Chapter 11
Species Variation, Allocation, and Tree Improvement

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Abstract

Planning for regenerating the southern pines should include an informed allocation of species and the appropriate seed sources within each species choice. Examples are given demonstrating successes and failures associated with allocation. Southern pine tree-improvement methodology and seed-orchard establishment and management are presented. Geographic variation in growth and disease resistance is discussed, and seed-source recommendations are given in detail for loblolly pine and for other species where pertinent. To aid in species and seed-source allocation, a key (appendix) is provided that incorporates biologic as well as management considerations.

11.1 Introduction

11.1.1 Objectives: General Importance of Proper Allocation

The intent in matching planting stock to sites is to fully utilize the productive capacity of sites by, first, selecting the species best adapted and, second, selecting appropriate individual sources or genotypes within that species. Failures to make good choices in matching sites and genotypes may have negative and spectacular results. Indeed, some of the stunted and understocked stands found in many areas of the South serve as tangible monuments to poor decisions about genotype allocation. Although the southern pines will grow on a remarkable diversity of sites, their inherent adaptability must be understood and exploited in order to maximize growth. Proper allocation of species and sources can be one of the landowner's most cost-effective decisions.

Our perceptions of what composes a native site change

Figure 11.1. Natural range (shaded) of the southern pines (adapted from Sternitzke and Nelson 1970): (a) loblolly, (b) slash, (c) shortleaf, (d) Virginia, (e) sand, (f) longleaf.

as pine plantations replace mixed natural stands or plantations of other species. Because we humans only recently began to reforest the pine land harvested, our perceptions of pine species range reflect the current distribution only. For example, we think of loblolly pine *(Pinus taeda* L.) and slash pine *(Pinus elliottii* Engelm. var. *elliottii)* as having the natural ranges depicted in Figures 11.1a and 11.1b. However, this view is only a snapshot in time of an ongoing evolutionary process. Schmidtling [501 suggests the two species have occupied their current natural

M.L. Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 207–231.

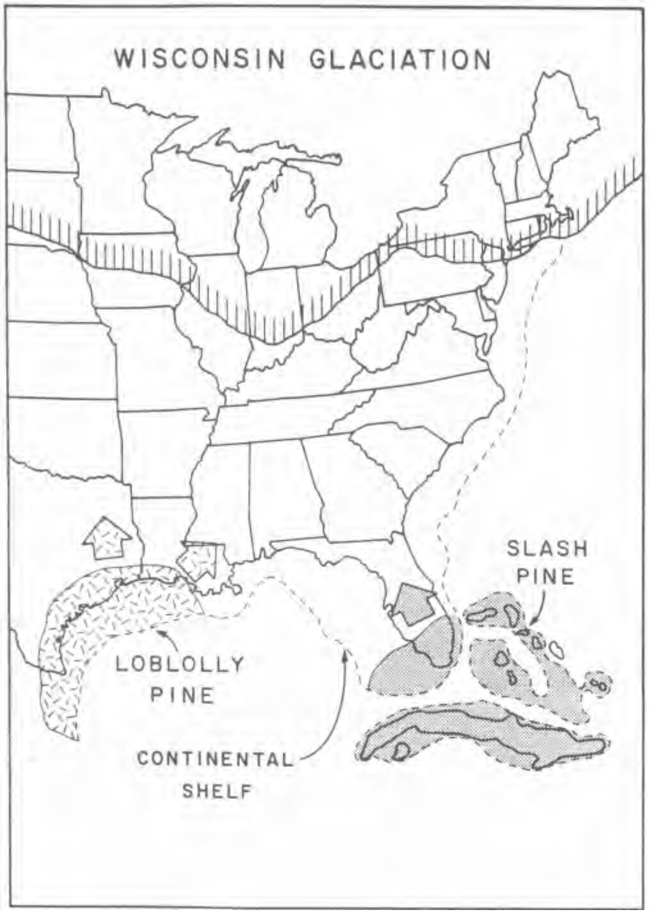

Figure 11.2. Suggested natural range of loblolly and slash pine during the Wisconsin Ice Age (adapted from Schmidtling 1984).

ranges for only about 10,000 years, or since the end of the Wisconsin ice age in the Quaternary period (Fig. 11.2). At that time, loblolly pine is believed to have begun a northward migration from southwestern Louisiana and eastern Texas. We may surmise that, even if these species had been untouched by humans, they might not yet be in equilibrium with their relatively new environments. Perhaps given sufficient time, both species might migrate further. With this perspective, the artificial allocation of species and seed-sources into new environments resembles accelerated evolution or the importation of exotic species: the rewards can be substantial — but the penalty of mistakes can be devastating.

In the absence of seed-source information, for many years landowners have been advised to plant local species and sources of southern pine [62]. Although this concept is still fundamentally valuable, we must point out that the natural range of plants has changed over time because of a variety of complex interactions including dynamic plant-animal coevolution, modifications in numbers and distribution of animal populations, temporal changes in climates and land forms, or any other factor which eliminates or creates barriers to seed-dispersal mechanisms. Consequently, it is not breaking the laws of nature to consider nonlocal seed sources for certain planting needs.

Results of extensive research into species selection and geographic patterns of variation are now available. The choices of what to plant are most clear for the Piedmont province and least clear for northern Coastal Plain sites, some Gulf and Atlantic flatwoods, and the Interior Highlands (Fig. 11.3). In some situations, however, there is no best species or source to plant because data are lacking to support any decision or because the availability of genetically improved stock has changed the basis of previous decisions.

In this chapter, our objectives are to review the body of knowledge concerning species' native ranges, to recommend species and seed sources for plantation establishment, and to familiarize the reader with tree-improvement and seed-production methods. To aid in the allocation process, we have included a dichotomous key (see Appendix A11.1) which begins with general geographic and market factors and ends with a species/seed-source recommendation resulting from a series of decisions by the user.

11.1.2 Allocation Successes and Failures: Some Examples

The most important planting decision a land manager makes is the choice of species and seed-source, but obtaining success with some planting choices requires intensive culture with herbicides and fertilization. Commitment to such management regimes may wane during bad economic times which, in the cyclical forest-products business, may occur several times during one rotation. If the choice of planting stock involves a well-adapted source, the absence of extra silvicultural treatments should have no serious effect. If the choice involves a poorly adapted source, significant volume losses or even total plantation failure are real possibilities. The following examples illustrate the potential for success or failure utilizing proper seed sources.

11.1.2.1 Fusiform rust infection

Fusiform rust *[Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*] infection has been at epidemic levels for many years in southern pine plantations (see also chapter 20, this volume). Volume losses due to rust-induced mortality and reduced growth exceed $110 million/year across the southern region [2]. Trees are usually infected by age 8 years, but growth loss and mortality follow at midrotation [19]. U.S.D.A. Forest Service scientists have attempted to estimate future losses based on infection at an early age [35, 36, 53]. According to the model developed by Nance et al. [36], a slash pine plantation having 400 trees/ac (1,000 trees/ha) at age 5 on site index 60 (base age 25 years) land will suffer a volume loss of 37% by age 20 as stem rust infection increases from 20 to 60% (Fig. 11.4).

If rust hazard is known before planting, it can be readily managed by selecting the proper seed-source. In test plantings on a high-hazard site in Marion County, Florida, substantial resistance to rust infection was observed in some seed-sources of loblolly and slash pines at age 3. The

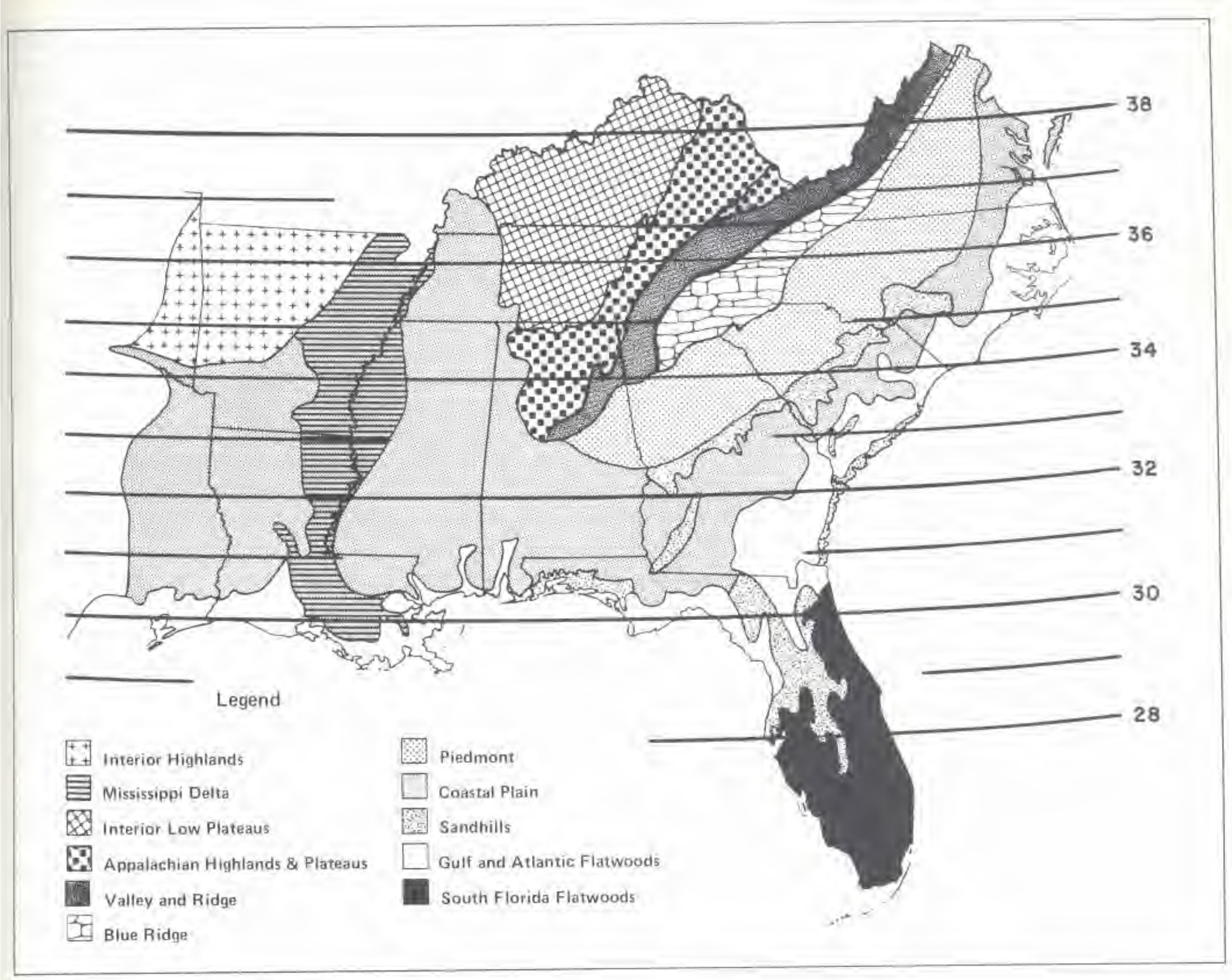

Figure 11.3. Physiographic regions of the southern United States.

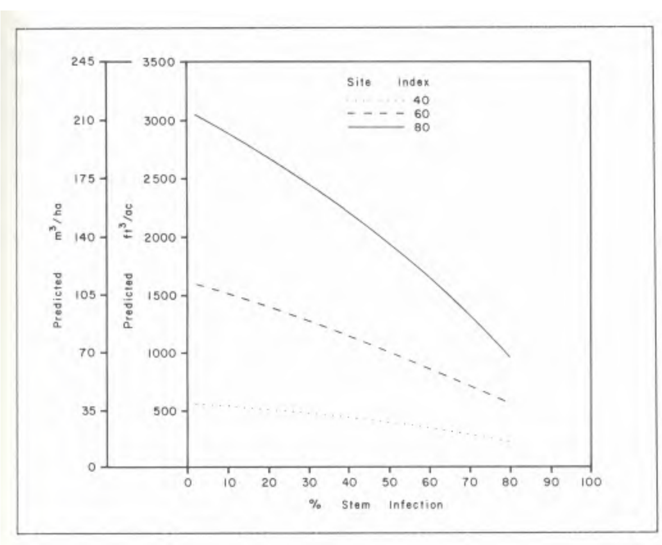

Figure 11.4. Predicted total volume of slash pine at age 20 years as a function of fusiform rust hazard and site index at base age 25 (after Nance et al. 1981).

susceptible loblolly orchard source suffered a 68.7% infection whereas the Livingston Parish, Louisiana, and East Texas sources incurred considerably lower rates of 21.0 and 9.6% respectively. Two susceptible slash pine orchard sources sustained 61.7 and 59.0% infection whereas the rust-resistant seed production area source suffered only 27.4% infection [40]. Results like these have been utilized operationally by many forest-products companies.

Most forest-products companies inventory their plantations at various times to gather stocking, growth, and disease information. One such firm, Jefferson Smurfit/Container Corporation of America, routinely assesses rust infection and survival on every southern pine plantation and has done so for over 20 years. As seed-source information became available and its tree improvement program matured, this company deployed rust-resistant sources of loblolly and slash pine into its high-hazard areas of Florida and Georgia. In a cooperative project with the Forest Service, this company's fifth-year data on incidence of fusiform rust were analyzed to

Table 11.1 Comparison of fifth-year fusiform rust data from 408 operational plantations of susceptible and resistant pine in areas of high rust hazard in Florida and Georgia.

Location	Plantations					Percent rust	
	Rust species	Rust susceptibility	Years planted	Number	Hectares	Mean	t statistic
SC GA	Loblolly	S	1963–71, 76	82	1673	31.4	6.96**
		R	1974–75,77–79	46	2157	15.0	
NC FL	Slash	S	1963–74	88	2457	49.1	7.56**
		R	1975–77, 79	22	635	20.5	
NC FL	Loblolly	S	1963, 72–74	14	310	35.6	4.84**
		R	1975–77, 79	24	586	11.0	
WC GA	Loblolly	S	1968–73	71	1666	44.4	12.31**
		R	1974–77, 79	61	3954	12.4	

[1] N = north, S = south, W = west, C = central; FL = Florida; GA = Georgia.
[2] S = susceptible; R = resistant,(R loblolly, East Texas and Livingston Parish Sources; R slash open-pollinated seed orchards and seed production areas).
[3] Means within species and location significantly different at P = 0.01.

determine the impact of planting resistant seedlings. Generally, the average infection rates of resistant plantations were at least 50% lower than infection rates of susceptible plantations in the same management area (Table 11.1). These results from almost 70,000 ac (28,000 ha) of plantations are an excellent example of operational use of seed-source information [49].

