Pinus taeda L. Loblolly Pine

Pinaceae Pine family

James B. Baker and 0. Gordon Langdon

Loblolly pine *(Pinus taeda)*, also called Arkansas pine, North Carolina pine, and oldfield pine, is the most commercially important forest species in the southern United States, where it is dominant on about 11.7 million ha (29 million acres) and makes up over one-half of the standing pine volume. It is a medium-lived, intolerant to moderately tolerant tree with rapid juvenile growth. The species responds well to silvicultural treatments and can be managed as either even-aged or uneven-aged natural stands, or can be regenerated artificially and managed in plantations.

Habitat

Native Range

The native range of loblolly pine (fig. 1) extends through 14 States from southern New Jersey south to central Florida and west to eastern Texas. It in-

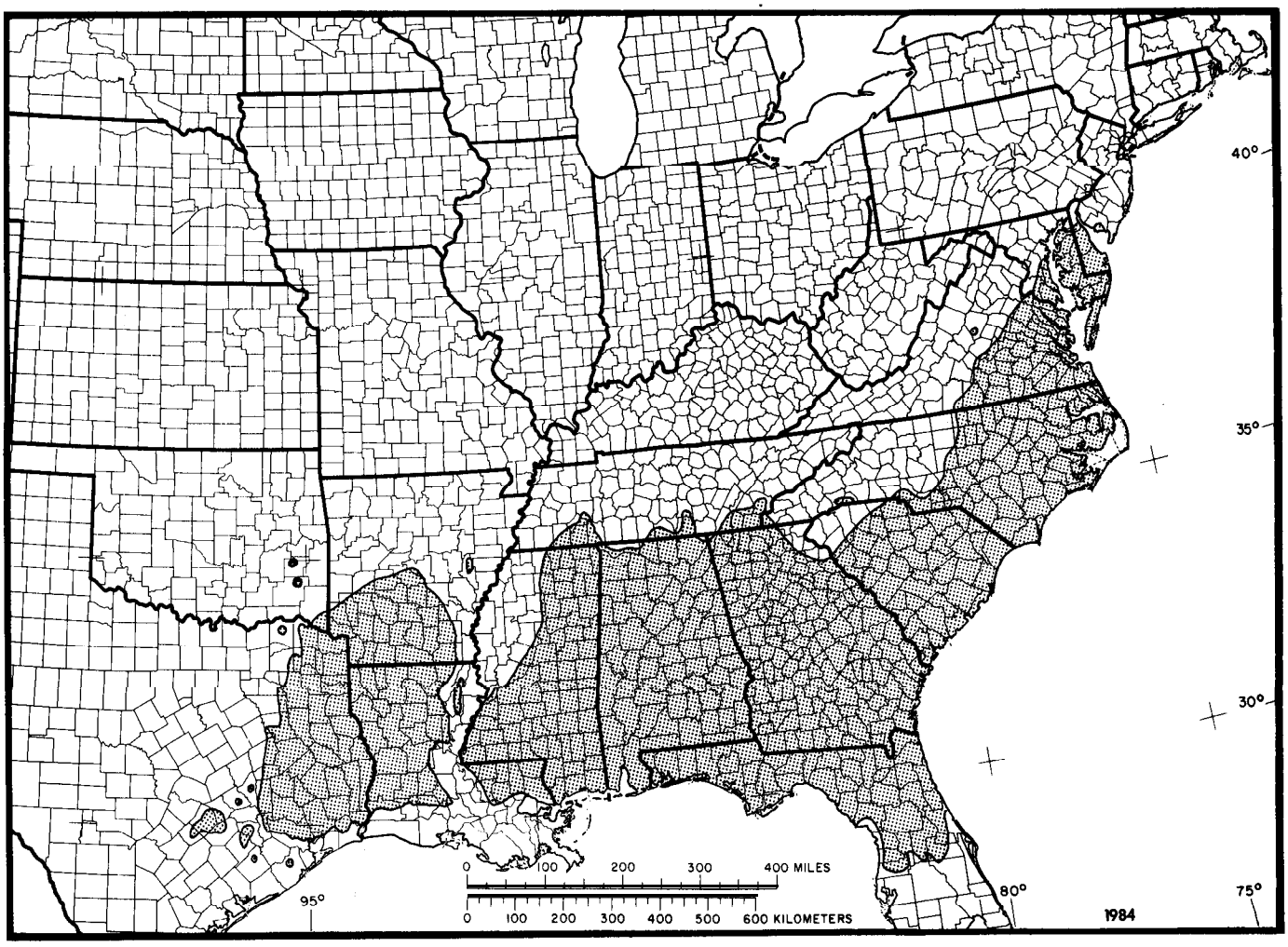

Figure *1-The native range of loblolly pine.*

The authors are Silviculturist, Southern Forest Experiment Station, New Orleans, LA, and Silviculturist (retired), Southeastern Forest Experiment Station, Asheville, NC.

cludes the Atlantic Plain, the Piedmont Plateau, and the southern extremities of the Cumberland Plateau, the Highland Rim, and the Valley and Ridge Provinces of the Appalachian Highlands. Loblolly pine does not grow naturally in the Mississippi River flood plain and is scarce in the deep, coarse sands of the lower Atlantic Plain and sandhills of North and South Carolina; it is important only in localized areas in southeastern Georgia and northern Florida *(37,55,69)*.

Loblolly pine is an adaptable species that has been successfully planted along the periphery of its natural range and has been introduced on other continents with varying degrees of success.

Climate

The climate over most of the loblolly pine range is humid, warm-temperate with long, hot summers and mild winters. Average annual rainfall varies from 1020 to 1520 mm (40 to 60 in). The frost-free period varies from 5 months in the northern part of the range to 10 months along the southern coastal States. Mean annual temperatures range from 13" to 24" C (55" to 75" F); average July temperature is 27" C (80° F) and frequently exceeds 38" C (100° F). January temperature averages 4" to 16" C (40" to 60" F) and occasionally drops to -23" C (–10° F) in the northern and western parts of the range (69).

During both winter and summer, weather within the range of loblolly pine differs from that immediately outside the range. There are a greater number of days with rain, a greater frequency of effective amounts of rain, that is, more than 13 mm (0.5 in), and higher average winter temperatures. In spring and autumn, the weather within and outside the range is more nearly the same (37).

The main factor limiting northern extension of the species is probably low winter temperature with associated damage from ice, snow, and sleet and cold damage during flowering. Lack of adequate growing-season precipitation probably limits western extension of loblolly pine in Oklahoma and Texas (37).

Soils and Topography

Soils within the native range of loblolly pine are predominantly Ultisols. Small areas of Entisols and Spodosols are found in the Southeastern States and there are some Alfisols throughout the region. Loblolly pine grows on a wide variety of these soils, ranging from the flat, poorly drained Aquults and Aquods of the coastal portion of the Atlantic Plain to the relatively dry Psamments, Udults, and Udalfs of the inland portion of the Atlantic Plain, Piedmont, and upland Provinces *(107)*. Best growth is on moderately acid soils with imperfect to poor surface drainage, a thick medium-textured surface layer, and a fine-textured subsoil. These soils are common in the uplands of the Atlantic Plain and on the flood plains and terraces of rivers and streams. Poorest performance is on shallow soils, eroded soils, and very wet or waterlogged sites (37).

Some typical examples of Ultisols on which loblolly pine grows include the Coxville, Bladen, Beauregard, Wahee, Dunbar, Ruston, Norfolk, Orangeburg, and Smithdale series found in the Atlantic Plain; the Cecil, Davidson, and Appling series in the Piedmont; and the Hartsells and Linker series in the upland Provinces. Ultisols have a site index measured at base age 50 years for loblolly pine of 23 to 30 m (75 to 100 ft) in the Coastal Plain, 20 to 29 m (65 to 95 ft) in the Piedmont, and 18 to 24 m (60 to 80 ft) in the upland Provinces. Typical Entisols on which loblolly pine is found include deep sands (Chipley, Eustis, and Lakeland series) and alluvial soils (Alpin and Osier series), with a site index ranging from 20 to 30 m (65 to 100 ft). Representative Spodosols include the Leon and Lynn Haven series, with a site index of 18 to 26 m (60 to 85 ft). Within the Atlantic Plain but confined to a strip on each side of the Mississippi River are loessial soils represented by the Memphis, Grenada, Providence, Calhoun, and Henry series. These loessial soils, as well as Caddo, Wrightsville, Meggett, and Bude series, all having a site index ranging from 23 to 34 m (75 to 110 ft), are some representative Alfisols on which loblolly pine grows.

In the Atlantic Plain, the productivity of mineral soils generally decreases with improvement in surface drainage. Productivity is sensitive to soil fertility, however, and if fertility is low on poorly drained sites, productivity decreases (63). The presence of a spodic horizon within the rooting zone, as in the Leon series, frequently is associated with low productivity. Deep, excessively drained sands are also very low in site quality unless a water table or a clay lens which holds moisture lies within reach of the tree roots (37).

In the Piedmont Plateau, where surface drainage is well developed, physical characteristics of the soil, rather than surface drainage, determine the availability of moisture, nutrients, and aeration. Here uneroded soils with a thick surface layer and a friable subsoil have a site index of 24 to 27 m (80 to 90 ft). Common series in this category are Appling, Durham, Davidson, Georgeville, and Cecil. The least productive sites are eroded soils with a very plastic subsoil such as the Orange and Iredell series. When

the A horizon is gone, site index is less than 12 m (40 ft) *(37)*.

