root rot sites.

APPENDIX III—IPM PROGRAM APPLICATIONS PLAN

Title: Forest management strategies for preventing or reducing beetle- and pathogen-caused losses: silvicultural treatment of planted stands in the Atlantic Coastal Plain.

Investigators: R. P. Belanger, Principal Silviculturist, T. Miller, Project Leader, R. S. Webb, Assistant Professor, and J. F. Godbee, Project Leader, Pest Management.

Performing Organizations: Southeastern Forest Experiment Station, Athens, GA; University of Florida, Gainesville, FL; and Union Camp Corporation, Rincon, GA.

1. Message: Maintaining healthy stands is the key to effective forest pest management. Guidelines are presented that describe stand, site, and individual tree characteristics that are associated with stands highly susceptible to beetle- and pathogen-caused losses. SPB, *Ips* spp., BTB, fusiform rust, and annosus root rot are the major pests covered. Cultural treatments are recommended that will reduce losses from these pests.

2. Audience: Forest managers, foresters, researchers, pest management specialists, and service and "linker" organizations.

3. Objective: The incorporation of pest prevention strategies into forest management planning and practice.

4. Team: Silvicultural practices and stand-rating systems TT team.

5. Media: Scientific publications, compendia, how-to handbooks, fact sheets, field demonstrations, slide-tape presentations, workshops, and symposia.

6. Evaluation: The effectiveness of technology transfer will be evaluated by determining:

   a. Number of management plans that contain new technology.
   b. Number of acres rated for susceptibility to attack by insects and diseases.
   c. Number of acres treated to reduce losses from insects and diseases.
   d. Biological and economic gains from implementation of pest management strategies.

7. Identifying additional research needs: Implementation of integrated pest management strategies in operational resource management is in its infancy. The researcher, technology transfer specialist, and user must make an effort to recognize and communicate additional research and applications needed to reduce losses from insects and diseases.