11.1.2.2 Off-site species allocation

The sandhills of the southern pine region have been recognized as problem sites to regenerate. Whether of marine or fluvial deposition, these soils are extremely infertile and droughty. Because longleaf pine *(Pinus palustris* Mill.) occupied most of these sites before logging, it was the first species selected for planting. However, longleaf's survival and early height growth were usually unsatisfactory. Slash pine was planted onto many sandhill sites.

Generally, the slash pine grew rapidly through about age 10. However, height and diameter growth often rapidly declined thereafter and mortality increased. Moreover, some of the sandhills and adjacent sites of the Carolinas planted with slash pine were also high-hazard fusiform rust sites. Slash pine quickly fell into disfavor as these plantations essentially disintegrated because of moisture stress and rust infection.

After many failures, sand pine *[Pin us clausa* (chapm. ex Engelm.) Vasey ex Sarg.] subsequently emerged as the species of choice for these dry and infertile sandhill soils. Results from a Florida trial by Brendemuehl [4] are typical: at age 21, the average heights of shortleaf *(Pinus echinata* Mill.), Virginia *(Pinus virginiana* L.) , loblolly, slash, longleaf, and Choctawhatchee sand (var. *immuginata* D.B. Ward) pine were approximately 3.0 (10.0), 3.3 (11.0), 3.6 (12.0), 7.0 (23.0), 7.3 (24.0), and 13.6 m (45.0 ft), respectively. Total volume of sand pine on these sites should be double that of any other southern pine at rotation age.

11.2 Natural Range, Geographic Variation, and Source Movement

Although the range of some southern pines (e.g., pitch pine, *Pinus rigida* Mill.) extends into northern latitudes, the range of loblolly pine serves as a good boundary for the southern pine region. Approximately three-quarters of this region lies in the Atlantic and Gulf Coastal Plains. The region begins on the DelMarVa peninsula and ends west of the natural limit of southern pines in East Texas, interrupted only by the alluvial plains of the Mississippi River. Of the 10 pine species occupying this region, loblolly, slash, shortleaf, and longleaf pine stands hold over 90% of the total southern pine volume [45].

11.2.1 Loblolly Pine

The natural range of loblolly pine encompasses the enormous diversity of soil types and climate from Delaware to central Florida and west to eastern Texas (see Fig. 11.1a). The sheer size of the range partially explains why loblolly is the most commercially important pine in the United States. The species is continuously distributed across its range except immediately east and west of the Mississippi River and, as a result, represents over half of the standing pine volume in the southern region [9]. Its popularity in the forest industry is manifested in the enormous genetic improvement efforts by the industry-university tree improvement cooperatives.

In natural stands, loblolly pine is found in three major forest cover types as described by the Society of American Foresters [54]: loblolly, loblolly-shortleaf pine, and loblolly-hardwood. The loblolly type occurs on both wet but well-drained upland soils and poorly drained flatwoods depressions. On drier sites, principal associates of loblolly are shortleaf pine, post oak *(Quercus stellata* Wangenh.), southern red oak *(Quercus falcata* Michx.), and blackjack oak *(Quercus marilandica* Muench.). On the more poorly drained sites, principal associates are blackgum *(Nyssa sylvatica* Marsh var. *sylvatica),* yellow-poplar *(Liriodendron tulipifera* L.), water oak *(Quercus nigra* L.), pond pine *(Pines serotina* Michx.), slash pine, and, farther south, laurel oak *(Quercus laurifolia* Michx.). Sweetgum *(Liquidambar styraciflua* L.) is a characteristic associate on the wetter sites. The loblolly-shortleaf cover type occurs in most states where the two species overlap, but is mostly found in southern Alabama, eastern Texas, and Louisiana. Principal associates of the loblolly-shortleaf type are hickories *(Carya* spp.), persimmon *(Diospyros virginiana* L.), hawthorns *(Crataegus* spp.), blackgum, southern red oak, and post oak.

The loblolly-hardwood type occurs along smaller branches, creeks, and streams or on southern-facing slopes generally on the lower Piedmont Plateau and Upper Coastal Plain. Principal associates range broadly, depending on moisture availability and drainage. On wetter sites, associates include sweetbay (*Magnolia virginiana* L.), redbay *[Persea borbonia* (L.) Spreng.], swamp tupelo *[Nyssa sylvatica* var. *biflora* (Walt.) Sarg.], sweetgum, red maple *(Acer rubrum* L.), and green ash *(Fraxinus pennsylvanica* Marsh). On drier sites, associates include the upland oaks, such as post oak, white oak *(Quercus alba* L.), northern red oak *(Quercus rubra* L.), scarlet oak *(Quercus coccinea* Muench.), the hickories, shortleaf pine, persimmon, and longleaf pine. The successional trend is toward hardwoods on the moist, moderately well-drained sites of the loblolly-hardwood cover type. Consequently, site preparation, which includes thorough vegetation control, may be necessary when converting these sites to loblolly pine (see chapter 13, this volume).

The diversity of soil and climate throughout the loblolly range and its association with a wide variety of species suggest that loblolly pine is quite adaptable. No other southern pine, except shortleaf, has as much within-species variation as does loblolly pine. Nevertheless choosing to plant loblolly pine without considering the seed-source is unwise and unnecessary. Severe fusiform rust infection, poor growth, and excessive ice damage can be mitigated by planting resistant and adapted sources. Over the past 50 years, considerable research on geographic and genetic variation of loblolly has yielded an excellent body of seed-source recommendations.

Data from the Forest Service southwide seed-source study [63, 64, 69] and other provenance tests indicate about eight distinct groupings of loblolly pine seed-sources. Generally, western and northeastern sources are resistant to fusiform rust, but differ substantially in their growth rates. Coastal sources grow rapidly but are not rust resistant; these sources are also more susceptible to drought, ice, and cold than are those from continental climates in the interior South. Other smaller populations have specific site adaptations or fast growth rates. Livingston Parish (Louisiana), Marion County (Florida), and Eastern Shore (Maryland) represent the extremes of the geographic or edaphic range of the species.

The following discussions are pertinent to use of the sources as wild, unimproved seed or seed orchard stock. Some of the following seed-sources are presented as "faster growing" or "more rust resistant," although use of improved populations (orchard bulked seedlots or "clonal" lots) may eliminate many of these comparative differences.

11.2.1.1 East Texas source

Loblolly pine from East Texas is resistant to fusiform rust, and some sources within the area may survive well under dry conditions. However, it is somewhat slower growing than most other southern loblolly sources. Even when grown in rust "hot spots" such as Madison County, Florida, where infection rates at age 5 for susceptible sources were 65 to 74%, the East Texas source incurred only 14% infection [39]. The origin of this resistance is unclear, although introgression (successive generations of natural, interspecific hybridization and backcrossing of hybrids to each respective species) with shortleaf pine has been suggested.

Drought hardiness is not an evenly distributed trait of the East Texas source. For example, during the dry winters of 1984-86 several East Texas source plantations failed in central Georgia. Eastern Texas is a large area containing several physiographic provinces (see Fig. 11.3). Drought-tolerant loblolly occurs in the western edge of the loblolly range in an area known as the "Lost Pines." In the southwide seed-source study [63] and other provenance tests containing the East Texas source [39, 40], East Texas Coastal Plain sources and not the "Lost Pines" sources were tested. The two provenances must not be confused. Seedlings grown from "Lost Pines" selections have consistently performed well on dry sites. Early survival rates in the Texas Forest Service studies of middle Coastal Plain and Lost Pines sources were substantially better than those of Texas flatwoods or Atlantic Coastal Plain sources [60, 61]. Thus, these distinctions between sources should be made when drought tolerance is necessary.

The slower growth rate of East Texas loblolly has been noted in studies of geographic variation [40, 39, 63], and a relationship between slower growth, rust resistance, and drought tolerance has been suggested. Regardless, efforts of the members of the Western Gulf Tree Improvement Cooperative have resulted in a considerable number of production seed orchards. Although realized gains in growth rates from first- and advanced-generation orchards have yet to be clearly demonstrated, increased stocking by planting this source on high-hazard rust sites should result in acceptable volume yields which may offset the slower growth rate.

Improvement in this population through selection, breeding, and testing may change our current perception of growth rate in this source. Identification of fast-growing families within this resistant source is very likely.

11.2.1.2 Livingston Parish, Louisiana source

The only provenance of loblolly pine possessing rust resistance and the growth potential of the generally susceptible Atlantic and Gulf Coastal Plain sources is the Livingston Parish source (LP)[65]. Since the tenth-year data of the Southwide Seed Source Study [63] became available, this source has been widely planted. From 1971 to 1980, approximately 122,400 ha (306,000 ac) of LP loblolly were planted across the Southeast (see Fig. 11.5). However, the LP source should be restricted to the lower and upper Gulf and Atlantic Coastal Plains of Louisiana, Mississippi, Alabama, Georgia, Florida, and South Carolina (see Fig. 4). Cold weather and ice damage are the chief causes of mortality when the source is planted too far north.

Rust resistance in the LP source is substantial and relatively stable. According to Wells [65], the LP source generally incurred about 50% less infection than the susceptible sources in the Southwide Seed Source Study regardless of the actual infection rates. One notable exception occurred in a provenance trial in Madison County Florida [39]. The LP source incurred an infection rate of 74%, which was higher than that of the susceptible check. On the basis of this result and another seed-source test, Pait et al. [40] recommended limiting LP loblolly to sites with moderate rust hazard where susceptible sources might incur no more than 50% total (bole and limb combined) infection.

11.2.1.3 Atlantic Coast sources

The Atlantic Coast sources include those from the Upper and Lower Coastal Plains of North Carolina, South Carolina, and Georgia. Generally, Upper and northern Coastal Plain seed from North Carolina is recommended for local sites as well as for other Upper Coastal Plain sites across the Southeast; it may do well in the lower Piedmont of Alabama, Georgia, South Carolina, and North Carolina [27]. The more southerly coastal sources from South Carolina and Georgia will grow well throughout the Coastal Plains westward to Louisiana. There may be a risk of pitch canker *(Fusarium moniliforme* var. *subglutinans)* infection when planted on flatwoods soils in northeast Florida [32]. The Atlantic Coast sources are planted extensively across the Southeast, often in areas considered too cold for coastal sources such as Arkansas and Oklahoma [unpubl. data, 38].

Figure 11.5. Area (shaded) planted to Livingston Parish, Lousiana (LP) loblolly pine. Heavy black line indicates estimated northern limits for movement of LP loblolly. + indicates location where planted LP loblolly performed well for 25 to 30 years; — indicates location where it performed poorly (adapted from Wells 1985).

Most provenance testing has indicated that seed from the Atlantic Coast has a growth rate superior to that of continental or Gulf Coast sources. Atlantic Coast sources perform better than Gulf sources especially when planted on Upper Coastal Plain or Piedmont sites; this may be due to the more northerly latitude and fewer frost-free days (270, Atlantic; 300, Gulf) found along the South and North Carolina coasts. Although the Atlantic Coast sources surpass Gulf Coast and other southern sources in growth rate, they are not generally recommended for sites with high rust hazard or Piedmont and colder sites. However, rust resistance is present in individual trees selected for tree improvement programs. Seed-orchard seed with significant rust resistance is currently produced and may become more available as advanced-generation orchards enter commercial production [43].

The Atlantic Coast source (from Georgia, South Carolina, and North Carolina) when grown in southwestern Arkansas outperformed local and Gulf sources [66]. At age 25, the Atlantic sources were taller than local sources by an average difference of 2.4 m (8 ft). Although mortality due to cold injury was insignificant in this case, it is generally the chief concern in planting a coastal source into continental areas.

It is tempting to move the Atlantic Coastal source into areas colder or drier than is normally thought safe in order to exploit its rapid growth rate. The risk depends on the frequency, intensity, duration, and timing of subfreezing temperatures and droughts, as well as the probability of ice storms. Stand-level stress due to moisture deficits may be reduced by prudent soil selection or by thinning. Soil classification schemes which can identify moisture-deficient sites are used by several organizations; for example, Weyerhaeuser Company relies on such a system in the deployment of North Carolina coastal loblolly into Arkansas and Oklahoma [26]. Reducing the stress on nonlocal seed sources through this kind of careful site selection mitigates some of the risks. However, frequent monitoring of such deployment is essential, particularly during droughty periods such as encountered in 1980 and 1986.

11.2.1.4 Marion County, Florida source

Loblolly pine from Marion County, Florida, is known for its excellent growth rate and adaptation to conditions in the southeastern extremity of the species' range. At the Marion County location, tenth-year data from a Container Corporation study showed the Marion County source to be superior in height compared to Livingston Parish, East Texas, Eastern Shore Maryland, and northeast Florida sources [unpubl. data, 38].

Draper [10] found that at age 5 the Marion County source was superior in height and diameter to four other sources from south Georgia, south Alabama, and north Florida at three out of four planting locations. Third-year data from a seed-source trial in Marion County showed the Marion County source superior in height and diameter to Livingston Parish, East Texas, and northeast Florida sources [40]. In Volusia County, Florida, adjacent to the slash pine pitch canker study reported by Lowerts et al. [32] is a coastal loblolly pine progeny test. By age 8, the average pitch canker infection rate across all families was 50%; however, three of the four Marion County families were infected < 20%.

Although the Marion County source may grow as well as the Livingston Parish source and better than the East Texas source, it is susceptible to fusiform rust. Family selection for rust resistance has been successful, but orchard production of such material is not widely available. Consequently, the Marion County source is recommended for the central Florida Ridge and the lower Coastal Plains and flatwoods of Georgia and Florida, specifically where fusiform rust hazard is expected to be low.