In the Ridge and Valley Provinces loblolly pine site index of 18 to 26 m (60 to 85 ft) generally increases from ridge tops to bottoms. This variation is related to landform, slope position and aspect, and geology. Soil features that determine site quality, such as soil temperatures, surface soil thickness, subsoil consistency, and soil moisture, are correlated with topography However, past land use, differences in soil parent material, and other factors also affect soil profile development and cause variations in site quality independent of topography (92).

Perhaps as significant as the soils on which loblolly pine grows are those soils in the region where loblolly pine does not grow. These are principally Mollisols of the Blackbelt, Entisols of calcareous river bottoms and terraces (that is, soils in the Louisa, Miller, and Precris series characterized by high base saturation and high pH) and Alfisols of the Coastal Prairie of Louisiana and Texas with moderately high base saturation. These soils may also have other unidentified properties which exclude pine (72).

The topography throughout the loblolly pine range varies from flat near the coast to mountainous in the interior highlands. The topography can best be related to the physiographic regions within the loblolly pine range.

The Atlantic Plain is generally flat near the coast but becomes rolling and hilly inland with elevations ranging up to 150 m (500 ft). The Piedmont Plateau is more rolling, with highly developed drainage patterns and generally finer textured soils. Elevations range up to 305 m (1,000 ft) in Georgia. The Ridge and Valley Province is about 64 km (40 mi) wide and extends into the loblolly pine range from southeastern Tennessee into northern Georgia and Alabama. The topography is characterized by a group of valley floors separated by long, narrow, zigzagging ridges; elevations range from about 185 m (600 ft) to about 365 m (1,200 ft). The Cumberland Plateau, which lies just west of the Ridge and Valley Province, is underlaid by massive sandstone and its topography is characterized by winding narrow-crested ridges and narrow valleys. In some places the sandstone has given rise to local upland flats and mesa-like forms or knobs. Elevations range from 150 m (500 ft) in the southern part of the region and in the valley floors to 305 m (1,000 ft) at the northern end of the region and on ridge tops. The topography of the Highland Rim that extends into south-central Tennessee and northern Alabama is undulating with depressions and low domes where elevations range from 150 to 245 m (500 to 800 ft).

Associated Forest Cover

Loblolly pine is found in pure stands and in mixtures with other pines or hardwoods, and in association with a great variety of lesser vegetation. When loblolly pine predominates, it forms the forest cover type Loblolly Pine (Society of American Foresters Type 81) (3.2). Within their natural ranges, longleaf, shortleaf, and Virginia pine *(Pinus palustris, P. echinata,* and *P. virginiana),* southern red, white, post, and blackjack oak *(Quercus falcata, Q. alba, Q. stellata,* and Q. *marilandica),* sassafras *(Sassafras albidum),* and persimmon *(Diospyros virginiana)* are frequent associates on well-drained sites. Pond pine *(Pinus serotina),* spruce pine *(P. glabra),* blackgum *(Nyssa sylvatica),* red maple *(Acer rubrum),* and water oak *(Quercus nigra),* willow oak *(Q. phellos),* and cherrybark oak *(Q. falcata* var. *pagodifolia)* are common associates on moderately to poorly drained sites. In the southern part of its range, loblolly frequently is found with slash pine *(Pinus elliottii)* and laurel oak *(Quercus laurifolia).*

In east Texas, southern Arkansas, Louisiana, and the lower Piedmont, loblolly and shortleaf pine are often found in mixed stands. In Loblolly Pine–Shortleaf Pine (Type 80), loblolly predominates except on drier sites and at higher elevations. When shortleaf pine predominates, the mixture forms Shortleaf Pine (Type 75).

In fertile, well-drained coves and along stream bottoms, especially in the eastern part of the range, yellow-poplar *(Liriodendron tulipifera),* American beech *(Fagus grandifolia),* and white and Carolina ash *(Fraxinus americana* and *F. caroliniana)* are often found in the Loblolly Pine-Shortleaf Pine cover type.

Loblolly pine also grows in mixture with hardwoods throughout its range in Loblolly Pine–Hardwood (Type 82). On moist to wet sites this type often contains such broadleaf evergreens as sweetbay *(Magnolia virginiana),* southern magnolia *(M. grandiflora),* and redbay *(Persea borbonia),* along with swamp tupelo *(Nyssa aquatica),* red maple, sweetgum, water oak, cherrybark oak, swamp chestnut oak *(Quercus michauxii),* white ash, American elm *(Ulmus americana),* and water hickory *(Carya aquatica).* Occasionally, slash, pond, and spruce pine are present.

In the Piedmont and in the Atlantic Plain of northern Virginia and Maryland, loblolly pine grows with Virginia Pine (Type 79). In northern Mississippi, Alabama, and in Tennessee it is a minor associate in the eastern redcedar-hardwood variant of Eastern Redcedar (Type 46). On moist lower Atlantic Plain sites loblolly pine is found in Longleaf Pine (Type 70),

Longleaf Pine-Slash Pine (Type 83), and Slash Pine–Hardwood (Type 85).

In the flood plains and on terraces of major rivers (except the Mississippi River) loblolly pine is a minor associate in Swamp Chestnut Oak-Cherrybark Oak (Type 91). On moist, lower slopes in the Atlantic Plain it is an important component in the Sweetgum-Yellow-Poplar (Type 87). In bays, ponds, swamps, and marshes of the Atlantic Plain it is a common associate in Pond Pine (Type 98), the cabbage palmetto-slash pine variant of Cabbage Palmetto (Type 74), and Sweetbay-Swamp Tupelo-Red Bay (Type 104).

There is a great variety of lesser vegetation found in association with loblolly pine. Some common understory trees and shrubs include flowering dogwood *(Cornus florida)*, American holly *(Ilex opaca)*, inkberry *(I. glabra)*, yaupon *(I. vomitoria)*, hawthorn *(Crataegus* spp.), southern bayberry *(Myrica cerifera)*, pepperbush *(Clethra* spp.), sumac *(Rhus* spp.), and a number of ericaceous shrubs. Some common herbaceous species include bluestems *(Andropogon* spp.), panicums *(Panicum* spp.), sedges *(Carex* spp. and *Cyperus* spp.), and fennels *(Eupatorium* spp.).

Life History

Reproduction and Early Growth

Flowering and Fruiting-Loblolly pine is monoecious; male flowers form in clusters at the tip of the preceding year's growth and female flowers form on the new year's growth. The pollen-bearing staminate flowers are catkinlike in appearance; they range from 2.5 to 3.8 cm (1.0 to 1.5 in) in length and vary from light green to red and yellow depending on stage of development. The pistillate flowers are generally ovoid and range from 1.0 to 1.5 cm (0.4 to 0.6 in) in length. They vary from light green through shades of pink to red depending on stage of development.

Flowering of loblolly pine is initiated in July and August in a quiescent bud that is set from middle June to early July The male strobili form in this bud in late July and the female in August, but they are not differentiated into recognizable structures until late September or October. In October the staminate buds develop at the base of a vegetative bud and the pistillate buds develop at the apex of a vegetative bud a few weeks later; both remain dormant until early February *(37,41)*. The date of peak pollen shed depends on the accumulation of 353" C (636" F) day-heat units above 13" C (55" F) after February 1 *(16)*. Flowering is also related to latitude, beginning earlier at lower latitudes than at higher ones, and it can occur between February 15 and April 10. Staminate flowers on a given tree tend to mature before the pistillate flowers, which helps to reduce self-pollination. Fertilization of the pistillate strobili takes place in the spring of the following year (37).

Loblolly pine does not normally flower at an early age, although flowering has been induced on young grafts with scion age of only 3 years. The phenomenon of inducing such early flowering in seedlings is dependent on reducing vegetative shoot growth so that quiescent buds are formed in the latter part of the growing season to allow for the initiation and differentiation of reproductive structures. The formation of quiescent buds in seedlings and saplings does not usually occur during that period because four to five growth flushes are common for trees of this age. As a loblolly pine tree ages, the number of growth flushes decreases, which accounts in part for increased flowering of trees at older ages. Flowering is also genetically controlled and is influenced by moisture (May-July rainfall) and nutrient stresses.

Seed Production and Dissemination-Seed production of loblolly pine varies according to physiographic region, climatic factors, and tree or stand condition. In the southern coastal portions of the Atlantic Plain, loblolly is generally a prolific and consistent seed producer, but in some of the inland portions of the Atlantic Plain, the Piedmont, and in the western extremities of its range, seed production is often lower and more erratic. Year-to-year variations in seed crops can range from failure to bumper crops. For example, in 27 years of seedfall records in the Atlantic Plain of South Carolina, there was one seed-crop failure but there were three seed crops of more than 2.5 million sound seeds per hectare (1 million/acre) with the other crops falling between these extremes. At most locations where seed-crop records have been kept, however, such wide annual variations have not been observed.

Despite fluctuations in seed production, loblolly usually produces some seeds every year and good seed crops normally occur at intervals of 3 to 6 years. More than 198,000 sound seeds per hectare (80,000/acre) is considered a good seed crop; 74,000 to 198,000/ha (30,000 to 80,000/acre) is an average crop, and less than 74,000/ha (30,000/acre) is considered marginal, depending on seedbed characteristics and weather conditions.

Throughout the range of loblolly pine, usually cones mature and seeds ripen by the second October after flowering or about 26 months after the strobili are initiated. The mature cones are light reddish

brown and range from 7.5 to 15.0 cm (3 to 6 in) in length. They are narrowly conical to ovoid-cylindrical. Each cone scale is tipped with a stout triangular spine. Mature cones have a specific gravity of 0.89 or less (they float in SAE 20 oil). Individual cones may contain from less than 20 to more than 200 seeds, and the percentage of sound seeds may vary from about 15 percent to nearly 100 percent. Loblolly seeds vary in size from 27,100/kg (12,300/lb) to 58,200/kg (26,400/lb) and average 40,100/kg (18,200/lb) *(37,88)*.