11.2.1.5 Piedmont source

The Piedmont regions of Alabama, Georgia, and the Carolinas have a comparable climate. As a result, there is no substantial variation among seed collections within this province. Longitudinal (east-west) source movement should produce acceptable results [28]. Cold in the upper Piedmont is a concern such that improved local sources or sources from more northerly areas should be planted. Improved loblolly sources from the northern Piedmont have performed well in the northern Coastal Plain in young plantations [59].

11.2.2 Slash Pine

Forest Service survey data taken in 1980 showed slash pine to be the South's third leading pine species. Occupying 5.1 million ha (12.8 million ac), the species accounts for 12% of southern yellow pine growing stock [52]. Its natural range extends from South Carolina to eastern Louisiana in a narrow strip along the Atlantic and Gulf Coastal Plains (see Fig. 11.1b).

According to Schultz [51], virgin slash pine was a transition species occurring in irregular stands associated with longleaf or loblolly pines and with cypress *(Taxodium* spp.), water tupelo (*Nyssa aquatica* L.), and other wetland species. Poorly drained flatwoods, stream banks, and pond margins as well as seasonally flooded areas such as bays, ponds, and swamps were its original habitat. But it could rapidly colonize wetter or drier sites as conditions permitted.

Since World War II, slash pine has been planted extensively in and out of its native range west into Texas and Arkansas, north into North Carolina, and into the sandhills of Georgia and South Carolina [12], resulting in disastrously low yields in some cases. Consequently, regeneration with slash pine has diminished, and forest managers now pay close attention to where it is planted [52].

Fisher [12] summarized research describing the soil parameters most closely associated with optimum height growth of slash pine. The species grows on very wet sites, but its height growth (expressed as site index base 25) increases with increasing depth to a mottled or spodic horizon up to about 76 cm (30 in.). From 1.0 m (40 in.) on, site index declines gradually. Generally, somewhat poorly drained loams in the flatwoods and shallow ponds or sloughs are the better sites. Equally good are narrow terraces which run parallel to streams in the Middle Coastal Plain [20]. For further details of soil descriptions of the entire slash pine range, see Pritchett and Comerford [44], Haines and Gooding [20], and Fisher [11].

Current practices among forest managers in allocating slash pine to sites basically follow the recommendation of Haines and Gooding [20]:

> (1) Within its natural range slash pine should be planted on Spodosols when the spodic horizon is dense and no argillic horizon occurs within 40 inches of the soil surface. (2) Slash pine should not be planted in areas where glaze storms are likely. (3) Slash pine should not be planted in areas where fusiform rust incidence is severe.

Practices within the past 10 years have favored loblolly over slash pine. However, with faster growth rates and rust resistance imparted to slash pine seedlings as a result of aggressive tree-improvement programs, continued emphasis on planting loblolly into the slash pine range may be unwarranted or even a mistake (see 11.2.5). Recently, several organizations have installed trials which quantify genetic gain but which also compare species; in time, these studies should substantially aid in making species/seed-source decisions.

11.2.3 Shortleaf Pine

Shortleaf pine has the most extensive range of the southern pines (see Fig. 11.1c). From New York to Texas, it occurs on heavy or clay soils of the mountains or Piedmont, but rarely on lighter Coastal Plain soils; the concentration of wood volume is largest in central Arkansas, eastern Texas, and the Piedmont of the Carolinas [58]. Because of its resistance to fusiform rust [15], shortleaf pine was once considered as an alternative to loblolly and slash pines on high-hazard sites. However, because of its slow initial growth rate, the difficulty in producing vigorous seedlings in the nursery, and its susceptibility to littleleaf disease *(Phytophthora cinnamomi* Rands), shortleaf pine has not been planted extensively. Loblolly from the proper source will outgrow shortleaf on many sites and has been planted on a number of sites formerly occupied by shortleaf.

There are a number of sites where shortleaf is still the preferred species. In some areas of the upper Piedmont and Appalachian Plateaus and in the Ouachita range, it is well adapted to dry ridges and shallow soils and will survive extended droughts, extreme cold periods, and snow and ice storms. On sites where littleleaf disease is prevalent, it is usually best to plant loblolly from a local source. An alternative is to plant shortleaf grown from seed of littleleaf-resistant trees [48].

Considerable effort has been spent in testing interspecifc hybrids of shortleaf with most of the other southern pines [9, 23]. Only hybrids with loblolly pine, many of which were (shortleaf x loblolly) x loblolly backcrosses, have shown much economic promise [25]. However, the difficulties in producing such hybrids through conventional sexual methods outweigh the benefits when the resulting progeny are compared to rogued or advanced-generation seed-orchard sources of loblolly pine. Only the operational development of rooted cuttings or tissue culture will allow the commercial production of interspecific hybrid propagules (see chapter 5, this volume).

The largest shortleaf reforestation program is currently operated by the Forest Service, Southern Region. About 7,400 ha (18,500 ac) of National Forest land in Arkansas, Georgia, Kentucky, and Tennessee are planted annually with shortleaf pine seedlings [24]. Moreover, Forest Service researchers have conducted the most extensive geographic variation studies available. The shortleaf southwide study initiated by Wells and Wakeley [68] and summarized by Dorman [9] tested 23 seed-sources at 40 range-wide locations. Provenance variations indicated by tenth-year data led to the designation of seed collection zones (see Fig. 11.6a). Generally, Coastal Plain sites should be planted with southerly sources and northern sites with northern seed [69]. Western sources were healthier than eastern sources when planted on sites susceptible to littleleaf disease in Georgia, South Carolina, and Virginia [48].

11.2.4 Longleaf Pine

Longleaf pine grows in pure and mixed pine stands in the Atlantic and Gulf Coastal Plains from the southeastern tip of Virginia to southern Florida and westward to eastern Texas (see Fig. 11.1f), extending northward into Alabama clay soils just south of the Appalachian foothills and west of the Valley and Ridge province. Successful artificial regeneration with longleaf pine is considerably more difficult than that with the other southern pines. As a result, longleaf now occupies only 10% of its original natural range [47].

Renewed interest in planting longleaf pine has developed in the past decade as foresters in the South attempt to better match species with sites. Significant improvements in nursery culture and attention to seedling handling have resulted in better field survival of longleaf [17, 41]. Furthermore, intensive culture has been found to dramatically shorten the grass stage and to improve height growth thereafter [30]. Increasing value of poles, pilings, and other solid wood products, greater losses (in other species) to fusiform rust, increasing emphasis on proper allocation of species to site, and suitablility of longleaf for planting in high fire-hazard areas have all contributed to renewed interest in this species [6].

The soils to which longleaf pine is allocated are often similar to those chosen for loblolly and slash pines. Friable, light-textured epipedons underlain by an argillic horizon with good internal drainage characterize the optimum soils for longleaf pine. However, the best longleaf site will also be a productive loblolly site. On such soils, loblolly pine will outperform longleaf pine. Under such conditions, market objectives, rust hazard and availability of resistant seed, and availability of high-quality longleaf seedlings will determine which species is planted. It is on drier and wetter sites where distinctions are necessary.

Longleaf pine is ill suited for planting on true sandhill sites when commercial rotations of 30 years or less are the objective. Although sandhill soils may receive considerable rainfall, they have low moisture holding capacity and depths of up to 6.5 m (20 ft); therefore, most plants are under considerable moisture stress throughout the year. These soils are best regenerated with sand pine [4].

Extensive longleaf pine stands exist in the Gulf Coastal Plain in southern Alabama, Mississippi, and the Panhandle of Florida — referred to as the "wiregrass belt" because of the common occurrence of wiregrass *(Aristida stricta* Michx.), particularly in areas which are control-burned frequently. The soils in this region are moderately well to well drained with 65 to 100 cm (20 to 40 in.) or less of surface sand underlain by an argillic horizon. Represented here are Arenic and gross Arenic Udults, Umbrepts, and Ochrepts in series such as the Blanton and Orsino [11]. These droughty soils should be heavily stocked with large-diameter or container-grown seedlings. Chemical site preparation or subsequent herbaceous weed control will prove beneficial for seedling survival and early height growth on such sites [30]. Although these soils are regionally thought of as classic longleaf sites, they also support loblolly pine at least as well.

Northward into the Middle and Upper Coastal Plains are similar soils which are typically less droughty than those mentioned previously and are well suited for longleaf pine. In southwestern and south-central Georgia are soils which are moderately well to well drained, have no spodic horizon, have a light-textured surface with an argillic horizon within 50 cm (20 in.) of depth, fall into the Typic or Plinthic Udult subgroups, and are represented by the Goldsboro and Norfolk series [11]. Longleaf fares better on these soils than on those in the wiregrass belt because of their greater moisture-holding capacity. The potential for fusiform rust infection is usually high in such areas.

Although these sites also support slash and loblolly pines, if these species are planted, rust-resistant sources should be used.

Longleaf pine will also grow on the wetter soils in the Lower Coastal Plain and Atlantic flatwoods, but should be planted on the better drained sites and will usually require bedding. Fisher [11] makes two groupings of such soils: (1) those which are poorly to moderately well drained with spodic but no argillic horizons fall into the Typic, Aeric, and Arenic Aquods or Humods subgroups and are represented by Ridgeland and Leon soil series, and (2) those which are very poorly to somewhat poorly drained with both spodic and argillic horizons fall into the Ultic Aquod and Humod subgroups and are represented by the Mascotte-Sapelo series. These two groups of soils are usually planted with slash or loblolly pine; however, with drainage and bedding they are suitable for longleaf.

11.2.5 Virginia Pine

Virginia pine covers a broad range from New York south to Alabama and Mississippi (see Fig. 11.1d). It grows well on a wide variety of soils derived from crystalline rocks, sandstones, shales, and limestone and is an aggressive pioneer on abandoned fields and other areas subject to severe erosion. This species grows best on clay, loam, or sandy soils and thrives only in moderately well-drained to well-drained soils [13].

In spite of its range, Virginia pine is not planted in great quantity except for Christmas trees or for pulpwood on sites that will not support other species. It is highly intolerant to shade and does not respond to thinning after age 15. As site characteristics improve and more hardwoods appear, it cannot withstand the increased competition [13]. The root system is shallow, making the species subject to windthrow. It is more difficult than other southern pines to log because natural pruning is very slow.

Yet as an aggressive colonizer, the species flowers early (age 5); its small seed size and seed-to-wing ratio allow it to be easily disseminated by wind; and it produces cone crops throughout the crown every year, with heavy crops every 3 years. However, these same attributes confound attempts to declare certain populations as distinct. Discussing Virginia pine provenance studies, Lantz and Kraus [28] concluded that there is insufficient data to establish definitive seed zones for this species because of its variable performance when planted.

A number of Virginia pine seed orchards established by federal, state, and industry organizations in the South have been producing commercial quantities of seed for several years, much of it for Christmas tree production. In the absence of definitive seed zones, local sources should be used whenever possible. If local sources are not available, seeds should be moved east or west within the same province rather that north or south [28].

11.2.6 Sand Pine

Sand pine is a minor southern pine species which has been receiving increasing attention in the past 20 years. Occurring on dry, infertile sandhills in Florida and extreme southern Alabama (see Fig. 11.1e), sand pine is remarkably productive. Because the range of sand pine is not continuous, two races have evolved. The Ocala race *[Pines clausa* (Chapm. ex Engelm.) Vasey ex Sarg. var *clausal* is confined to central Florida, the Choctawhatchee race to western Florida and southern Alabama. Of 38 conifer species tested on sandhills, Brendemuehl [4] found Choctawhatchee sand pine to perform best. In the South Carolina sandhills, sand pine yielded more than twice as much total cubic volume as longleaf pine at age 14 [34]; in the Georgia and South Carolina sandhills, it yielded twice the total volume of slash and loblolly pines at age 15 [21].

The Choctawhatchee race is preferred over the Ocala because of its superior height growth, tree form, and greater resistance to root disease [14, 46]. Cones of this race are nonserotinous, thus expediting seed extraction. Consequently, most of the recent regeneration and genetic improvement of sand pine has focused on the Choctawhatchee race.

Before the onset of logging and agriculture, the predominant forest cover on the sandhills was open-grown stands of longleaf pine in association with several sandhill oak species [37]. The sandhill soils generally are classified as Quartzipsamments having a sand depth of 1 to 6 m (40 in. to 20 ft). Representative soil series are the Lakeland, Kershaw, Alagra, and Troup. Some sandhill soils retain moisture better than others becuase of the fine-textured horizons and coating of organic matter. In all of them, however, competition for moisture is severe. As a result, regeneration and subsequent growth of longleaf pine are poor. The excellent survival and growth rate of sand pine make it the species of choice for such sites.

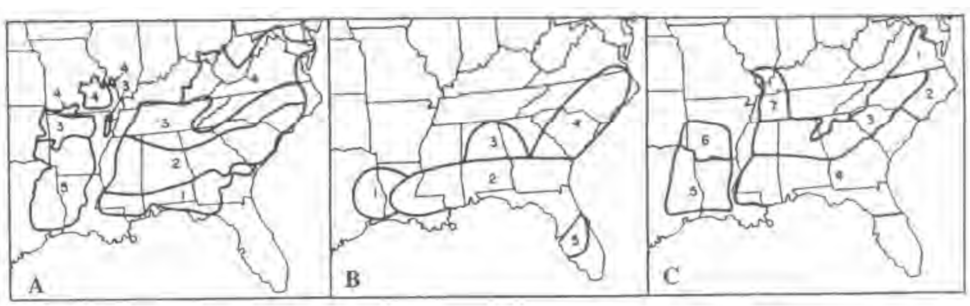

Figure 11.6. Seed collection zones (numbered) for (A) shortleaf, (B) longleaf, and (C) loblolly pines.

With approximately 4.8 million ha (12 million ac) of sandhills in the southern Coastal Plain, a considerable opportunity exists to produce commercial rotations of sand pine in < 30 years. The species has been recommended for sandhill sites well north of its natural range along the fall line of Georgia and the Congaree sandhills of South Carolina (0.8 million ha, or 2 million ac) [5, 21, 33, 34].

11.3 Tree Improvement and Seed Production

Like other management activities that benefit crops, tree improvement is a cyclical process in which a base population is selected, bred, and tested (see Fig. 11.6) [71].The cycle returns to the selection phase as field-test data pinpoint promising families and individuals to select for the next cycle. During the 1940s and 1950s, efforts of many individuals and institutions in the South laid the foundation for southern pine tree-improvement research cooperatives which are world renowned today. Most of the major industrial and state forestry organizations have their own tree improvement programs or belong to a university-directed tree improvement cooperative.

In 1988, southern pine seed orchards produced enough seed to plant 0.74 million ha (1.85 million ac), or 85% of the area planted in the South. In the near future, however, vegetative propagation techniques such as tissue culture and rooted cuttings may become an important addition to the production phase of tree improvement (see chapter 5, this volume). Theoretically, vegetative propagation represents a way to increase genetic gain compared to seed orchards. Because orchard seed is a product of wind pollination, an individual orchard tree's seed will have many pollen parents which differ in their genetic superiority. Some pollen parents (males) will be better than, equal to, or worse than compared to a specific orchard clone (female) in one or all traits of interest. Moreover, pollen from non-orchard trees contaminates most orchards to some degree. Finally, a selected tree may owe some of its genetic worth to the specific combining of its parents' genes, a form of expression called non-additive variation. These non-additive or dominance effects of the specific combination are lost or altered in any new sexual reproduction like wind pollination.

Cloning selected parents provides the opportunity to duplicate excellent specific combinations without any of the diluting effects of wind pollination and to utilize advances in molecular genetics. Currently, vegetative propagation schemes are largely experimental in the southern pines. Even when they come into commercial use, it is doubtful they will completely replace seed orchards. Regardless of whether seedlings or plantlets are used operationally, however, they will result from the same process of selection, breeding, and progeny testing which is the cornerstone of tree improvement.

11.3.1 Selection

Considerable effort is spent in selecting individual trees for a tree improvement program. Trees from either natural stands or plantations are chosen for one or more traits such as rapid growth, good form, insect and disease resistance, or desirable wood characteristics. This strategy is called "plus tree" selection. The gain per trait decreases as more traits are included in the selection criteria [72, 73].

Tree improvement programs in the South are supported by a broad genetic base, well in excess of 14,000 selected trees. Reasons for such a broad base are many. First and foremost, the eventual genetic gain is limited by the size of the base population. Second, a broad base avoids mating of related trees (inbreeding) and associated decline of vigor or fertility (inbreeding depression). Third, a broad base provides a variety of genotypes adapted to the wide range of site conditions across the South (see also chapters 9 and 10, this volume).

Outstanding trees selected for use in a breeding program are initially chosen on the basis of how they look - that is, according to their phenotype, which is a function of genotype (the allelic configuration of all genes in the tree) and environment. Since the genotype cannot be measured directly, it is not clear how much of a candidate tree's apparent superiority is due to environmental influences - the soil, water, competition - and how much is due to genetic makeup.

Since any apparent superiority due to environment cannot be captured and passed on in a breeding program, the key to the selection process is to reduce or mediate environmental influences so that the genetic worth of the tree can be estimated more precisely. In the initial round of tree selection (first parental generation), selection errors due to environmental effects are reduced by comparing a candidate tree to the best neighboring trees in the stand. The most accurate comparisons are made in plantations or even-aged natural stands where trees are of the same age and are growing under similar environmental conditions. Progeny tests (see 11.3.3) provide an even better degree of reliability for selection.

11.3.2 Grafting

Grafting is a method of cloning selected genotypes for use in either production seed orchards or clone banks. The method is possible because all genetic material of the select tree is present in each of its cells. In the grafting process, scions (branch tips) are collected from the select tree with a rifle or pole pruners depending on the size of the donor tree (ortet). These scions are then spliced onto rootstock seedlings which provide the scions with nutrients, moisture, and physical support. Select trees are grafted and planted into clone banks to provide additional scions if needed during orchard grafting.

Grafted trees often flower earlier than trees of seedling origin. Because grafts maintain the chronological age of the scion, grafting sexually mature ortets tends to decrease the lead time to flowering [73]. Thus, a vigorous loblolly pine graft may produce flowers in 3 or 4 years rather than the 8 or 10 years needed for seedlings. Although early flower production usually is not well distributed across all clones, it may be sufficient to begin breeding work.

For seed production, the grafts from 25 to 50 select trees are planted in specific designs to encourage maximum cross pollination. The resulting orchards are managed for seed production employing cultural methods similar to those used in fruit and nut orchards. In most southern pine seed orchards, significant quantities of seed are produced by the eighth year, and as of this writing several 25- to 30 year-old orchards continue to be productive.

11.3.3 Progeny Testing

Select trees are evaluated for their breeding value by a procedure known as progeny testing, in which they are bred with one another and the resultant offspring planted at a variety of locations in specially designed plantations called progeny tests. The performance of an individual progeny in growth rate, straightness, or other traits for which the parents were selected is then compared either to the overall mean of the test or to the mean of checklot (unimproved) seeds. Breeding values are then expressed in terms of deviations from these means. Those progenies that express the superior characteristics of their parents, when grown in different environments, are proof of a high breeding value of the parents (the original selections). In other words, the superiority expressed is influenced by heredity to a higher degree than it is by environment.

The results of a progeny test are used in several ways. First, seed-orchard parents with low breeding values can be pinpointed and removed ("rogued"). This orchard roguing is a critical step in improving the genetic gains from orchards and may be carried out several times during an orchard's productive life. Second, genetic gain for a given trait can be estimated using progeny test information. Finally, excellent families can be identified for use as parents for the next cycle of breeding, selection, and possible orchard establishment.

11.3.4 Seed Orchards

Some pine seed crops are still harvested from wild stands of specific geographic sources or from seed production areas which are usually natural stands set aside for seed production. Although in decreasing use, wild stands and seed production areas can provide inexpensive seed with valuable traits. For example, collecting rust-resistant East Texas or Livingston Parish, Louisiana, loblolly seed from wild stands for use in areas of high rust hazard is a sensible practice, as is creating a seed production area by removing rust-infected trees from high-hazard areas (>70% stem infection) and leaving resistant trees to produce cones, as has been effective for slash pine [40]. However, the large majority of southern pine seedlings are grown from seed orchard seed because the genetic constitution of seed orchards can largely be controlled and because the quality of orchard seed is usually superior to that of wild seed. Currently, there are more than 4,000 ha (10,000 ac) of seed orchard in the South — which make up over 78% of the area in seed orchards in the United States.

Orchards established with grafted stock are referred to as clonal orchards whereas orchards formed by thinning progeny tests are known as seedling seed orchards. Since most southern pine orchards are clonal, the following discussion does not address seedling seed orchards. Productive clonal orchards result from careful site selection, diligent establishment, and intensive culture. Maximizing genetic gains from clonal orchards demands optimum seed production per tree. This provides flexibility in genetic thinnings (roguing) and in utilizing different harvest strategies.

11.3.4.1 Orchard site selection

The high costs and longevity associated with a clonal orchard require a thorough review of potential sites before the first rootstock is grafted. General local access, proximity to other operations, and future land use are important first considerations. Topography, soils, water availabilty, pest problems, and isolation of pollen source are local factors which should be reviewed [72, 73].

The potential future use of the site, though seemingly obvious, can not be overlooked. If, for instance, state or federal agencies have plans for highway construction through the site, major engineering or legal costs will be incurred, not to mention that seed production will be delayed. The site should not be in a potential reservoir embayment. Flooding for an artificial lake necessitated the relocation of one orchard in the Southeast. Conferral with the U.S. Army Corps of Engineers, hydroelectric utilities, or other agencies may be required to make such confirmations.

The local topography must provide good air drainage, but not so much that the orchard becomes a wind funnel, which can cause substantial damage [70]. Similarly, orchards should not sited on the edge of a plateau where a constant downflow of cold air occurs, or near an ocean or other large body of water, where hurricane frequcncy is high or where strong winds can quickly develop.

The orchard's substrate, the soil, is a major consideration in site selection. Because fertilization is a normal orchard management practice, the nutrient status (base saturation) is not critical. Surface texture and drainage class are more important than inherent soil fertility. Well-drained sandy loamy and loamy sands which have good moisture retention and which overlay sandy clays are desirable [72]. However, the two textural extremes, clays and sands, should be avoided for several reasons. During droughty periods, clays can hold water too tightly for absorption through roots while sands simply do not retain enough moisture. Both conditions can be responsible for poor graft survival during the establishment phase of the orchard. Heavy clays are physically unsuitable for crop production and may provide an avenue for infection by littleleaf disease, a pathogen which attacks shortleaf and loblolly pines. Entisols, including deep sands such as the Psammaquents or Fluvaquents, can be conducive to the spread of annosus root rot *[Heterobasidion annosum* (Fr.) Bref.] and should

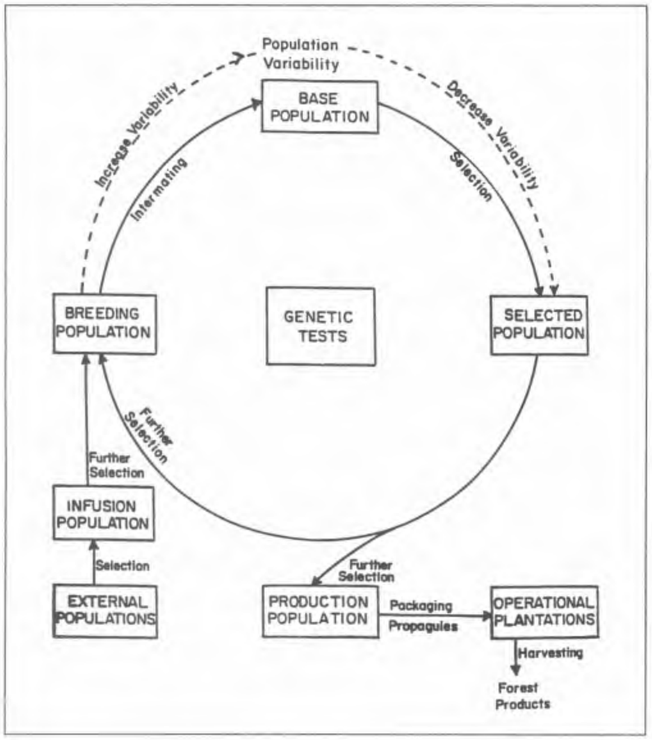

Figure 11.7. Major components of the tree-improvement cycle [71].

therefore be avoided. Vertisols, which are 2:1 lattice clays and often consist of montmorillonite, should be avoided because they shrink and swell, producing large cracks which may expose or damage root systems. Many sites in the Coastal Plains having proper surface textures may have accumulated free sesquioxides and illuviated organic matter in the B horizon to such an extent that a cemented spodic horizon results. Such hardpans have very low hydraulic conductivities and foster poorly drained, acidic conditions. Consequently, a thorough examination of soil types is imperative before the site is selected.

Isolation from non-orchard pollen sources is very important, but difficult to achieve. Pollen contamination dilutes genetic gains from tree improvement and therefore should be aggressively minimized. Isolation strips can provide a barrier to outside pollen; however, their width represents a tradeoff among orchard size, land availability, and range of pollen flight. In one small slash pine orchard (2.25 ha, or 5.6 ac), all male flowers were removed following the preparation of a 120 m (400-ft) isolation strip. Yet the strip was ineffective because enough background pollen reached the orchard to result in normal rates of fertilization, yielding seed which were 80% viable [56]. Because small orchards produce small amounts of pollen, contamination from outside trees will be greater there than in larger orchards.

11.3.4.2 Orchard design

Clonal seed orchards are planted in a variety of designs the details of which are beyond the scope of this chapter. The objectives of most designs, however, are to foster random mating among unrelated clones. True random mating, referred to as panmixis, should result in minimal inbreeding if the orchard is properly designed.

An often used rule of thumb is to separate related individuals by 27 m (90 ft). Clones are typically arranged across the orchard such that a given clone will be planted adjacent to all other clones when all ramet (individual propagules of a given clone) locations are summarized. The location of each ramet is generally assigned a row and column cell location. Orchard maps are then developed and are securely stored so that a ramet's identity can be recovered in the event of missing field labels.

Clonal orchards are generally established at dense initial spacings, usually either 4.5x 9.0 or 6.1x 12.2 m (15x 30 or 20x 40 ft) with the expectation of roguing and thinning. Multiple roguings over long periods of time have resulted in residual densities as low as 50 ramets/ha (20/ac) with no loss in cone production per tree.

11.3.4.3 Orchard management

The goal in managing seed orchards is to produce high-quality seed with a desirable genotypic mix in quantities sufficient for regeneration needs in the shortest possible time. This goal is achieved by managing the orchard for rapid vegetative growth in the years before sexual maturity, and for maximum cone production thereafter.

Rapid, juvenile growth is achieved by controlling weeds, insects, and water stress and by ameliorating soil nutrient deficiencies. Weed control is relatively easy to achieve using herbicides in spot or banded applications 1 to 2 times/year (see chapter 19, this volume). Soil-active herbicides generally are not recommended. Damage to apical meristems by the Nantucket tip moth [*Rhyacionia frustana* Comstock] can be severe especially in loblolly and Virginia pine. However, the larvae of this moth may be controlled by timing insecticide sprays to coincide with emergence of each of the moth's generations. Other damaging insects such as spider mites (*Oligonychus* spp.), aphids (*Eulachnus* and *Essigella* spp.), woolly pine scale (*Pseudophilippia quaintancii* Cockerell), pine tortoise scale (*Toumeyella parvicornis* Cockerell), and the redheaded pine sawfly (*Neodiprion lecontei* Fitch) can be readily controlled but require frequent observation for detection (see chapter 20).

Maintaining young ramets in a free-to-grow state also means keeping drought stress to a minimum. In the southeastern U.S., rainfall is usually adequate until late spring, when a dry period develops and persists until summer thunder storms begin. However, when extreme droughty conditions (such as those experienced in the early to mid-1980s) occur, the ability to water young grafts is crucial. Waterings with large tractor-pulled nurse tanks can accomplish this task but require considerable labor and frequency; therefore, permanent irrigation is installed in many orchards. High-volume systems such as fixed riser, impulse head systems do a good job but are quite costly.