Seed production of individual trees increases with tree age, size, and freedom from crown competition. By age 25, enough seeds may be produced in widely spaced trees to regenerate a stand; however, trees at 40 years generally produce three to five times more. Rotations shorter than 30 years usually do not lend themselves to natural regeneration.

In well-stocked and overstocked stands, cone production of loblolly pine can be stimulated threefold to tenfold by releasing the seed trees from competitors at least three growing seasons before the seed is needed. If seed-tree release is delayed later than May 1, seed-crop stimulation will be delayed 1 year. In overstocked stands, if seed trees are not released before a harvest cutting, then seed-crop stimulation will be delayed 2 or 3 years, depending on the season of the harvest cut *(37,61,95)*.

Seedfall usually begins in October, and the bulk of the seeds are released in November and early December. Seedfall is hastened by dry, warm, windy weather and retarded by cool, wet weather. Seed dispersal in or adjacent to a stand varies with height and stocking level of the seed-source trees, magnitude of the seed crop, terrain, and weather conditions at the time of seedfall. The effective seeding distance ranges from 61 to 91 m (200 to 300 ft) in a downwind direction from the seed source and 23 to 30 m (75 to 100 ft) in other directions. Viability of seeds varies with seed-crop size and the month that the seed is dispersed. Seed viability is often lower in years of poor seed crops and in seeds dispersed late in the season (37).

Loblolly pine seeds generally go through a stage of dormancy after seedfall, which lasts longer than that of any other southern pine. Seed dormancy is related to the impermeable properties of the seedcoat that constrain water imbibition and oxygen uptake; chemical germination inhibitors do not play a significant role *(11,73)*. Dormancy is broken naturally as the seeds overwinter on the forest floor. Germination is epigeal *(88)*. Natural seed germination usually begins in March when daytime temperatures range between 18° and 27° C (65" and 80" F). Few seeds remain viable (not more than 0.1 percent) on the forest floor for germination in the second year after seedfall (70). Secondary seed dormancy can be induced during seed handling procedures. Cold, moist stratification of the seed for 30 to 90 days at temperatures 3" to 5" C (37" to 41" F) are generally recommended to artificially break dormancy for direct seeding or for nursery sowing (74).

Seedling Development-Moisture is a critical factor in seed germination and seedling establishment; the amount of rainfall in the spring is related directly to seedling catches. Scarifying the seedbed exposes mineral soil and increases contact of the seeds with moist soil surfaces. Failure of the root radicle to penetrate compacted or puddled soil surfaces reduces seedling establishment, especially on major skid trails and log decks. Soil compaction and puddling also reduce root growth, seedling survival, and shoot growth *(36,37,40,61)*.

Seedbed preparation by scarification or burning greatly increases seed germination and seedling survival, which reduces the number of seeds required to produce one seedling. For example, undisturbed seedbeds with a litter depth of 8 to 10 cm (3 to 4 in) require 5 to 6 times more seeds to produce the number of seedlings produced in disturbed seedbeds.

Seed germination decreases with age of seedbed and increases with clay content of the soil. Two-year-old seedbeds require 3 to 4 times more seed for successful establishment than do l-year-old seedbeds, and 3-year-old seedbeds require 9 to 14 times more seed than is needed in the first year. Thus, favorable seedbeds usually exist for only 1 year after disturbance, after which they rapidly deteriorate. Heavier textured soils provide better seedbeds which results in higher seedling survival than do lighter textured soils (37,104).

Drought is a major cause of mortality for planted loblolly pine seedlings, especially in areas with low rainfall during the growing season. Improper care, handling, and planting of nursery stock and inadequate site preparation for control of competing vegetation also contribute to poor survival by indirectly increasing moisture strees *(34,57)*.

Height growth of loblolly pine seedlings occurs annually in a series of two to five growth flushes and is dependent on variables such as temperature, day length, soil moisture, nutrients, competition, and genetics. Temperature has a dominant influence on the initiation of height growth in the spring. High day temperatures increase height growth, but high night temperatures decrease it. When day and night temperatures differ by 12" to 13" C (54" to 55" F), the best height growth occurs *(15,43)*.

Soil moisture influences growth of loblolly pine by its effect on internal water relations and vital physiological processes. Growth is reduced with increasing water deficits. For example, at a soil moisture tension of 1520 mm of mercury (2 atm), height growth of loblolly pine seedlings is greatly reduced and at 2660 mm of mercury (3.5 atm), height growth ceases. Height and diameter growth are significantly reduced by a late spring and summer drought, which also reduces early height growth the following year *(37,98,116).*

Growth of loblolly pine seedlings in a natural stand is inversely related to overstory stocking of pine and hardwoods. As the proportion of hardwoods increases for a given pine stocking, loblolly pine seedling growth decreases. Size and shape of openings affect seedling growth up to 9 m (30 ft) from edges of openings. Seedlings growing beneath overstory hardwoods are not likely to survive more than a few years and if they do survive their growth will be slow. Growth and survival of loblolly pine seedlings during the first 7 years after a stand is regenerated may be reduced by 80 percent because of the faster growth of competing hardwood sprouts and shrubs. Pine seedlings not overtopped by hardwoods at age 3 or older have an excellent chance to outgrow the hardwood competition (37).

Photosynthesis in loblolly pine seedlings is related to light and soil moisture conditions, which in turn are affected by competing hardwoods. Photosynthetic rates of many hardwoods are inherently higher than those of loblolly pine at relatively low light intensities and with low soil moisture (37).

Fertilization often increases seedling growth in waterlogged soils. In some instances where specific nutrients are limiting growth, fertilization results in growth equal to or greater than that with drainage. Loblolly pine grows well on wet, fertile sites because of the effects of moisture on nutrient availability *(63,101).*

Vegetative Reproduction-Young loblolly pine seedlings up to 3 years of age may sprout from buds in axils of primary needles if tops are clipped off, but older trees will not produce basal sprouts at root collars if stems are cut or top-killed by fire, nor do they produce root sprouts. Rooting is related to tree age and is more successful with cuttings from younger trees. Techniques and materials used to root cuttings are of critical importance. For example, a fine mist over the rooting bench is better than a heavy mist, and Hare's powder is a better compound to use than indolebutyric acid when rooting loblolly pine cuttings. Although needle bundles and buds of loblolly pine have been rooted, the success rate has been low. Air layering, a modification of rooting cuttings, has been the more successful method of the two. Success rates have been high for young trees but older trees are more difficult to air layer *(29,42,48,110).*

Grafting is the most common method of vegetative propagation used to produce genetically uniform trees, especially in seed orchards. Grafting success is usually high but varies with scion material because problems may develop from incompatibility of scion and root stock *(29,37,66).*

Producing genetically uniform plantlets from tissue cultures is a promising technique, and research is underway to develop procedures for the commercial production of loblolly pine clones *(19,94).*

Sapling and Pole Stages to Maturity

Growth and Yield-Growth of loblolly pine stands is inherently good when compared to most hardwood competitors and on many sites doubles or triples the production of common associates (108). Growth is influenced by the physical and chemical properties of soils (texture, compaction, aeration, moisture, pH, nutrients), light, temperature, photoperiod, allelopathy, precipitation and its seasonal pattern, and intra- and inter-species competition for space and essential elements. Because many of these factors interact, it is difficult to specify the most limiting one. Consequently, these biotic and environmental effects are commonly expressed as the average height of dominant trees at age 50 years, that is, site index.

Yield estimates for natural, even-aged loblolly pine (fig. 2) in fully stocked stands were first made more than 50 years ago (3,106). Additional estimates have been made in more recent years for stands of various stocking levels *(18,81,90,99).*

Normal yields of natural, even-aged loblolly pine stands on average sites, such as those with a site index of 27 m (90 ft), have ranged from 133.0 m^3/ha (1,900 ft^3/acre) in trees 9 cm (3.6 in) and larger in d.b.h. including 29.4 m^3/ha (2,100 fbm/acre) in trees 24 cm (9.6 in) and larger d.b.h. at age 20 to 427.7 m^3/ha (6,110 ft^3 or 40,000 fbm/acre) at age 60 (all board-foot volumes reported in International quarter-inch rule). Mean annual cubic volume growth generally culminates at about age 40 on these sites with approximately 8.0 m^3/ha (115 ft^3/acre). As a result of larger sawtimber merchantability limits, mean annual board-foot growth culminates at about age 50 at a rate of 9.5m^3/ha (680 fbm/acre).

Growth of loblolly pine may be affected adversely by drought, excess moisture (flooding), and nutrient deficiencies. Growth of this species is highly corre-

Figure 2—*Old-field stand of natural, even-aged loblolly pine.*

lated with departure from the normal rainfall of April through October. Extreme negative and positive departures (-117 vs. 229 mm or -4.6 vs. 9.0 in) in seasonal rainfall over 21 years resulted in differences of nearly 2.1 m^3 (74 ft^3) of annual growth *(12,39,65)*. Drainage (including bedding) and fertilization have been shown to increase dominant height and basal-area growth, resulting in dramatic increases in volume growth *(45,63,76,101)*.

Growth of planted loblolly pine is affected by the same factors affecting natural stands. Sites are usually prepared before planting on cutover lands, and some are fertilized to correct nutrient deficiencies. Such practices are applied to control competition and to supply nutrients at optimum levels to establish vigorous, uniform stands at spacings that will fully utilize site potentials (fig. 3).