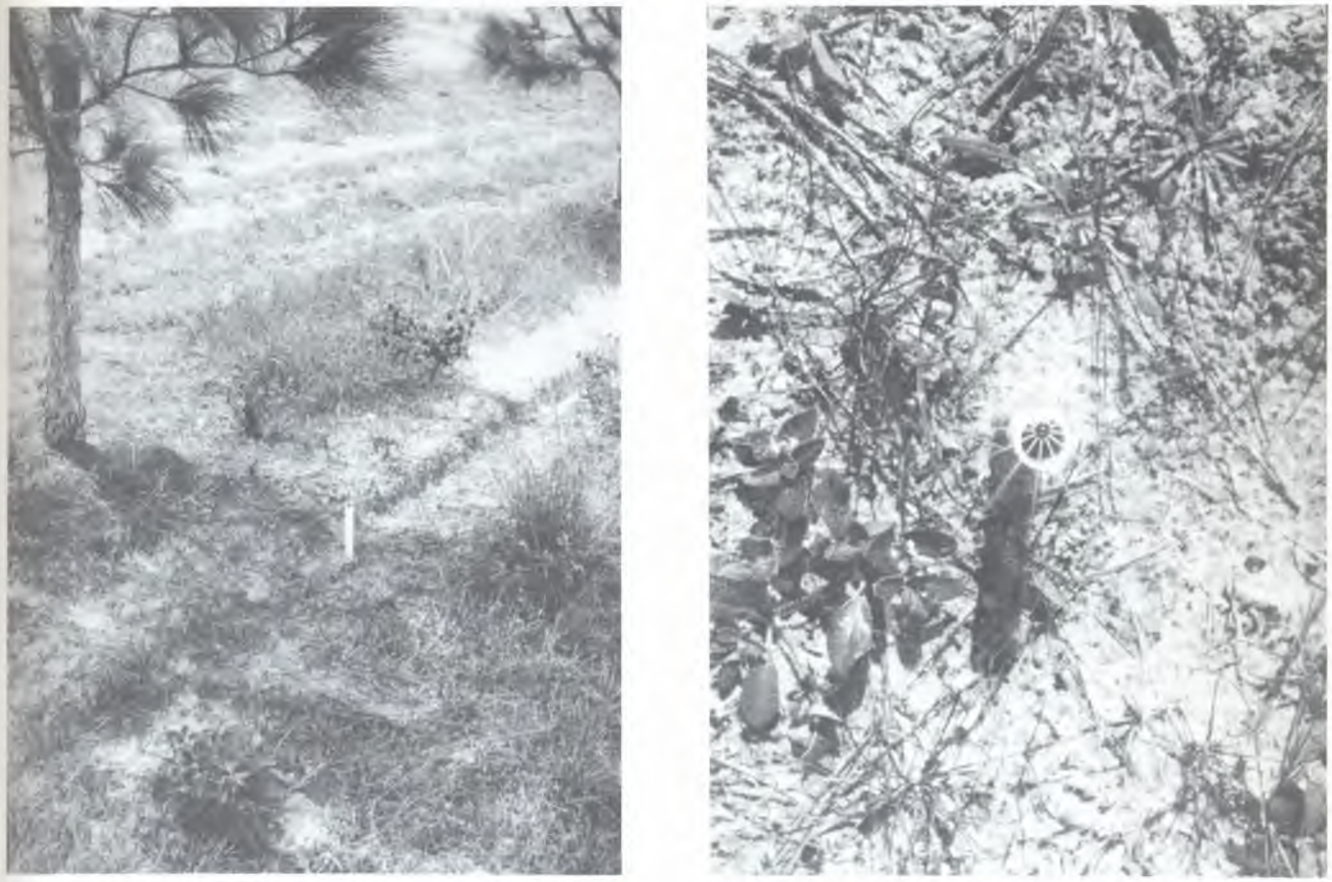

Figure 11.8. Low-volume, low-pressure microspray irrigation system installed in a loblolly pine seed orchard. Left: emitter placement 1 meter from tree; Right: top view of spray pattern. (Photo courtesy of Jefferson Smurfit/Container Corporation of America.).

Low-volume systems such as drip or microspray, developed for citrus groves, are less expensive and more efficicent for seed orchards (see Fig. 11.8).

Soil testing can reveal overall nutritional problems which are readily corrected, and foliage testing is being explored as a more accurate detection method. However, until a better understanding of optimal nutrient levels for cone production exists, orchard personnel must rely on soil tests to at least indicate pH problems and general nutrient status. Fertilization of young orchards should be completed in spring just before budbreak [55]. Liming acid soils to achieve pH of 5 to 6 should be done in winter or early spring for maximum effectiveness. Fertilizers should be applied as balanced blends to individual trees to avoid waste until trees become about 3 m (10 ft) tall.

Management activities shift as the orchard begins to produce catkins and conelets. Spring fertilization continues only to maintain desirable levels of nutrients for overall tree vigor. To increase cone production, high rates of nitrogen (110 to 220 kg N/ha, or 100 to 200 lb N/ac) are applied in late July or early August as vegetative bud primordia are actively differentiating. Although the reasons are unclear, the treatment appears to either result in a higher proportion of vegetative buds differentiating to reproductive buds or to simply increase the number of total meristems available for differentiation.

If irrigation is available, timing the watering to enhance tree vigor and then flower production is a common practice. Early to late spring irrigation should proceed to keep trees in full turgor and thus unimpeded vegetative growth. Supplemental watering equivalent to 35 mm (1.25 in.)/week from April to June, then tapering off to induce moisture stress until September, has effectively increased flower production in loblolly pine [8, 55].

Insect control in maturing orchards is mostly devoted to preventing losses of first-year conelets and feeding in second-year cones (see chapter 20, this volume). Typical regimes in slash pine orchards are to control slash pine flower thrips 2 weeks before and during conelet receptivity using low-volume aerial sprays or high-volume ground-applied sprays. For slash, longleaf, and loblolly pines, controlling coneworms *(Dioryctria* spp.) and seedbugs *(Leptoglossus* spp.) is the chief objective from spring through fall. General practice is to apply insecticides at maximum labeled rates in the spring to suppress insect population buildup, and then use lighter rates monthly until early fall when one or two heavy sprays may be applied. These treatments are costly and their necessity is not always clear. Moreover, detecting cone and seed insect populations is difficult, and interpreting the observations even more so. For example, pheromone bait traps are widely used to determine which coneworm species are present. However, only adult moths are trapped, and the relationship between trap counts of adults and the feeding activity of larvae is unclear.

Ground-cover control, pruning, and subsoiling are practiced in most southern pine orchards. Developing and maintaining a desirable ground cover (varies by region) by seeding, mowing, fertilizing, and applying herbicides reduce fire hazard, facilitate seed harvests, reduce evapotranspiration, and improve nutrient cycling. Pruning in the first years of sapling growth promotes good tree form as well as prevents rootstock limbs from overtaking the scion. Pruning again around age 10, after pollen flight, facilitates machine access and maintains good form. Because catkins are found in higher frequency in the lower crown, late spring or summer pruning insures the heaviest pollen cloud possible and thus minimizes any negative effects of pruning on seed production.

Machine traffic during mowing, controlled pollination, harvesting, and thinning compacts the soil, the effects becoming more damaging as clay content increases. Therefore, periodic subsoiling to lower bulk density is part of many orchards' normal cultural operations. Additionally, before orchard establishment, subsoiling lanes may be aligned in a grid and grafts then planted at the intersection of lanes; this approach is especially helpful when the orchard site has a dense plow layer from previous agriculture. Generally, the depth of the cut is 38 to 76 cm (15 to 30 in.). The subsoiler chisel raises and loosens the soil adjacent to the slit. Subsequently, the sod and soil settle in the slit, and loose soil falls into the opening made by the chisel. In one loblolly pine orchard, bulk density was reduced in the slit center, both at the surface and at the 15-cm (6-in.) depth 10 months after subsoiling [18]. Another benefit to be derived from subsoiling, albeit a transitory one due to tree stress after subsoiling severs roots, is increased seed production. In the same loblolly pine orchard [18], deep subsoiling resulted in 2.5 times the cones per tree than shallower treatments.

Subsoiling in pine orchards came about as a desperation measure where apical dominance was being lost, cambial patches were dying, and roots were appearing on the soil surface [7]. The need for subsoiling, especially on heavier soils, is now recognized. In such cases, the North Carolina State University-Industry Tree Improvement Cooperative staff recommends subsoiling orchards in alternate years during August. The treatments are administered on one side of the tree in year 1, the opposite side in year 2. Soil moisture should be low enough that the chisel actually fractures the soil. Subsoiling is indicated when apical dominance is lost as crowns round out or flatten. Although the severed roots are courts of infection for root rot, very rarely has this been a problem because heavier soils are not typically high-hazard sites for annosus root rot.

11.3.4.4 Cone harvesting

Cone harvests in the southern pines are labor-intensive operations. In slash and longleaf pine, an abscission layer forms between the cone and stem as the cone matures. Therefore, at peak ripeness, cones can be harvested using a high-frequency shaker (Fig. 11.9). A padded arm grips the bole; then a motor in the shaker head generates a powerful shock wave which shakes 75 to 90% of the cones to the ground. Although some mechanization is being developed, cones are usually hand gathered into either burlap bags or wooden crates to await extraction. Typically, one worker can pick up 50 to 100 bushels/day depending on crop abundance and production incentives.

Figure 11.9. Slash pine cones being harvested with high. frequency, shock-wave shaker (photo courtesy of Jefferson Smurfit/Container Corporation of America).

Neither loblolly, shortleaf, Virginia, nor sand pine forms an abscission layer at the cone base as do slash and longleaf. Thus aerial platforms are needed to harvest cones. Cones are cut or twisted off their stems and either placed in small containers to be gathered later or tossed singly to the ground to be picked up by hand. Production rates are variable depending on species, cone abundance, tree height, spacing, and type of harvest (e.g., bulk, specialty, family).

Two mechanical harvesting systems — net retrieval and paddle — have been developed over the last decade. Both reduce labor requirements, but otherwise differ con-

Figure 11.10. Weiss-McNair two paddle cone harvester operating in slash pine seed orchard. (Photo courtesy of Union Camp Corporation).

siderably. The Forest Service designed the net retrieval system for use in loblolly pine and other hand-picked cone species. Plastic netting is laid out in 3.3-m (10-ft) strips throughout the orchard before cones ripen. As cones begin to open, the trees are shaken, the winged seed falls into the netting, and the netting is rolled onto a large spool. Needles, limbs, and other debris are automatically removed as the seed is dumped into fiber drums. Such a system is ideal when an organization needs large quantities of seed regardless of its clonal makeup. Dependency on weather favorable to cone opening, loss of seed to animals, inability to conduct specialty or family harvests, possible shaker damage, and high capital outlays are limitations which must be weighed against the advantages offered by net retrieval.

Also showing considerable promise is an adaptation of the paddle-sweeping nut harvester. Union Camp Corporation pioneered the modification of this machine in 1985, harvesting over 5,500 kg (12,000 lb) of loblolly and slash pine with one unit [31]. The harvester consists of a gasoline-powered sweeper, which resembles a large riding lawn mower, and a small trailer carrying a standard 20-bu crate (Fig. 11.10). After cones are on the ground by shaking or picking, the operator drives the machine around each tree in a series of radially increasing concentric circles. The rotating paddles float along the ground, rolling cones onto a mesh metal conveyor. Needles, limbs, and empty cones are air blown off the conveyor before reaching the crate. As the harvest progresses, a forklift tractor retrieves filled crates and supplies empty ones. Slash and longleaf pine cones harvested with this machine no longer require the 10 to 20 laborers now used for hand gathering. The paddle-type harvester works best in well-mowed orchards with smooth terrain and is ideal for specialty or clonal harvests; since one tree is harvested at a time, the operator can proceed to the exact ramet locations specified by the orchard manager, thus preserving control of genetic makeup of the harvest.

Regardless of the species or harvest method used, cone ripeness is a critical factor in obtaining maximum extraction yield and seed germination percentage (see chapter 4, this volume). Typically, the southern pines ripen in the following order (earliest to latest): slash, longleaf, loblolly, shortleaf, Virginia, and sand. Harvests begin as early as the end of August and end as late as mid-November, with species overlap depending on latitude and weather conditions. Ripeness is generally determined by measuring cone specific gravity by either water displacement or by floating cones in oil with a specific gravity that matches the target for the species of interest.

Clones do not all ripen at the same time. When a cone harvest begins irrespective of clonal ripening order, "early" clones may shed their seed because they are picked late, and "late" clones may case harden because they are picked early. Therefore, best results are obtained by developing records of ripening order over a 3- to 5-year period.

11.3.5 Improved Material: Risk vs. Gain

Tree improvement programs in the South preserve selected genotypes via grafting in seed orchards, clone banks, or breeding arboreta. Because the unique gene combinations produced by breeding programs would never have occurred in nature, these programs have enriched our forests with hundreds of thousands of new gene combinations, many of which will enhance forest productivity in the future.

Southern pines from tree improvement programs outperform unimproved checklots by 6 to 20% [57]. These gains are largely the results of first-generation selection, breeding, and testing. Advanced-generation selection, breeding, and testing promise even more impressive gains. Currently, there are at least 280 ha (700 ac) of second-generation seed orchards in the South. Traits such as high gum yield, pitch canker resistance, and high specific gravity have been included in mainline breeding programs. These genetic infusions have the additional benefit of adding diversity to the overall gene base of the southern pines. However, although gains are being realized, there can be risks associated with deployment of genetically improved seedlings.

Moving seed or seedlings — whether orchard grown or "woods run" — to a region where they have not been tested involves some degree of risk. Although some nonlocal sources may perform better (in terms of survival, growth, and disease resistance) than local ones, drought, disease, ice, or extreme cold can be devastating to trees from seedlots not adapted to that specific hazard. Moreover, we must be careful to distinguish between the performance of experimental and production plantations [29]. Determining the degree of risk involves balancing the potential gains from wood produced by fast-growing sources against possible losses from extreme weather, pathogens, or unusual growing conditions. Some organizations have elected to accept some risk in the belief that most gains will outweigh losses.

For example, Weyerhaeuser Company's planting of loblolly pine seedlings form North Carolina coastal loblolly source seed orchards in Oklahoma and Arkansas has been a very successful program for several years [26]. Seed-source studies have also indicated a 3.0- to -3.6 m (10- to 12-ft) height advantage of South Carolina coastal loblolly seedlings over an Oklahoma source after 25 years in a south Arkansas plantation [66]. Similar gains have been reported with other Atlantic coastal loblolly sources [27, 67]. Recent volume estimates of all of these plantations indicate a 20 to 30% gain when North Carolina sources are compared to local sources [26], although mortality was higher in the North Carolina than the local sources as a result of the severe 1980 drought.