Yields of planted loblolly pine vary with plantation age, site quality, number of trees planted, and interactions of these variables. Yields generally increase with increasing age and site quality. Yields also increase with higher planting density or closer spacing; however, on some sites, moderately wide spacing of 2.4 by 2.4 m (8 by 8 ft) or 3.0 by 3.0 m (10 by 10 ft) outproduce both wider and closer spacing. Mean annual increment culminates at younger ages on better sites than on poorer ones. Better sites can carry more stocking than poor sites; consequently, initial spacing can be closer *(9,77,93)*.

Closer spacing tends to produce higher total cubic volumes at younger ages than does wider spacing; however, average tree sizes are larger on wider spacings than on closer ones, If sawtimber is a primary management objective, then wider spacing or lower density would be advantageous. Although thinning seldom increases cubic volume yield of loblolly pine, light thinnings that salvage suppressed and moribund trees have increased net yields by as much as 20 percent in 50 years, Thinnings usually result in increased diameter growth of residual trees and allow the growth to be put on the better trees in the stand. Another benefit is that thinnings provide intermediate returns on investment *(2,17)*.

Average total solid-wood yields of unthinned loblolly pine planted at 1,730 seedlings per hectare (700/acre) on non-old-field sites at various locations within its range were predicted to increase from ap-

Figure *3-The A. J. Mitchell loblolly pine plantation, Wadmalaw Island, SC, at* age *12.*

proximately 155 m^3/ha (2,200 $ft^3/acre$) at age 15 to 300 m^3/ha (4,200 $ft^3/acre$) at age 30. Mean annual increment at age 30 was about 10 m^3/ha (145 $ft^3/acre$) *(1,4,27,33,67).* Estimates are also available for a variety of site and stand conditions and geographic areas *(8,21,22,23,25,44,68,71).*

Growth and yield in natural uneven-aged loblolly pine stands is dependent on stand structure, stocking, and site quality. To optimize average annual growth on average sites with a site index of 27 m (90 ft), stand structure should be manipulated so that approximately 70 percent of the merchantable cubic volume is in the saw-log portion of the stand, that is, trees 25 cm (10 in) in d.b.h. and larger. On average sites, stands with approximately 17 m^2/ha (75 $ft^2/acre$) of basal area, or 140 m^3/ha (2,000 $ft^3/acre$) total merchantable volume, or 10,000 fbm saw-log volume at the end of the cutting cycle would be considered well stocked *(5,84,86).*

On good sites in southern Arkansas, with a site index of 27 m (90 ft) managed uneven-aged loblolly pine stands that are well stocked have averaged 0.7 m^2/ha (3 $ft^2/acre$) of basal-area growth, 5.6 m^3/ha (80 $ft^3/acre$) of merchantable volume growth, or 432 fbm/acre of saw-log volume growth per year for a 29-year period. On somewhat poorer sites in the Georgia Piedmont with a site index of 23 m (75 ft), annual growth has averaged 5.3 m^3/ha (76 $ft^3/acre$) or 319 fbm/acre over a 21-year period *(5,17,82,85,86).*

In sapling stands, differences in growth rate of individual loblolly pines are evident at early ages when competition between trees begins. The growth differentiation process begins at earlier ages on better sites or at higher levels of stocking; it begins later on poor sites or at low levels of stocking ***(51).*** The result is separation of trees into crown classes. Growth in height is a critical factor in the occupation of available space. Loblolly pine is a species in which individual trees tend to express dominance at an early age, and the most vigorous individuals that are best adapted to the microsite environment become dominants as the stand ages.

Faster growing trees develop larger live-crown ratios than do slower growing trees. Diameter growth of individual trees generally increases as crown surface area and crown ratio increase, with optimal diameter growth occurring when trees have at least a 40 percent live-crown ratio. Diameter increment does not occur uniformly on portions of the bole. Annual diameter growth is greatest within the crown and decreases with increased distance below the crown. This phenomenon causes the bole of loblolly pine trees to become cylindrical with increasing age (fig. 4). Height growth is not as sensitive as diameter growth to differences in crown size. Height

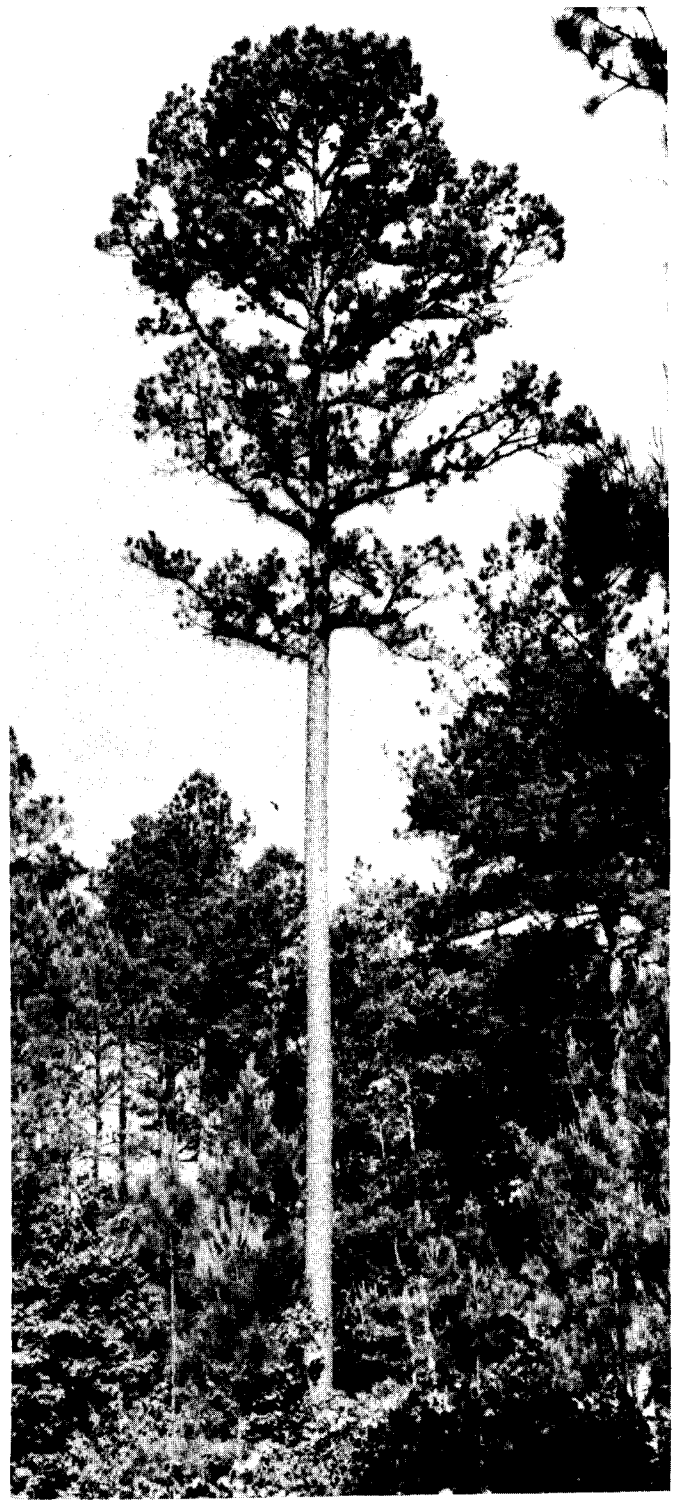

Figure *4-A 61-cm (24-in) loblolly pine with three clear logs, on Crossett Experimental Forest, AR.*

growth of codominants is significantly less, however, in dense stands of trees with small crowns than in low-density stands of trees with larger crowns *(37,38,51)*.

Loblolly pine is a medium-lived tree. Maximum recorded age of one tree in a small stand of 20 trees in North Carolina was 245 years, with the group averaging 240 years. The largest tree in this stand was 135 cm (53 in) in d.b.h. and 45.7 m (150 ft) tall. Currently, the champion for the species in the "National Register of Big Trees" is located near Urania, LA, and is 143 cm (56.3 in) in d.b.h. and 49.7 m (163 ft) tall (52).

Rooting Habit-The rooting habit of loblolly pine is strongly influenced by tree age, soil, and the soil environment. A young tree develops a short taproot but in most cases it ceases growth in favor of an extensive lateral-root system. A taproot 1.5 to 2.0 m (5.0 to 6.5 ft) long is often produced on deep, sandy or loamy soils. On heavy clay soils, the taproot tends to be stout and short. Taproots of loblolly pines are much smaller and shorter than those of shortleaf and longleaf pines. On excessively wet sites or when a water table or an impenetrable hardpan confines the roots to surface layers of soil, lateral roots are prominent in a superficial system *(3,50,108)*.

In a 6-year-old loblolly pine plantation in southeast Louisiana, 83 percent of total root weight was in the upper 46 cm (18 in) of soil. In a 31-year-old natural stand in North Carolina, the majority of the feeder roots less than 2.5 mm (0.1 in) in diameter were concentrated in the 15-cm (6-in) deep A horizon; practically no lateral roots were found below the 15- to 53-cm (6- to 21-in) depth of the B horizon *(14,59)*.

Roots of loblolly generally spread laterally farther than their crowns. As a result, root grafting is a common occurrence both in natural stands and closely spaced plantations. Roots grow at all times of the year, but most root growth occurs in April and May, and in late summer and early fall *(37,80,89,108)*.

Reaction to Competition-Loblolly pine is moderately tolerant when young but becomes intolerant of shade with age. Its shade tolerance is similar to that of shortleaf and Virginia pines, less than that of most hardwoods, and more than that of slash and longleaf pines *(31,37,108)*. Loblolly pine is most accurately classed as intolerant of shade.