The management strategy adopted by Weyerhaeuser includes a site classification system used to designate those sites which are suitable for the North Carolina coastal sources [26]. In this system, an estimate of soil moisture deficit separates the high- and low-risk sites. Currently, about 60% of the Arkansas-Oklahoma lands are to be planted with North Carolina coastal sources, on the basis of this site classification system [26]; the balance will be planted with material from the company's Arkansas/Oklahoma tree improvement program.

Naturally, the resources of the landowner must be considered when advice is offered as to the best species and seed-source. Typically, a large forest-products corporation can absorb growth and mortality losses without extreme difficulty compared to a small nonindustrial private landowner.

11.4 Conclusions and Recommendations

11.4.1 Operational Monitoring and Feedback

The ultimate success of a seed-production and seed-allocation program is measured by standing volume at the end of the rotation. Predictions or indications of this success are possible by establishing and maintaining some type of monitoring system. If the wrong species or seed source has been chosen, corrective action can be taken through subsequent decisions. Although most large companies have technical departments which address problems concerning plantation inventory and stand condition, it is surprising that, in many cases, seed sources are not known or disease levels not estimated. Defining the essentials of such a monitoring system are so affected by owner objectives and local conditions that they are beyond the scope of this chapter. However, we can offer a few general recommendations.

Document the species and seed source from seed orchard through the nursery and into plantations. Some type of coding system will be necessary and should include species, provenance, seed production location (orchard identity), attributes of seedlot (e.g., orchard bulk vs. specialty group, rust resistant), and year of seed production. The code should be flexible enough to accommodate maturation of the regeneration program and simple enough to be implemented. Mapping seed sources in the field is imperative and will require trained personnel. Planting a specific seed source is a long-term commitment; inability to later identify is tantamount to concluding that seed source does affect final yield.

Several other factors are important in monitoring the development of an artificially regenerated forest. Initial stocking, first-year survival rate, fifth-year stocking, and midrotation stand density are indicators of site preparation, seedling, and planter quality, and of problems arising from competing vegetation, disease status, and overall suitability of the planting choice.

Insect and disease attacks should be routinely monitored. Early problems such as pales weevils (age 1), tip moth (age 1 to 4), brown spot (age 1 to 3), fusiform rust (age 5), or pitch canker (age 5 to 10) must be assessed to plan a replant or observe the performance of a specialty seed source. Using a monitoring scheme that is intensive in the juvenile stages of plantation development is therefore the most effective way to improve genotype deployment strategies and increase harvest volumes.

11.4.2 Summary

The southern pines occupy an extensive range representing one of the most economically important assets of the United States. In deciding what species to plant and which seed source of the species to use, foresters should consider biological as well as management and product factors. Our views of species' natural ranges and thus their adaptations are short sighted at best. The southern pines continue to evolve in response to climatic changes in their current ranges and selection pressures exerted by new environments as they migrate and expand their natural ranges.

Testing of different seed sources has provided the information needed for us to exploit the inherent variation present within and among these species, and tree improvement programs have allowed us to capitalize on this tree-to-tree variation to produce high-quality, dependable sources of orchard seed. Although many questions of adaptability and risk continue to challenge us, perhaps few other decisions will have as great an impact on forest productivity as those dealing with the proper allocation of species, their respective seed sources, and superior genotypes.

A.11.1 Appendix: Decision Keys for Matching Species/Sources to Sites

A.11.1.1 Factors Affecting Planting Choices

Decision criteria involved with matching the appropriate species or genotype to a specific site vary substantially throughout any region. In addition to considering site and biological factors, landowners must also consider management and silvicultural requirements along with product and economic objectives.

To obtain more information about the decision criteria which influence species selection, in 1987, Mitchell Flinchum surveyed regeneration foresters throughout the southern United States by mail. The survey asked how pine species are chosen for various sites within each of the physiographic regions of the southern United States. Forty three out of 55 respondents indicated that more than one species of southern pine could be successfully planted on the same site within each physiographic region. The final decision regarding the *one* pine species actually planted was made by evaluating management objectives as well as biological, edaphic, and environmental characteristics of the site. For example, consider a site where longleaf and loblolly pine may both produce equal investment potential on a 50-year rotation. Loblolly pine may be selected because, unlike longleaf, the landowner can choose between a short rotation for pulpwood or a longer rotation for sawtimber.

A.11.1.2 Decision Criteria

Although it is virtually impossible to incorporate and assign weights or values to all decision criteria considered in selecting a species or seed source of a species, we have attempted to include as many as possible in the keys that follow. However, some important factors which influence pine growth or survival were omitted simply because they are not species or site specific. Examples of these factors include, but are not limited to, proper seedling handling, storage and transport, and general reputation of seedling suppliers. In addition, clonal (open- pollinated, single-family collection) sources were not recommended in the keys because of their limited accessibility. Following are the rationales for excluding certain factors from the decision keys or for including them to a limited extent or in a particular way.

A.11.1.2.1 Southern pine beetle

How severely a planting is affected by southern pine beetles *(Dendroctonus frontalis* Zimmerman) appears to be related to the beetles' current distribution, population levels, planting densities, antecedent weather conditions, and stress of individual trees [22]--few of which can be strongly related to individual site characteristics from a regional perspective. In the southeastern United States, the southern pine beetle appears to prefer loblolly and shortleaf pines; however, it has been reported to attack and kill all pines species in its range [42]. Since beetle occurrence could not be associated with the site characteristics or species attacked, it was not incorporated into the decision keys.

A.11.1.2.2 Annosus root rot

Annosus root rot is fairly site specific on well-drained, deep, sandy soils [1], but the degree of damage tends to relate more to intermediate silvicultural activities such as thinnings than to factors that would be considered when selecting the appropriate species for a given site. Thus, it was not incorporated into the decision keys. However, annosus root rot could be an important criterion if the landowner planned a sawtimber rotation which includes thinnings. For long-term management, the landowner would be wiser to plant on wider spacings and avoid thinnings because none of the southern pine species that grow on these sites arc immune to this root rot.

A.11.1.2.3 Fusiform rust

Fusiform rust is more species specific than the southern pine beetle or annosus root rot [3]; therefore, it was incorporated into the decision keys because reduction in incidence will result from selecting the appropriate species, seed sources, or genotypes. The disease usually occurs on moderately well to well-drained sites due to the proximity and abundance of oaks, the alternate host. However, it was included in many of the wet-site keys because such sites might be near better drained areas likely to support high densities of oaks. Rust-resistant families from orchards of appropriate provenances are the preferred seed sources where fusiform rust hazard is high. However, since such seed may not be available to small landowners, the use of east Texas or Livingston Parish, La. unimproved sources may be substituted and therefore **is** suggested in the keys.

A.11.1.2.4 Pitch canker

Pitch canker disease can be found damaging pines from Virginia to eastern Texas. Although many species are affected, slash, loblolly, shortleaf, and Virginia pine are most susceptible. Regional survey data necessary to define where pitch canker is causing the most serious damage does not exist. In addition, controls for the disease are not yet available. For these reasons, it was not included in the decision keys.

At the University of Florida, in vivo screening with pitch canker inoculum in slash pine has led to successful identification of genotypes resistant to pitch canker. Resistant individuals in seed orchards could be selectively harvested and the resulting seedlings deployed to areas prone to pitch canker infestation. A smaller effort is underway with loblolly pine.

Breeding for resistance shows some promise as part of an integrated system to minimize damage. Other tools which may contribute to disease management include salvage harvest of heavily diseased stands, burning of logging debris from harvested, infected trees, practices to improve stand vigor (thinning, water management), and use of natural regeneration techniques or local seed sources from seed production areas which have been rogued for pitch canker [16].

A.11.1.2.5 Fertilization

Fertilization was included as a decision criterion on some sites to help differentiate between slash and loblolly pine as the recommended species. In decision couplets where fertilization is used to distinguish between these two pine species, fertilization leads to selecting loblolly pine--although this does not necessarily preclude planting slash pine (which may be fertilized). The species-site fertilization criteria in the keys are based on recommendations of Fisher [11].

A.11.1.3 Directions for Using the Keys

Since site criteria, costs, and product objectives may be assigned different weights or values for different sites, it is imperative that the reader start at the beginning for each site. The user must read the decision couplet that begins with the same number--for example, statement 1. and statement V. At each identically numbered couplet (number and number ') the user must select the statement that most closely describes the site being considered. At the end of the selected statement is another number which leads the user to the next decision couplet. This process should be repeated until the user finally arrives at a single species, seed source, or genotype of the recommended species.

As with all dichotomous keys, the initial decision criteria are quite general and become more specific as the keys progress. Since only one of two statements can be selected, the user may find some difficulty in describing a moderately well drained site as "wet" or "dry." If such difficulty arises, the user should mentally note that couplet and return to it later if subsequent criteria seem far afield from the site being considered.

A.11.1.4 Key 1

Site located in flatwoods, Coastal Plains, sandhills, or Piedmont of the southern United States. Soils well to excessively drained; surface soil sandy with sand depth > 2 m (6 ft).

1. Site west of Mississippi River 2
1'. Site east of Mississippi River 6
2. Site north of 34 latitude
Pinus taeda L.
(improved east Texas drought-hardy)
2'. Site south of 34 latitude 3
3. Incidence of brown-spot needle blight high

Pinus taeda L.
(improved east Texas drought-hardy)
3'. Incidence of brown-spot needle blight low 4
4. Pulpwood rotation planned
Pinus taeda L.
(improved east Texas drought-hardy)
4'. Dimension-stock rotation planned 5
5. Site preparation includes herbaceous weed control
Finns palustris Mill.
(zone 5 seed source, Fig. 11.6b)
5'. Site preparation does not include herbaceous weed control
Pima taeda L.
(improved east Texas drought-hardy)
6. Site south of 28° latitude 7
6'. Site north of 28° latitude 8
7. Pulpwood rotation planned
Pizzas clausa var. *immuginata* D.B. Ward
(Choctawhatchee race)
7'. Dimension-stock rotation planned
Pinus palustris Mill.
(zone 5 seed source, Fig. 11.6b)
8. Site in Atlantic Coast states 9
8'. Site in Gulf Coast states or states bordered by Mississippi River 14
9. Site in Virginia
Firms taeda L.
(zone 1 seed source, Fig. 11.6c)
9'. Site not in Virginia 10
10. Site north of 34° latitude
Pinus taeda L.
(zone 3 seed source, Fig. 11.6c)
10'. Site south of 34° latitude 11
11. Incidence of brown-spot needle blight high
Pinus clausa var. *immuginata* D.B. Ward
(Choctawhatchee race)
11'. Incidence of brown-spot needle blight low 12
12. Site south of 32° latitude
Pinus palustris Mill.
(zone 2 seed source, Fig. 11.6b)
12'. Site north of 32° latitude 13
13. Site in northwest Georgia
Pinus palustris Mill.
(zone 3 seed source, Fig. 11.6b)
13'. Site not in northwest Georgia
Pinus palustris Mill.
(zone 4 seed source, Fig. 11.6b)
14. Site south of 32.5° latitude 15
14'. Site north of 32.5° latitude 18
15. Incidence of brown-spot needle blight low
Pinus palustris Mill.
(zone 2 seed source, Fig. 11.6b)
15'. Incidence of brown-spot needle blight high 16
16. Dimension-stock rotation planned
Pinus taeda L.
(improved east Texas drought-hardy)
16'. Pulpwood rotation planned 17
17. No market for sand pine
Finns taeda L.
(improved east Texas drought-hardy)
17'. Market for sand pine
Pizzas clausa var. *immuginata* D.B. Ward
(Choctawhatchee race)
18. Site in Alabama
Pinus palustris Mill.
(zone 3 seed source, Fig. 11.6b)
18'. Site in Mississippi, Tennessee, or Kentucky 19
19. Site in Mississippi
Pinus taeda L.
(improved east Texas drought-hardy)
19'. Site in Tennessee or Kentucky
Pinus taeda L.
(zone 7 seed source, Fig. 11.6c)

A.11.1.5 Key 2

Site located in flatwoods, Coastal Plains, sandhills, or Piedmont of the southern United States. Soils well to excessively well drained. Surface soil clay, loam, chert, loess, or gravel; or if surface soil is sandy, depth to clay or other impervious material is < 2 m (6 ft).

1. Site west of Mississippi River 2
1'. Site east of Mississippi River 6
2. Site north of 32° latitude
Finns taeda L.
(improved east Texas drought-hardy)
2'. Site south of 32° latitude 3
3. Incidence of brown-spot needle blight high
Pizzas taeda L.
(improved east Texas drought-hardy)
3'. Incidence of brown-spot needle blight low 4
4. Pulpwood rotation planned
Pinus taeda L.
(improved east Texas drought-hardy)
4'. Dimension-stock rotation planned 5
5. Site preparation includes herbaceous weed control
Pinus palustris Mill.
(seed source corresponding with zones in Fig. 11.6b)
5'. Site preparation does not include herbaceous weed control
Pinus taeda L.
(improved east Texas drought-hardy)
6. Site south of 28° latitude
Pinus palustris Mill.
(zone 5 seed source, Fig. 11.6b)
6'. Site north of 28° latitude 7
7. Site south of 32° latitude 8
7'. Site north of 32° latitude 13
8. Incidence of brown-spot needle blight high 9
8'. Incidence of brown-spot needle blight low 10
9. Incidence of fusiform rust high
Pinus taeda L.
(Livingston Parish, La., seed source)
9'. Incidence of fusiform rust low
Pinus taeda L.
(improved east Texas drought-hardy or zone 4 seed source, Fig. 11.6c)
10. Incidence of fusiform rust high
Pizzas palustris Mill.
(zone 2 seed source, Fig. 11.6b)
10'. Incidence of fusiform rust low 11
11. Pulpwood rotation planned
Pinus taeda L.
(improved east Texas drought-hardy or zone 4 seed source, Fig. 11.6c)
11'. Dimension-stock rotation planned 12
12. Site preparation includes herbaceous weed control
Pinus palustris Mill.
(zone 2 seed source, Fig. 11.6b)
12'. Site preparation does not include herbaceous weed control
Pinus taeda L.
(improved east Texas drought-hardy or zone 4 seed source, Fig. 11.6c)
13. Site north of 35° latitude 14

13'. Site south of 35° latitude 15
14. Site in Virginia
Pinus taeda L.
(zone 1 seed source, Fig. 11.6c)
14'. Site in western Kentucky
Pinus echinata Mill)
(zone 3 seed source, Fig. 11.6a)
15. Site in North or South Carolina 16
15'. Site in Georgia, Alabama, Mississippi, or Tennessee 20
16. Incidence of fusiform rust high 17
16'. Incidence of fusiform rust low 19
17. Rust-resistant loblolly pine seedlings available
Pinus taeda L.
(rust-resistant stock from corresponding zones in Fig. 11.6c)
17'. Rust-resistant loblolly pine seedlings unavailable 18
18. Pulpwood rotation planned
Pinus echinata Mill.
(seed source corresponding with zones in Fig. 11.6a)
18'. Dimension-stock rotation planned
Pinus palustris Mill.
(zone 4 seed source, Fig. 11.6b)
19. Site in North Carolina
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
19'. Site in South Carolina
Pinus taeda L.
(**improved** east Texas drought-hardy or zone 4 seed source, Fig. 11.6c)
20. Incidence of fusiform rust high 21
20'. Incidence of fusiform rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
21. Rust-resistant loblolly pine seedlings available
Pinus taeda L.
(rust-resistant stock from corresponding zones in Fig. 11.6c)
21'. Rust-resistant loblolly pine seedlings unavailable
Pinus echinata Mill.
(seed source corresponding with zones in Fig. 11.6a)

A.11.1.6 Key 3

Site located in Piedmont of the southern United States. Soils moderately to poorly drained, or good internal drainage but site subject to periodic floods.

1. Moderately to poorly drained, permeability slow 2
1'. Periodically flooded but permeability and internal drainage good 3
2. Incidence of fusiform rust high
Pinus taeda L.
(rust-resistant stock from corresponding zones in Fig. 11.6c)
2'. Incidence of fusiform rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
3. Subsoil plastic 4
3'. Subsoil friable 5
4. Incidence of fusiform rust high
Pinus taeda L.
(rust-resistant stock from corresponding zones in Fig. 11.6c)
4'. Incidence of fusiform rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
5. Incidence of littleleaf disease high 6
5'. Incidence of littleleaf disease low 7
6. Incidence of fusiform rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
6'. Incidence of fusiform rust high
Pinus echinata Mill.
(upland sources of seed corresponding with zones in Fig. 11.6a)
7. Incidence of fusiform rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
7'. Incidence of fusiform rust high
Pinus echinata Mill.
(seed source corresponding with zones in Fig. 11.6a)

A.11.1.7 Key 4

Site located in flatwoods or Coastal Plains of the southern United States. Soils poorly to very poorly drained, or good internal drainage but site subject to periodic floods. Organic epipedon > 50 cm (20 in.) thick.

1. Access drainage needed 2
1'. Access drainage not needed 3
2. Access drainage feasible 3
2'. Access drainage not feasible
Consider hardwood species
3. Silvicultural drainage or bedding planned 4
3'. Silvicultural drainage or bedding not planned.
Consider hardwood species
4. Phosphorus fertilization feasible 5
4'. Phosphorus fertilization not feasible
Consider hardwood species
5. Incidence of fusiform rust high 6
5'. Incidence of fusifonn rust low
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
6. Site west of Mississippi River
Pinus taeda L.
(seed source corresponding with zones in Fig. 11.6c)
6'. Site east of Mississippi River 7
7. Site north of 33° latitude
Pinus taeda L.
(rust-resistant stock from corresponding zones in Fig. 11.6c)
7'. Site south of 33° latitude 8
8. Site south of 28° latitude
Pinus elliottii Engelm. var. *elliottii*
(rust-resistant seed source collected south of 30° latitude)
8'. Site north of 28° latitude (but south of 33° latitude)
Pinus taeda L.
(Livingston Parish, La., seed source)

A.11.1.8 Key 5

Site located in flatwoods or Coastal Plains of the southern United States. Soils poorly to very poorly drained, or good internal drainage but site subject to occasional high water. Organic epipedon < 50 cm (20 in.) deep; spodic horizon present, but no argillic horizon.

1. Poorly to very poorly drained, permeability slow 3
1'. Periodically flooded but permeability and internal drainage good 2
2. Site west of Mississippi River 3
2'. Site east of Mississippi River 7
3. Site more than 150 miles from Gulf Coast
Pinus taeda L.
(east Texas seed source)
3'. Site within 150 miles of Gulf Coast 4
4. Incidence of brown spot needle blight high

Pinus taeda **L.**
(east Texas seed source)
4'. Indicence of brown spot needle blight low 5
5. Pulpwood rotation planned
Pinus taeda **L.**
(east Texas seed source)
5'. Dimension-stock rotation planned 6
6. Site preparation includes herbaceous weed control.
Pinus palustris Mill.
(seed source corresponding with zones in Fig. 11.6b)
6'. Site preparation does not include herbaceous weed control
Pinus taeda **L.**
(east Texas seed source)
7. Site in Alabama, Florida, Georgia, or Mississippi 8
7'. Site in South Carolina, North Carolina, or Virginia 10
8. Incidence of fusiform rust high 13
8'. Incidence of fusiform rust low
Pinus elliottii Engelm. var. *elliottii*
(genetically improved local seed source)
9. Rust-resistant slash pine stock available.
Pima elliottii Engelm. var. *elliottii*
9'. Rust-resistant slash pine stock not available
Pinus taeda **L.**
(Livingston Parish, La. seed source)
10. Site north of 35° latitude 11
10 Site south of 35° latitude 12
11. Site in Virginia
Pinus taeda **L.**
(zone 1 seed source, Fig. 11.6c)
11'. Site in North Carolina
Pinus taeda **L**
(zone 2 seed source, Fig. 11.6c)
12. Site north of 33° latitude 13
12'. Site south of 33° latitude 14
13. Incidence of fusiform rust high
Pinus taeda **L.**
(Livingston Parish, La. seed source)
13'. Incidence of fusiform rust low
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source)
14. Incidence of fusiform rust high
Pinus taeda **L.**
(Livingston Parish, La. seed source)
14'. Incidence of fusiform rust low
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source)
15. Access drainage feasible 16
15'. Access drainage not feasible
Consider hardwood species
16. Silvicultural drainage or bedding planned 17
16'. Silvicultural drainage or bedding not planned
Consider hardwood species
17. Site west of Mississippi River 18
17'. Site east of Mississippi River 19
18. Site north of 33° latitude
Pinus taeda **L.**
(zone 6 seed source, Fig. 11.6c)
18'. Site south of 33° latitute
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source)
19. Site north of 33° latitude 20
19'. Site south of 33° latitude 21
20. Incidence of fusiform rust high
Pinus taeda **L.**
(rust-resistant sources corresponding with zones in Fig. **11.6c)**
20'. Incidence of fusiform rust low
Pinus taeda **L.**
(fertilization and seed source corresponding with zones in Fig. 11.6c)
21. Fertilization feasible 22
21'. Fertilization not feasible 23
22. Incidence of fusiform rust high
Pinus taeda **L.**
(Livingston Parish, La. seed source)
22'. Incidence of fusiform rust low
Pinus elliottii var. *elliottii*
(genetically improved seed source)
23. Incidence of fusiform rust high
Pinus elliottii var. *elliottii*
(rust-resistant seed source)
23'. Incidence of fusiform rust low
Pinus elliottii var. *elliottii*
(genetically improved seed)

A.11.1.9 Key 6

Site located in flatwoods or Coastal Plains of the southern United States. Soils poorly to very poorly drained. Organic surface less than < 50 cm (20in.) thick; spodic and argillic horizons present.

1. Access drainage needed 2
1'. Access drainage not needed 3
2. Access drainage feasible 3
2'. Access drainage not feasible
Consider hardwood species
3. Silvicultural drainage or bedding planned 4
3'. Silvicultural drainage or bedding not planned
Consider hardwood species
4. Site south of 28° latitude
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed from south of 30° latitude)
4'. Site north of 28° latitude 5
5. Site south of 33° latitude 6
5'. Site north of 33° latitude 9
6. Incidence of fusiform rust high 7
6'. Incidence of fusiform rust low 8
7. Fertilization feasible
Pinus taeda **L.**
(Livingston Parish, La., seed source)
7'. Fertilization not feasible
Pinus elliottii Engelm. var. *elliottii*
(rust-resistant seed source)
8. Fertilization feasible
Pinus taeda **L.**
(genetically improved seed from appropriate zone in Fig.11.6c)
8'. Fertilization not feasible
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source)
9. Site south of 35° latitude 10
9'. Site north of 35° latitude
Pinus taeda **L.**
(seed source from corresponding zone in Fig. 11.6c)
10. Incidence of fusiform rust high
Pinus taeda **L.**
(Livingston Parish, La. seed source or rust-resistant source from corresponding zone in Fig. 11.6c)
10'. Incidence of fusiform rust low
Pinus taeda **L.**
(seed source from corresponding zone in Fig. 11.6c)

A.11.1.10 Key 7

Site located in flatwoods or Coastal Plains of the southern United States. Soils poorly to very poorly drained. Spodic horizon absent, but argillic horizon present and within 50 cm (20 in) of the surface.

1. Access drainage needed 2
1'. Access drainage not needed 3
2. Access drainage feasible 3
2'. Access drainage not feasible
Consider hardwood species
3. Silvicultural drainage or bedding planned 4
3'. Silvicultural drainage or bedding not planned
Consider hardwood species
4. Site east of Mississippi River 6
4'. Site west of Mississippi River 5
5. Fertilization feasible
Pinus taeda L.
(zone 5 seed source, Fig. 11.6c)
5'. Fertilization not feasible
Pinus elliottii Engelm. var. *elliottii*
(Mississippi seed source)
6. Site south of 28° latitude
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source from south of 30° latitude)
6'. Site north of 28° latitude 7
7. Site south of 33° latitude 9
7'. Site north of 33° latitude 8
8. Incidence of fusiform rust high
Pinus taeda L.
(rust-resistant source from corresponding zone in Fig. 11.6c)
8'. Incidence of fusiform rust low
Pinus taeda L.
(source from corresponding zone in Fig. 11.6c)
9. Fertilization feasible 10
9'. Fertilization not feasible 11
10. Incidence of fusiform rust high
Pinus taeda L.
(Livingston Parish, La., seed source)
10'. Incidence of fusiform rust low
Pinus taeda L.
(zone 4 seed source, Fig. 11.6c)
11. Incidence of fusiform rust high
Pinus taeda L.
(Livingston Parish, La., seed source)
11'. Incidence of fusiform rust low
Pinus elliottii Engelm. var. *elliottii*
(improved source from southern Georgia-northern Florida)

A.11.1.11 Key 8

Site located in flatwoods or Coastal Plains of the southern United States. Soils poorly to very poorly drained. Spodic horizon absent; argillic horizon present but not within 50 cm (20 in.) of the surface.

1. Access drainage needed 2
1'. Access drainage not needed 3
2. Access drainage feasible 3
2'. Access drainage not feasible
Consider hardwood species
3. Silvicultural drainage or bedding planned 4
3'. Silvicultural drainage or bedding not planned
Consider hardwood species
4. Site east of Mississippi River 7
4'. Site west of Mississippi River 5
5. Site south of 33° latitude
Pinus elliottii Engelm. var. *elliottii*
(west Mississippi or Louisiana seed source)
5'. Site north of 33° latitude 6
6. Fertilization feasible
Pinus taeda L.
(zone 5 seed source, Fig. 11.6c)
6'. Fertilization not feasible
Pinus echinata Mill.
(zone 5 seed source, Fig. 11.6a)
7. Site south of 28° latitude
Pinus elliottii Engelm. var. *elliottii*
(genetically improved seed source from south of 30° latitude)
7'. Site north of 28° latitude 8
8. Site south of 33° latitude 12
8'. Site north of 33° latitude 9
9. Site in Tennessee or Kentucky; inland
Pinus taeda L.
(northern Mississippi, northern Alabama, or northwestern Georgia sources OR Virginia, northern North Carolina, or central Arkansas sources)
9'. Site in South Carolina, North Carolina, or Virginia; coastal 10
10. Site in Virginia
Pinus taeda L.
(seed source from corresponding zone in Fig. 11.6c)
10'. Site in South or North Carolina 12
11. Incidence of fusifonn rust high
Pinus echinata Mill.
(rust-resistant source from corresponding zone in Fig. 11.6c)
11'. Incidence of fusiform rust low
Pinus taeda L.
(source from corresponding zone in Fig. 11.6c)
12. Incidence of fusiform rust high 13
12'. Incidence of fusiform rust low
Pinus elliottii Engelm. var. *elliottii*
(improved southern Georgia-north Florida sources)
13. Fertilization feasible
Pinus taeda L.
(Livingston Parish, La., seed source)
13'. Fertilization not feasible
Pinus elliottii Engelm. var. *elliottii*
(local seed production area rogued for fusiform rust or rust-resistant families from local seed orchards)

A.11.1.12 Key 9

Site located in Blue Ridge, Valley and Ridge, Appalachian Plateau, Interior Low Plateaus, or Interior Highlands physiographic regions. Soils well drained to excessively drained.