Succession in loblolly pine stands that originate in old fields and cutover lands exhibit a rather predictable pattern. The more tolerant hardwoods (including various species of oaks and hickories, sweetgum, blackgum, beech, magnolia, holly, and dogwood) invade the understory of loblolly pine stands and, with time, gradually increase in numbers and in basal area. The hardwoods finally share dominance with each other and with loblolly pine *(37,83,100)*.

The climax forest for the loblolly pine type has been described as oak-hickory, beech-maple, magnolia-beech, and oak-hickory-pine in various parts of its range *(28,37)*. Others view the climax forest as several possible combinations of hardwood species and loblolly pine. There is evidence that within the range of loblolly pine several different tree species could potentially occupy a given area for an indefinite period of time and that disturbance is a naturally occurring phenomenon. If this is so, then the climax for this southern forest might best be termed the southern mixed hardwood-pine forest *(83)*.

Competition affects the growth of loblolly pine in varying degrees depending on the site, the amount and size of competing vegetation, and age of the loblolly pine stand. Across the southern region, average loss of volume production resulting from hardwood competition has been estimated at 25 percent in natural stands and 14 percent in plantations (35). In a North Carolina study, residual hardwoods after logging reduced cubic-volume growth of a new stand of loblolly pine by 50 percent at 20 years, and where additional small hardwoods of sprout and seedling origin were present, growth was reduced by another 20 percent by age 20 *(10,64)*. Similar growth responses in young seedling and sapling stands have been observed in Arkansas, Louisiana, and Texas *(24,26,39)*. Although several short-term studies (5 years or less) of the effects of understory hardwoods on growth of older loblolly pine did not show measurable effects *(58)*, a long-term study (11 to 14 years) showed growth increases of 20 to 43 percent in cubic volume and 21 to 54 percent in board-foot volume after removal of understory vegetation (39). Control of both residual overstory and understory hardwoods is a financially attractive silvicultural treatment for loblolly pine management *(10)*.

Silvicultural practices such as prescribed burns, the use of herbicides, and mechanical treatments arrest natural succession in loblolly pine stands by retarding the growth and development of hardwood understories. Prescribed fire is effective for manipulating understory vegetation, reducing excessive fuel (hazard reduction), disposing of logging slash, preparing planting sites and seedbeds, and improving wildlife habitat. Responses of the understory to prescribed fire varies with frequency and season of burning. Periodic winter burns keep hardwood understories in check, while a series of annual summer burns usually reduces vigor and increases mortality of hardwood rootstocks *(62)*. In the

Atlantic Coastal Plain, a series of prescribed burns, such as a winter burn followed by three annual summer burns before a harvest cut, has been more effective than disking for control of competing hardwood vegetation and improvement of pine seedling growth after establishment of natural regeneration *(103,104).*

Loblolly pine expresses dominance early, and various crown classes develop rapidly under competition on good sites; but in dense stands on poor sites, expression of dominance and crown differentiation are slower (37).

Dense natural stands of loblolly pine usually respond well to precommercial thinning. To ensure the best volume gains, stocking should be reduced to 1,235 to 1,730 stems per hectare (500 to 700/acre) by age 5. When managing for sawtimber, thinnings increase diameter growth of residual trees and allow growth to be put on the better trees in the stand, thus maximizing saw-log volume growth and profitability *(56,78).*

Loblolly pines that have developed in a suppressed condition respond in varying degrees to release. Increases in diameter growth after release are related to live-crown ratio and crown growing space, but trees of large diameter generally respond less than trees of small diameter. Trees with well-developed crowns usually respond best to release. Trees long suppressed may also grow much faster in both height and diameter after release but may never attain the growth rate of trees that were never suppressed (37,751.

Loblolly pine can be regenerated and managed with any of the four recognized reproduction cutting methods and silvicultural systems. Even-aged management is most commonly used on large acreages; however, uneven-aged management with selection cutting has proved to be a successful alternative.

Damaging Agents-Agents that cause periodic damage to individual trees or stands of loblolly pine include wind, lightning, temperature extremes, ice, drought, flooding, insects, and diseases. Voluminous literature about the effects of these agents in loblolly pine stands on a range of sites, soils, and stand conditions is available; a brief summary follows.

Large dominant trees usually are more vulnerable to high winds than smaller trees, and trees with large cankers caused by rust disease break more readily than sound trees. In general, damage resulting from severe winds associated with hurricanes or thunderstorms is caused primarily by windthrow or blowdown. Windthrow is most common on shallow soils with coarse-textured profiles. Wind damage is also more likely to occur in recently thinned stands *(37,105).*

Direct losses to lightning are small, averaging only about 5 trees per 100 hectares (2/100 acres> per year. Large, dominant, open-grown trees are generally the most vulnerable to lightning strikes. Probably more important than the direct damage caused by lightning is the possibility that a lightning-struck tree will become a center for insect infestation (37).

Damage or seedling mortality caused by low or freezing temperatures occurs primarily in the northern extremities of the loblolly pine range. Older, vigorous trees can usually withstand occasional low temperatures *(37,79).* Greater damage frequently occurs from ice or glaze storms. This damage is normally associated with branch and stem breakage, severe bending and, in some cases, uprooting. Ice damage is usually more severe in recently thinned (particularly row thinned) plantations and in heavily stocked stands made up of slender, small-crowned trees *(37,91).* Extremely high summer temperatures and drought often cause mortality of seedlings and, in some cases, of larger trees. Heat and drought more often cause stress and a resultant loss of vigor and growth in larger trees, which can lead to more serious problems with insect infestations.

Loblolly pine seedlings or saplings cannot withstand prolonged flooding. Complete inundation for more than 2 weeks during the growing season often results in significant mortality. Larger trees are classed as moderately tolerant of flooding; typically they can survive one season but usually succumb during the second growing season if continuously in 0.3 m (1 ft) or more of water *(37,113).*

A comprehensive review of insects associated with loblolly pine is provided by Baker *(7).* Loblolly pine serves as host to a multitude of insect pests; however, insect outbreaks vary greatly in frequency, area, and duration. The majority of outbreaks are small and short-lived and usually consist of only one or a few spots in a stand, but some may expand until they encompass hundreds of hectares and last for several years before subsiding. With only a few exceptions, the majority of the insects that attack loblolly pine are insignificant in terms of damage or mortality.

The most serious insect pests to loblolly pine are bark beetles, particularly the southern pine beetle *(Dendroctonus frontalis),* whose attack may result in extensive mortality, and pine engraver beetles *(Ips* spp.), that can cause death of isolated or small groups of trees; pine tip moths *(Rhyacionia* spp.), that often infest young trees; seedling debarking weevils *(Hylobius* spp. and *Pachylobius* spp.), that sometimes result in girdling and death of young seedlings up to 13 mm (0.5 in) in d.b.h.; and cone and

seed feeders *(Dioryctria* spp. and *Leptoglossus* spp.), that can seriously reduce seed crops. Loblolly pine is generally the preferred host of the southern pine beetle, which is the most destructive insect for this species *(102)*. Most infestations originate in stands that are under stress because of poor site, adverse weather, overstocking, or overmaturity. Once a build-up of southern pine beetle occurs, adjacent well-managed stands may also be attacked. Preventive measures include avoidance of planting offsite and maintenance of vigorous stands through silvicultural practices such as controlling density through thinning and harvesting trees at or before maturity ***(6,102).***

A general account of diseases associated with loblolly pine is provided by Hepting *(54)*. The most common disease problems in loblolly pine are related to seedling susceptibility to black root rot ***(Fusarium*** spp., ***Macrophomina*** spp., and possibly others) and fusiform rust ***(Cronartium quercuum*** f. sp. ***fusiforme);*** sapling susceptibility to fusiform rust; root rot by ***Heterobasidion annosum*** in thinned stands; and heart rot in old stands with *Phellinus pini* in the bole and ***Phaeolus schweinitzii*** primarily in the butt.

Nursery seedlings are subject to root rot in soils with pH above 6.0 under moist conditions; however, root rot becomes severe only if soil temperatures remain above 32" C (90" F) for long periods. Fusiform rust is also a major nursery disease in many parts of the South, requiring rigid spray programs to keep infections low.

The most serious stem disease is fusiform rust, which kills and disfigures young trees from Virginia to Texas. Saplings and older trees, especially if planted, are subject to attacks by ***Heterobasidion annosum*** in stands where some cutting has taken place. It is considered a disease problem in plantation management second only to fusiform rust. Losses in natural stands or in the absence of some cutting are generally negligible.

Phaeolus schweinitzii causes a root and butt rot, usually after basal or root injuries, and in the Deep South it has caused more loss in some areas than ***Heterobasidion annosum.*** Red heart ***(Phellinus pini),*** entering almost entirely through dead branch stubs, is rarely a factor under the age of 60 years. However, when large branches that have heartwood begin to die, red heart can set in and destroy much of a tree.

Special Uses

Natural loblolly pine stands as well as intensively managed plantations provide habitat for a variety of game and nongame wildlife species. The primary game species that inhabit pine and pine-hardwood forests include white-tailed deer, gray and fox squirrel, bobwhite quail, wild turkey, mourning doves, and rabbits (94). Some of these species utilize the habitat through all stages of stand development, while others are attracted for only a short time during a particular stage of development. For example, a loblolly pine plantation can provide forage for deer only from the time of planting to crown closure. Without modifying management practices, this usually occurs in 8 to 10 years ***(13).*** Bobwhite tend to use the plantation until a decline in favored food species occurs (20). As the habitat deteriorates, deer and quail usually move to mature pine or pine-hardwood forests (47) or to other newly established plantations. Management modifications such as wider planting spacing and early and frequent thinnings will delay crown closure, and periodic prescribed burns will stimulate wildlife food production.

Wild turkeys inhabit upland pine and pine-hardwood forests and do particularly well on large tracts of mature timber with frequent openings and where prescribed burning is conducted *(96,97)*.

Pine lands are the chief habitat for some birds such as the pine warbler, brown-headed nuthatch, and Bachman's warbler. Old-growth stands are very important to the existence of the red-cockaded woodpecker. Large loblolly pine trees are favorite roosting places for many birds and provide an important nesting site for ospreys and the bald eagle (46).

In urban forestry, loblolly pines often are used as shade trees and for wind and noise barriers throughout the South. They also have been used extensively for soil stabilization and control of areas subject to severe surface erosion and gullying. Loblolly pine provides rapid growth and site occupancy and good litter production for these purposes ***(114,115).***

Biomass for energy is currently being obtained from precommercial thinnings and from logging residue in loblolly pine stands. Utilization of these energy sources will undoubtedly increase, and loblolly pine energy plantations may become a reality.

Genetics

Population Differences

Many studies of racial and geographical variation in loblolly pine have been carried out since research with loblolly pine began in the early part of this century. Provenance studies have shown differences in survival, growth, disease resistance, drought hardiness, and cold hardiness attributable to source of the seed. The many findings of geographical differences (some of which show continuous, others discon-

tinuous variation with geographic location) have led geneticists to consider some differences to be racial. Although distinct races of loblolly pine have not been named and described, recommended zones for collecting seed for planting of seedlings in a given geographic area have been established. Seed orchards for producing seed for specific areas have been established *(29,30,111)*.

Resistance of certain families of loblolly pine to fusiform rust and the geographic variation in susceptibility of loblolly pine to the rust are important research findings now in use. Special rust-resistant seed orchards have been established with the most rust-resistant clones producing seed for specific geographic areas. Rust resistance of seedlings is low from seed sources in some areas such as east Texas and high for those in other areas such as Georgia and South Carolina. Rust resistance seems to be clinal and is strongly related to longitude of the seed source-the westerly sources are more resistant than the easterly ones (30,109, *117)*.

Loblolly pine from the Lost Pines area of east Texas is more drought resistant than those with more easterly seed sources. The use of drought-hardy strains of loblolly pine for planting in drought-prone areas is most important. Cold hardiness is also an important characteristic to be considered, especially if loblolly is to be planted north or inland of its natural range. As expected, the more northerly sources of loblolly pine are more cold resistant *(29,37)*.

Seed source affects yields of loblolly pine. These yield differences are usually attributable to the combined effects of seed source on survival, height and diameter growth, and susceptibility to fusiform-rust infection. Clinal effects in growth also are evident in the data, with trees from coastal areas growing faster than those from inland sources, except in northerly plantings. Loblolly pine trees within a seed source also vary in growth. Progeny tests of half-sib families (most of which are less than 10 years old) have shown significant differences in height growth with differences between races and families being additive. Nursery-bed selections of plus-seedlings have been effective in producing height growth gains for loblolly pine of 45 percent at age 10, and volume of the average plus-tree was 3.4 times that of the control. Although gains in other traits are not consistent, nursery-bed selection appears to be an effective first step in choosing fast-growing seedlings *(30,53,109,112)*.

Wood characteristics of loblolly pine have been extensively investigated. Specific gravity generally decreases from southeast to northeast and from the coastal areas to the Piedmont. Wide tree-to-tree variation also has been found for specific gravity, tracheid length, fiber angle, and cellulose type. A most important research result for geneticists has been that wood quality characteristics and growth rate at older ages are not highly correlated and, more important, not negatively correlated, which allows breeding for several traits (30).

Hybrids

The best-known southern pine hybrid is Sondereg-ger pine *(Pinus x sondereggeri* H. H. Chapm.), a cross between longleaf and loblolly pine. This natural hybrid occurs quite frequently in Louisiana and east Texas. It is conspicuous in nursery beds and plantings of longleaf pine because the hybrid gains height growth in the first year in contrast to longleaf seedlings, which do not. Natural hybrids of pond and loblolly pine have been observed in North Carolina, and those of pond, loblolly, and pitch pine have been recognized and studied in New Jersey, Delaware, and Maryland *(37,87)*. Natural hybrids of loblolly and shortleaf are known to occur in Oklahoma and east Texas *(29,37,49)*, and based on observations of tree characteristics intermediate between loblolly and shortleaf, they probably also occur in Louisiana and Arkansas in areas where the two species commonly occur together. Hybridization between these two species is thought to contribute to the fusiform-rust resistance of loblolly pine from those sources *(29)*.

Artificial hybrids of loblolly pine and the other southern yellow pines have been produced. 'Iwo crosses-loblolly x shortleaf pine and loblolly x pitch pine-show considerable promise for use on a commercial scale. The loblolly x shortleaf cross will be used in areas with high fusiform-rust incidence for breeding a strain of loblolly pine resistant to the disease *(60)*. The loblolly x pitch cross has growth characteristics of loblolly pine and cold resistance of pitch pine, making the hybrid more suitable for plantings in the north *(30)*.

Literature Cited

1. Amateis, Ralph L., Harold E. Burkhart, Bruce R. Knoebel, and Peter T. Sprinz. 1984. Yields and size class distributions for unthinned loblolly pine plantations on cutover site-prepared lands. School of Forestry and Wildlife Resources Publication No. FWS-2-84. Virginia Polytechnic Institute and State University, Blacksburg, VA. 69 p.
2. Andrulot, A. E., L. P. Blackwell, and P. Y. Burns. 1972. Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech. University, Bulletin 6. Ruston. 145 p.
3. Ashe, W. W. 1915. Loblolly or North Carolina pine. North Carolina Geological and Economic Survey, Bulletin 24. Raleigh. 176 p.

4. Bailey, Robert L., Galen E. Grider, John W. Rheney, and Leon V. Pienaar. 1985. Stand structure and yields for site-prepared loblolly pine plantations in the Piedmont and upper coastal plain of Alabama, Georgia, and South Carolina. The University of Georgia College of Agriculture Experiment Stations Research Bulletin 328. The University of Georgia, Athens. 118 p.
5. Baker, James B. 1986. The Crossett farm forestry forties after 41 years of selection management. Southern Journal of Applied Forestry 10(4):233–237.
6. Baker, James B., and William E. Balmer. 1983. *In* Silvicultural systems for the major forest types of the United States. Russell M. Burns, tech. comp. p. 148-152. USDA Forest Service, Agriculture Handbook 445. Washington,DC.
7. Baker, Whiteford L. 1972. Eastern forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1175. Washington, DC. 642 p.
8. Baldwin, V. C., Jr., and D. P. Feduccia. 1987. Loblolly pine growth and yield prediction for managed West Gulf plantations. USDA Forest Service, Research Paper SO-236. Southern Forest Experiment Station, New Orleans, LA. 27 p.
9. Balmer, W. E., E. G. Owens, and J. R. Jorgenson. 1975. Effects of spacings on loblolly pine growth 15 years after planting. USDA Forest Service, Research Note SE-211. Southeastern Forest Experiment Station, Asheville, NC. 7 p.
10. Balmer, W. E., K. A. Utz, and 0. G. Langdon. 1978. Financial return from cultural work in natural loblolly pine stands. Southern Journal of Applied Forestry 2(4):111–117.
11. Barnett, J. P. 1970. Germination inhibitors unimportant in dormancy of southern pine seeds. USDA Forest Service, Research Note SO-112. Southern Forest Experiment Station, New Orleans, LA. 4 p.
12. Bassett, J. R. 1964. Tree growth as affected by soil moisture availability. Soil Science Society of America Proceedings 28:436–438.
13. Blair, R. M., and H. G. Enghardt. 1976. Deer forage and overstory dynamics in a loblolly pine plantation. Journal of Range Management 29(2):104–108.
14. Box, B. H. 1967. A study of root extension and biomass in a six-year-old pine plantation in southeast Louisiana. Thesis (Ph.D.). Duke University, School of Forest Resources, Durham, NC. 178 p.
15. Boyer, William D. 1970. Shoot growth patterns of young loblolly pine. Forest Science 16(4):472–482.
16. Boyer, William D. 1978. Heat accumulation: an easy way to anticipate the flowering of southern pines. Journal of Forestry 76(1):20–23.
17. Brender, E. V. 1973. Silviculture of loblolly pine in the Georgia Piedmont, Georgia Forest Research Council, Report 33. Macon. 74 p.
18. Brender, E. V., and J. L. Clutter. 1970. Yield of even-aged natural stands of loblolly pine. Georgia Forest Research Council, Report 23. Macon. 7 p.
19. Brown, Claud L. 1976. Forests as energy sources in the year 2000: what man can imagine, man can do. Journal of Forestry 74(1):7–12.
20. Brunswig, N. L., and A. S. Johnson. 1972. Bobwhite quail foods and populations in the Georgia Piedmont during the first seven years following site preparation. Proceedings Southeastern Association of Game and Fish Commissioners 26:96–107.
21. Burkhart, Harold E., and Peter T. Sprinz. 1984. A model for assessing hardwood competition effects on yields of loblolly pine plantations. School of Forestry and Wildlife Resources Publication No. FWS-3-84. Virginia Polytechnic Institute and State University, Blacksburg, VA. 55 p.
22. Burkhart, Harold E., Quang V. Cao, and Kenneth D. Ware. 1981. A comparison of growth and yield prediction models for loblolly pine. School of Forestry and Wildlife Resources Publication No. FSW-2-81. Virginia Polytechnic Institute and State University, Blacksburg, VA. 59 p.
23. Burkhart, Harold E., Kenneth D. Farrar, Ralph L. Amateis, and Richard F. Daniels. 1987. Simulation of individual tree growth and stand development in loblolly pine plantations on cutover, site-prepared areas. School of Forestry and Wildlife Resources Publication No. FWS-1-87. Virginia Polytechnic Institute and State University, Blacksburg, VA. 47 p.
24. Cain, M. D., and W. F. Mann, Jr. 1980. Annual brush control increases early growth of loblolly pine *(Pinustaeda)*. Southern Journal of Applied Forestry 4(2):67–70.
25. Cao, Quang V., Harold E. Burkhart, and Ronald C. Lemin, Jr. 1982. Diameter distributions and yields of thinned loblolly pine plantations. School of Forestry and Wildlife Resources Publication No. FWS-1-82. Virginia Polytechnic Institute and State University, Blacksburg, VA. 62 p.
26. Clason, T. R. 1978. Removal of hardwood vegetation increases growth and yield of a young loblolly stand. Southern Journal of Applied Forestry 2(3):96–97.
27. Clutter, Jerome L., William R. Harms, Graham H. Brister, and John W. Rheney. 1984. Stand structure and yields of site-prepared loblolly pine plantations in the lower coastal plain of the Carolinas, Georgia, and north Florida. USDA Forest Service, General Technical Report SE-27. Southeastern Forest Experiment Station, Asheville, NC. 173 p.
28. Delcourt, H. R., and P. A. Delcourt. 1977. Presettlement magnolia-beech climax of the Gulf coastal plain: quantitative evidence from the Apalachicola river bluffs, north-central Florida. Ecology 55:1085–1093.
29. Dorman, Keith W. 1976. The genetics and breeding of southern pines. U. S. Department of Agriculture, Agriculture Handbook 471. Washington, DC. 407 p.
30. Dorman, Keith W., and B. J. Zobel. 1973. Genetics of loblolly pine. USDA Forest Service, Research Paper WO-19. Washington, DC. 21 p.
31. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
32. Farrar, Robert M., Jr., Paul A. Murphy, and R. Larry Willett. 1984. Tables for estimating growth and yield of uneven-aged stands of loblolly-shortleaf pine on average sites in the West Gulf area. Arkansas Agricultural Experiment Station Bulletin 874. University of Arkansas, Fayetteville, AR. 21 p.

33. Feduccia, D. P., T. R. Dell, W. F. Mann, Jr., T. E. Campbell, and B. H. Polmer. 1979. Yields of unthinned loblolly pine plantations on cutover sites in the West Gulf region. USDA Forest Service, Research Paper SO-148. Southern Forest Experiment Station, New Orleans, LA. 88 p.
34. Ferguson, E. R. 1956. Causes of first-year mortality of planted loblolly pines in east Texas. *In* Proceedings, Annual Meeting, Society of American Foresters, 1956. p. 89-92.
35. Fitzgerald, Charles H., Fred A. Peevy, and Darwin E. Fender. 1973. Rehabilitation of forest land: the Southern Region. Journal of Forestry 71(3):148–162.
36. Foil, R. R., and C. W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Proceedings 31(4):565–568.
37. Fowells, H. A., comp. 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC. 762 p.
38. Grano, Charles X. 1969. Precommercial thinning of loblolly pine. Journal of Forestry 67(11):825–827.
39. Grano, C. X. 1970. Small hardwoods reduce growth of pine overstory. USDA Forest Service, Research Paper SO-55. Southern Forest Experiment Station, New Orleans, LA. 9 p.
40. Grano, C. X. 1971. Conditioning loessial soils for natural loblolly and shortleaf pine seeding. USDA Forest Service, Research Note SO-116. Southern Forest Experiment Station, New Orleans, LA. 4 p.
41. Greenwood, M. S. 1978. Flowering induced on young loblolly pine grafts by out-of-phase dormancy. Science 201(4354):443–444.
42. Greenwood, M. S., T. M. Marino, R. D. Meier, and K. W. Shahan. 1980. The role of mist and chemical treatments in rooting loblolly and shortleaf pine cuttings. Forest Science 26(4):651–655.
43. Griffing, Charles G., and William W. Elam. 1971. Height growth patterns of loblolly pine saplings. Forest Science 17:52–54.
44. Hafley, W. L., W. D. Smith, and M. A. Buford. 1982. A new yield prediction model for unthinned loblolly pine plantations. Southern Forest Research Center, School of Forest Resources Technical Report No. 1. North Carolina State University, Raleigh. 65 p.
45. Haines, L. W., T. E. Maki, S. G. Sanderford, and others. 1975. The effect of mechanical site preparation treatments on soil productivity and tree *(Pinus taeda & P. elliottii)* growth. *In* Forest soils and forestland management, Proceedings, Fourth North American Forest Soils Conference. p. 379-386. Lava1 University Press, Quebec, PQ.
46. Halls, Lowell K., ed. 1977. Southern fruit-producing woody plants used by wildlife. USDA Forest Service, General Technical Report SO-16. Southern Forest Experiment Station, New Orleans, LA. 235 p.
47. Halls, L. K., and J. J. Stransky. 1971. Atlas of southern forest game. USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA, 24 p.
48. Hare, R. C. 1965. Breaking and rooting of fascicle buds in southern pines. Journal of Forestry 63:544–546.
49. Hare, R. C., and G. L. Switzer. 1969. Introgression with shortleaf pine may explain rust resistance in western loblolly pine. USDA Forest Service, Research Note SO-88. Southern Forest Experiment Station, New Orleans, LA. 7 p.
50. Harlow, W. M., E. S. Harrar, and F. M. White. 1978. Textbook of Dendrology. 6th ed. McGraw-Hill, New York. 510 p.
51. Harms, William R., and 0. Gordon Langdon. 1976. Development of loblolly pine in dense stands. Forest Science 22(3):331–337.
52. Hartman, Kay. 1982. National register of big trees. American Forests 88(4):17–31, 34–48.
53. Hatchell, Glyndon E., Keith W. Dorman, and 0. Gordon Langdon. 1972. Performance of loblolly and slash pine nursery selection. Forest Science 18(4):308–313.
54. Hepting, George H. 1971. Diseases of forest and shade trees of the United States. U.S. Department of Agriculture, Agriculture Handbook 386. Washington, DC. 658 p.
55. Hunt, C. B. 1967. Physiography of the United States. W. H. Freemont Company, San Francisco, CA. 480 p.
56. Jones, E. P. 1974. Precommercial thinning for slash and loblolly pines. *In* Proceedings, Symposium on Management of Young Pines. p. 229-233. USDA Forest Service, Southeastern Area State and Private Forestry, Atlanta, GA.
57. Jones, Leroy, and Sam Thacker. 1965. Survival. *In* A guide to loblolly and slash pine plantation management in southeastern USA. p. 68-73. Georgia Forest Research Council, Report 14. Macon.
58. Klawitter, R. A. 1966. Diameter growth of mature loblolly unaffected by understory control. Southern Lumberman 213(2656):154–155.
59. Korstian, C. F., and T. S. Coile. 1938. Plant competition in forest stands. Duke University School of Forest Resources, Bulletin 3. Durham, NC. 125 p.
60. Kraus, J. F., and T. LaFarge. 1977. The use of *Pinus echinata x taeda* hybrids for the development of *P. taeda* resistant to *Cronartium fusiforme*. *In* Intraspecific hybridization in plant breeding. p. 377-381. Proceedings of 8th EUCARPIA Congress. (Madrid, Spain)
61. Langdon, 0. Gordon. 1979. Natural regeneration of loblolly pine. *In* Proceedings, National Silviculture Workshop. p. 191-116. USDA Forest Service, Washington, DC.
62. Langdon, 0. G. 1981. Some effects of prescribed fire on understory vegetation in loblolly pine stands. *In* Prescribed Fires and Wildlife in Southern Forests: Proceedings of a Symposium; April 6-8, Myrtle Beach, SC. Gene W. Wood, ed. p. 143-154. Belle Baruch Forest Institute, Georgetown, SC.
63. Langdon, 0. G., and W. H. McKee, Jr. 1981. Can fertilization of loblolly pine on wet sites reduce the need for drainage? *In* Proceedings, First Biennial Southern Silvicultural Research Conference. p. 212-218. USDA Forest Service, General Technical Report SO-34. Southern Forest Experiment Station, New Orleans, LA.
64. Langdon, 0. G., and K. B. Trousdell. 1974. Increasing growth and yield of natural loblolly pine by young stand management. *In* Proceedings, Symposium on Management of Young Pines. p. 288-296. USDA Forest Service, Southeastern Area State and Private Forestry, Atlanta, GA.
65. Langdon, 0. G., and K. B. Trousdell. 1978. Stand manipulation: effects on soil moisture and tree growth in southern pine and pine-hardwood stands. *In* Proceedings, Symposium on Soil Moisture-Site Productivity, Myrtle Beach, SC. p. 221-236. USDA Forest Service, Southeastern Area State and Private Forestry, Atlanta, GA.

66. Lantz, C. W. 1973. Survey of graft incompatibility in loblolly pine. *In* Proceedings, Twelfth Southern Forest Tree Improvement Conference. p. 79-85.
67. Ledbetter, Julia R., Alfred D. Sullivan, and Thomas G. Matney. 1986. Yield tables for cutover site-prepared loblolly pine plantations in the Gulf coastal plain. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 135. Mississippi State University, Mississippi State. 31 p.
68. Lenhart, David J. 1988. Diameter-distribution yield-prediction system for unthinned loblolly and slash pine plantations on non-old-fields in East Texas. Southern Journal of Applied Forestry 12(4):239–242.
69. Little, Elbert L., Jr. 1971. Atlas of United States trees. vol. 1. Conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146. Washington, DC. 9 p., 313 maps.
70. Little, S., and H. A. Somes. 1959. Viability of loblolly pine seed stored in the forest floor. Journal of Forestry 57(11):848–849.
71. Matney, T. G., A. D. Sullivan, and J. R. Ledbetter. 1986. Diameter distributions and merchantable volumes for planted loblolly pine in cutover site-prepared land in the West Gulf coastal plain. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 132. Mississippi State University, Mississippi State. 12 p.
72. McKee, W. F., Jr. 1981. Personal communication. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, NC.
73. McLemore, B. F. 1964. Light during stratification hastens dark-germination of loblolly pine seed. Forest Science 10(3):348–349.
74. McLemore, B. F. 1966. Temperature effects on dormancy and germination of loblolly pine seed. Forest Science 12(3):284–289.
75. McLemore, B. F. 1987. Development of intermediate and suppressed loblolly pines following release. *In* Proceedings, Fourth Biennial Southern Silvicultural Research Conference. p. 439-444. USDA Forest Service, General Technical Report SE-42. Southeastern Forest Experiment Station, Asheville, NC.
76. Maki, T. E. 1971. Drainage: effect on productivity. *In* Proceedings, Annual Meeting, Society of American Foresters, Applied Section. p. 16-23.
77. Mann, W. F., Jr., and T. R. Dell. 1971. Yields of 17-year-old loblolly pine planted on cutover site at various spacings. USDA Forest Service, Research Paper SO-70. Southern Forest Experiment Station, New Orleans, LA. 9 p.
78. Mann, W. F., Jr., and R. E. Lohrey. 1974. Precommercial thinning of southern pine. Journal of Forestry 42(9):557–560.
79. Mignery, A. L. 1967. Winter injury to loblolly pine in Tennessee related to seed origin. Southern Lumberman 215(2680):146.
80. Miller, L., and F. W. Woods. 1965. Root-grafting in loblolly pine. Botanical Gazette 126:252–255.
81. Murphy, Paul A. 1983. Merchantable and sawtimber volumes for natural even-aged stands of loblolly pine in the West Gulf region. USDA Forest Service, Research Paper SO-194. Southern Forest Experiment Station, New Orleans, LA. 38 p.
82. Murphy, P. A., and R. M. Farrar. 1982. Interim models for basal area and volume projection of uneven-aged loblolly-shortleaf pine stands. Southern Journal of Applied Forestry 6(2):115–119.
83. Quarterman, E., and C. Keever. 1962. Southern mixed hardwood forest: climax in the southeastern coastal plain United States of America. Ecological Monographs 32(2):167–185.
84. Reynolds, R. R. 1959. Eighteen years of selection timber management on the Crossett Experimental Forest. U.S. Department of Agriculture, Technical Bulletin 1206. Washington, DC. 68 p.
85. Reynolds, R. R. 1969. Twenty-nine years of selection timber management on the Crossett Experimental Forest. USDA Forest Service, Research Paper SO–40. Southern Forest Experiment Station, New Orleans, LA. 19 p.
86. Reynolds, R. R., James B. Baker, and Timothy T. Ku. 1984. Four decades of selection management on the Crossett farm forestry forties. Arkansas Agricultural Experiment Station Bulletin 872. University of Arkansas, Fayettevile, AR. 43 p.
87. Saylor, L. C., and K. W. Kang. 1973. A study of sympatric populations of *Pinus taeda* L. and *Pinus serotina* Michx. in North Carolina. Journal of the Elisha Mitchell Scientific Society 89:101–110.
88. Schopmeyer, C. S., tech. coord. 1974. Seeds of woody plants in the United States. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC. 883 p.
89. Schultz, Robert P., and Frank W. Woods. 1967. The frequency and implications of intraspecific root-grafting in loblolly pine. Forest Science 13:226–239.
90. Schumacher, F. X., and T. S. Coile. 1960. Growth and yield of natural stands of the southern pines. T. S. Coile, Inc. Durham, NC. 115 p.
91. Shepard, R. K., Jr. 1974. Ice storm damage to thinned loblolly pine plantations in northern Louisiana. Southern Journal of Applied Forestry 2(3):83–85.
92. Smalley, G. W. 1979. Classification and evaluation of forest sites on the southern Cumberland Plateau. USDA Forest Service, General Technical Report SO-23. Southern Forest Experiment Station, New Orleans, LA. 59 p.
93. Smalley, G. W., and R. L. Bailey. 1974. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia highlands. USDA Forest Service, Research Paper SO-96. Southern Forest Experiment Station, New Orleans, LA. 81 p.
94. Smeltzer, R. H., R. L. Mott, and A. Mehra-Polta. 1977. Influence of parental tree genotype in the potential for *in vitro* cloning progenation from loblolly pine embryos. *In* Forest biology wood chemical conference, 1977. p. 5-8. Tappi Press, Atlanta, GA.
95. Stewart, J. T. 1965. Regenerating loblolly pine with four seed trees. Virginia Forests 20(2):14–15, 26, 28.
96. Stoddard, H. L. 1963. Maintenance and increase of the eastern wild turkey on private lands of the Coastal Plain of the Deep Southeast. Tall Timbers Research Station, Bulletin 3. Tallahassee, FL. 49 p.
97. Stransky, J. J., and L. K. Halls. 1967. Timber and game food relations in pine-hardwood forests of the southern United States. *In* Proceedings, Fourteenth International Union of Forestry Research Organizations Congress. p. 208-217.

98. Stransky, J. J., and D. R. Wilson. 1964. Terminal elongation of loblolly and shortleaf pine seedlings under soil moisture stress. Soil Science Society of America Proceedings 28:439–440.
99. Sullivan, Alfred D., and Jerome L. Clutter. 1972. A simultaneous growth and yield model for loblolly pine. Forest Science 18(1):76–86.
100. Switzer, G. L., M. G. Shelton, and L. E. Nelson. 1979. Successional development of the forest floor and soil surface on upland sites of the East Gulf Coastal Plain. Ecology 60(6):1162–1171.
101. Terry, T. A., and J. H. Hughes. 1975. The effects of intensive management on planted loblolly pine (*Pinus taeda* L.) growth on poorly drained soils of the Atlantic Coastal Plain. *In* Forest soils and forest land management. Proceedings, Fourth North American Forest Soils Conference. p. 351-377. Lava1 University Press, Quebec, PQ.
102. Thatcher, R. C., J. L. Searcy, J. E. Coster, and others, eds. 1980. The southern pine beetle. U.S. Department of Agriculture, Technical Bulletin 1631. Washington, DC. 267 p.
103. Trousdell, K. B. 1970. Disking and prescribed burning: sixth year residual effects on loblolly pine and competing vegetation. USDA Forest Service, Research Note SE-133. Southeastern Forest Experiment Station, Asheville, NC. 6 p.
104. Trousdell, Kenneth B., and 0. Gordon Langdon. 1967. Disking and prescribed burning for loblolly pine regeneration. Journal of Forestry 65(5):548–551.
105. Trousdell, Kenneth B., Wilfred C. Williams, and Thomas C. Nelson. 1965. Damage to recently thinned loblolly pine stands by Hurricane Donna. Journal of Forestry 63(2):96–100.
106. U.S. Department of Agriculture, Forest Service. 1929. Volume, yield, and stand tables for second-growth southern stands. U.S. Department of Agriculture, Miscellaneous Publication 50. Washington, DC. 202 p.
107. U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Soil Survey Staff, coords. U.S. Department of Agriculture, Agriculture Handbook 436. Washington, DC. 754 p.
108. Wahlenberg, W. G. 1960. Loblolly pine: its use, ecology, regeneration, protection, growth, and management. Duke University, School of Forestry, Durham, NC. 603 p.
109. Wakeley, Philip C., and T. E. Bercaw. 1965. Loblolly pine provenance test at age 35. Journal of Forestry 63:168–174.
110. Wells, D. W., and M. Reines. 1965. Vegetative propagation of needle bundles of pines. Georgia Forest Research Council, Report 26. Macon. 8 p.
111. Wells, 0. 0. 1969. Results of the southwide pine seed source study through 1968-69. *In* Proceedings, Tenth Southern Forest Tree Improvement Conference. p. 117-129.
112. Wells, 0. O., and P. C. Wakeley. 1966. Geographic variation in survival, growth, and fusiform-rust infection of planted loblolly pine. U.S. Department of Agriculture, Monograph 11. Washington, DC. 40 p.
113. Williston, H. L. 1962. Loblolly seedlings survive twelve days' submergence. Journal of Forestry 60:412.
114. Williston, H. L. 1971. Guidelines for planting and maintaining loblolly pine and other cover for road bank stabilization. Tree Planters' Notes 22(2):14–17.
115. Williston, H. L., and S. J. Ursic. 1979. Planting loblolly pine for erosion control: a review. Tree Planters' Notes 30(2):15–18.
116. Zahner, R. 1968. Water deficits and the growth of trees. *In* Water deficits and plant growth, vol. 2. Plant water consumption and response. p. 191-254. Academic Press, New York.
117. Zobel, Bruce J., Roger Blair, and Marvin Zoerb. 1971. Using research data: disease resistance. Journal of Forestry 69:486–489.