I. Site west of Mississippi River 2
1'. Site east of Mississippi River 3
2. Site north of 34° latitude
Pinus echinata Mill.
(zones 2, 3, or northern half of 5, seed source, Fig. 11.6a)
2'. Site south of 34° latitude
Pinus echinata Mill.
(zone 5 seed source, Fig. 11.6a)
3. Incidence of littleleaf disease high 4
3'. Incidence of littleleaf disease low 9
4. Incidence of fusiform rust high 5
4'. Incidence of fusiform rust low 7
5. Site north of 34° latitude
Pizzas virginiana Mill.
(local seed source)
5'. Site south of 34° latitude 6
6. Pulpwood rotation planned

Pinus virginiana Mill.
(local seed source)
6'. Dimension-stock rotation planned
Pinus palustris Mill.
(zone 3 seed source, Fig. 11.6b)
7. Site north of 35° latitude
Pinus virginiana Mill.
(local seed source)
7'. Site south of 35° latitude
Pinus taeda L.
(improved east Texas drought-hardy)
8. Incidence of fusiform rust high
Pinus echinata Mill.
(seed source corresponding with zones in Fig. 11.6a)
8'. Incidence of fusiform rust low 9
9. Site north of 35° latitude
Pinus echinata Mill.
(seed source corresponging with zones in Fig. 11.6a)
9'. Site south of 35° latitude 10
10. Site south of 34° latitude 11
10'. Site north of 34° latitude
Pinus taeda **L.**
(improved east Texas drought-hardy)
11. Pulpwood rotation planned
Pinus taeda **L.**
(improved east Texas drought-hardy)
11'. Dimension-stock rotation planned 12
12. Site preparation includes herbaceous weed control
Pinus palustris Mill.
(zone 3 seed source, Fig. 11.6b)
12'. Site preparation does not includes herbaceous weed control
Pinus taeda **L.**
(improved east Texas drought-hardy)

A.11.1.13 Key 10

Site located in Blue Ridge, Valley and Ridge, Appalachian Plateau, Interior Low Plateaus, or Interior Highland physiographic regions. Soils moderately to poorly drained.

1. Site moderately drained 6
1'. Site poorly drained 2
2. Site west of Mississippi River
Consider hardwood species
2'. Site east of Mississippi River 3
3. Site in Interior Low Plateaus 4
3'. Site not in Interior Low Plateaus
Consider hardwood species
4. Site subject to snow, ice, and late spring frosts 5
4'. Site not subject to snow, ice, and late spring frosts
Pines taeda **L.**
(Northern Alabama seed source)
5. Cold-hardy loblolly pine seedling stock available
Pinus taeda **L.**
(zone 1 seed source, Fig.11.6c)
5'. Cold-hardy loblolly pine seedling stock not available
Consider hardwood species
6. Site west of Mississippi River
6'. Site east of Mississippi River 7
7. Site in Interior Low Plateaus 8
7'. Site not in Interior Low Plateaus 15
8. Site in Alabama
Pinus taeda L.
(zone 3 seed source, Fig. 11.6c)
8'. Site in Tennessee or Kentucky 9
9. Site subject to snow, ice, and late spring frosts 10
9'. Site not subject to snow, ice, and late spring frosts 12
10. Cold-hardy loblolly pine seedling stock available
Pinus taeda L.
(northern Alabama seed source)
10'. Cold-hardy loblolly pine seedlings stock not available 11
11. Surface soil depth (to constricting layer) > 16 cm (6 in.) but < 30.5 cm (12 in.)
Pinus strobus L.
(East Tennessee seed source)
11'. Surface soil depth (to constricting layer) > 30.5 cm (12in.)
Pinta echinata Mill.
(zone 3 seed source, Fig. 11.6a)
12. Surface soil depth (to constricting layer) > 16 cm (6 in.) but < 30.5 cm (12in.)
Pinus strobes L.
(East Tennessee seed source)
12'. Surface soil depth (to constricting layer) > 30.5 cm (12in.)
Pinus taeda L.
(zone 1 seed source, Fig. 11.6c)
13. Site east of eastern Continental Divide 15
13'. Site west of eastern Continental Divide 19
14. Surface soil depth (to constricting layer) > 16 cm (6 in.) but < 30.5 cm 12 in.) 15
14'. Surface soil depth (to constricting layer) > 30.5 cm (12in.) 16
15. Pulpwood rotation planned
Pines virginiana Mill.
(local seed source)
15'. Dimension-stock rotation planned
Pinus strobus **L.**
(North Carolina seed source)
16. Site north of 36° latitude 17
16'. Site south of 36° latitude
Pinus taeda L.
(zone 3 seed source, Fig. 11.6c)
17. Site subject to snow, ice, and late spring frosts 18
17'. Site not subject to snow, ice, and late spring frosts
Pinus taeda **L.**
(zone 1, 2, or 3 seed source, Fig. 11.6c)
18. Incidence of littleleaf disease high
Pinta virginiana L.
(local seed source)
18'. Incidence of littleleaf disease low
Pinus echinata Mill.
(zone 4 seed source, Fig. 11.6a)
19. Surface soil depth (to constricting layer) > 16 cm (6 in.) but < 30.5 cm (12 in.) 20
19'. Surface soil depth (to constricting layer) > 30.5 cm (12 in.) 21
20. Pulpwood rotation planned
Pinus virginiana Mill.
(local seed source)
20'. Dimension-stock rotation planned
Pinus strobes **L.**
(east Tennessee seed source)
21. Site north of 35° latitude 22
21'. Site south of 35° latitude 26
22. Incidence of littleleaf disease high 23
22'. Incidence of littleleaf disease low 25
23. Site subject to snow, ice, and late spring frosts 24
23'. Site not subject to snow, ice, and late spring frost
Pinus taeda **L.**
(zone 3 seed source, Fig. 11.6c)
24. Pulpwood rotation planned
Pinus virginiana Mill.
(local seed source)
24'. Dimension-stock rotation planned
Pinus strobus **L.**
(local seed source)

25. Site subject to snow, ice, and late spring frosts
Pinus echinata Mill.
(zone 3 or 4 seed source, Fig. 11.6a)
25'. Site not subject to snow, ice, and late spring frosts
Pinus taeda L. (zone 3 seed source, Fig. 11.6c)
26. Incidence of fusiform rust high 27
26'. Incidence of fusiform rust low
Pinus taeda L.
(zone 3 seed source, Fig. 11.6c)
27. Site subject to snow, ice, and late spring frosts
Pinus virginiana Mill.
(local seed source)
27'. Site not subject to snow, ice, and late spring frosts
Pinus taeda L.
(rust-resistant source from zone 3, Fig. 11.6c)

References

1. Anderson, R. L., and P. A. Mistretta. 1982. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. U.S.D.A. Forest Serv., Southeast. Area, State and Private Forestry, Asheville, N.C. Agric. Handb. No. 597. 30 p.
2. Anderson, R. L., and H. R. Powers, Jr. 1984. The resistance screening center - screening for disease resistance as a service for tree improvement programs. Pages 59-65 *In* Proc. Rusts of Hard Pines Working Party Conference. (J. Barrows-Broaddus and H. R. Powers, eds.). Sponsored by IUFRO and U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. S2.06-10.
3. Anderson, R. L., H. R. Powers, Jr., and G. A. Snow. 1980. How to identify fusiform rust and what to do about it. U.S.D.A. Forest Serv., Southeast. Area, State and Private Forestry, Atlanta, Ga. Forestry Bull. SA-FB/P 24. 12 p.
4. Brendemuehl, R. H. 1981. Options for management of sandhill forest land. South. J. Appl. Forestry 5(4):216-222.
5. Burns, R. 1972. Choctawhatchee sand pine: good prospect for Georgia-Carolina sandhills. J. Forestry 70:741-742.
6. Byram, T. D., and W. J. Lowe. 1985. Longleaf pine tree improvement in the Western Gulf Region. Pages 78-87 *In* Proc. 18th Southern Forest Tree Improvement Conference (R. C. Schmidtling and M. M. Griggs, eds.). May 21-23, 1985, Long Beach, Miss. Southern Forest Tree Improvement Committee Sponsored Publ. 40.
7. Davey, C. B. 1975. Increasing seed yield through cultural practices - today and tomorrow. Pages 138-144 *In* Proc. 13th Southern Forest Tree Improvement Conference. June 10-11, 1975, Raleigh, N.C. Southern Forest Tree Improvement Committee Sponsored Publ. 33.
8. Dewers, R. S., and D. M. Moehring. 1970. Initiation of ovulate primordia in *Pinus taeda* L. relative to soil water stress. Forest Sci. 16:219-221.
9. Dorman, K. W. 1976. The Genetics and Breeding of Southern Pines. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. No. 471.407 p.
10. Draper, L., Jr. 1975. Provenance study of five geographic sources of loblolly pine. Pages 83-88 *In* Proc. 13th Southern Forest Tree Improvement Conference. Raleigh, N.C. Southern Forest Tree Improvement Committee Sponsored Publ. 33.
11. Fisher, R. F. 1981. Soils interpretations for silviculture in the southeastern Coastal Plain. Pages 323-330 *In* Proc. 1st Biennial Southern Silvicultural Research Conference (J. P. Barnett, ed). U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Atlanta, Ga. Gen. Tech. Rep. SO-34.
12. Fisher, R. F. 1983. Silvical characteristics of slash pine *(Pines elliottii* Engelm. var *elliottii).* Pages 48-68 *In* Proc. The Managed Slash Pine Ecosystem (E.L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Symposium, Univ. of Florida, Gainesville.
13. Fowells, H. A. (ed.). 1975. Silvics of forest trees of the United States (revised). U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 271. 761 p.
14. Goddard, R. E., and R. K. Strickland. 1973. Genetics of sand pine and the program for superior tree selection. Pages 226-235 *In* Proc. Sand Pine Symposium. Dec. 5-7, 1972, Panama City Beach, Fla. U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. Gen. Tech. Rep. SE-2.
15. Goddard, R. E., and 0. 0. Wells. 1977. Susceptibility of southern pines to fusiform rust. Pages 52-58 *In* Proc. Management of Fusiform Rust in Southern Pines (R. J. Dinus and R. A. Schmidt, eds.). Univ. of Florida, Gainesville.
16. Goddard, R. E., 0. 0. Wells, and A. E. Squillace. 1983. Genetic improvement of slash pine. Pages 56-68 *In* Proc. The Managed Slash Pine Ecosystem (E. L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Symposium, Univ. of Florida, Gainesville.
17. Goodwin, 0. C. 1979. Progress made in North Carolina in planting longleaf pine. Pages 12-23 *In* Proc. Longleaf Pine Workshop (W. E. Balmer, ed.). U.S.D.A. Forest Serv., Southeast. Area, State and Private Forestry, Atlanta, Ga. Tech. Pub. SA-TP 3.
18. Gregory, J. D., and C. B. Davey. 1977. Subsoiling to stimulate flowering and cone production in a loblolly pine seed orchard. South. J. Appl. Forestry 1(2):20-24.
19. Griggs, M. M., and R. A. Schmidt. 1977. Increase and spread of fusiform rust. Pages 32-38 *In* Proc. Management of Fusiform Rust in Southern Pines (R. J. Dinus and R. A. Schmidt, eds.). Univ. of Florida, Gainesville.
20. Haines, L. W., and J. Gooding. 1983. Site selection: slash pine versus other species. Pages 112-129 *In* Proc. The Managed Slash Pine Ecosystem (E. L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Symposium, Univ. of Florida, Gainesville.
21. Hebb, E. A. 1982. Sand pine performs well in the Georgia-Carolina sandhills. South. J. Appl. Forestry 6(3):144-147.
22. Hicks, R. R., Jr. (n.d.). Climate, site and stand factors. Pages 55-67 *In* The Southern Pine Beetle (R.C. Thatcher, J. L. Searcy, J.E. Coster, and G.D. Hertel, eds.). U.S.D.A. Forest Serv., Washington, D.C. Tech. Bull. 1631.
23. Jewell, F. F. 1985. Anatomical reaction to fusiform rust of interspecific progeny from crosses between shortleaf and slash pines. Pages 209-216 *In* Proc. Rusts of Hard Pines Working Party Conference S2.06-10 (J. Barrows-Broaddus and J. R. Powers, eds.). International Union of Forestry Research Organization. Athens, Ga.
24. Kitchens, R. N. 1987. Trends in shortleaf pine tree improvement. Pages 89-100 *In* Symposium on the Shortleaf Pine Ecosystem (P. A. Murphey, ed.). Cooperative Extension Serv., Univ. of Arkansas, Fayetteville.
25. LaFarge, T. A., and J. F. Kraus. 1980. A progeny test of (shortleaf x loblolly) x loblolly hybrids to produce rapid-growing hybrids resistant to fusifonn rust. Silvae Genet. 29(5-6):197-200.
26. Lambeth, C. C., P. M. Dougherty, and W. T. Gladstone. 1984. Large scale planting of North Carolina loblolly pine in Arkansas and Oklahoma: a case of gain versus risk. J. Forestry 8202):736-741.
27. Lantz, C. W., and J. C. Hofmann. 1969. Geographic variation in growth and wood quality of loblolly pine in North Carolina. Pages 175-188 *In* Proc. of the 10th Southern Forest

'free Improvement Conference. Houston, Tex. Southern Forest Tree Improvement Committee Sponsored Publ. 30.

28. Lantz, C. W., and J. F. Kraus. 1987. A guide to southern pine seed sources. U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. Gen. Tech. Rep. SE-43. 34 p.

29. Long, E. M. 1980. Texas and Louisiana loblolly pine study confirms importance of local seed sources. South. J. Appl. Forestry 4(3):127-132.

30. Loveless, R. W., J. A. Pait, and T. McElwain. 1989. Response of longleaf pine to varying intensity of silvicultural treatments. Pages 159-166 *In* Proc. 5th Biennial Southern Silvicultural Research Conference (J. Miller, compl.). U.S.D.A. Forest Serv., South. Forest Exp. Sta., New Orleans, La. Gen. Tech. Rep. SO-74. 618 p.

31. Lowerts, G. A., and M. H. Zoerb. 1987. The Weiss-McNair cone harvester. Pages 195-198 *In* 19th Southern Forest Tree Improvement Conference. June 16-18, 1987, College Station, Tex. Southern Forest Tree Improvement Committee Sponsored Publ. 41.

32. Lowerts, G. A., M. H. Zoerb, and J. A. Pait. 1985. Resistance to the development of pitch canker in open pollinated slash pine families. Pages 334-340 *In* Proc. 18th Southern Forest Tree Improvement Conference. May 21-23, 1985, Long Beach, Miss. Southern Forest Tree Improvement Committee Sponsored Publ. 40.

33. McNab, H. W., and R. H. Brendemuehl. 1982. Choctawhatchee sand pine survival, height, and biomass in South Carolina: third year results. Pages 96-100 *In* Proc. 2nd Biennial Southern Silviculture Research Conference (E. Jones, Jr., ed.). Atlanta, Ga. 503 p.

34. McNab, H. W., and A. R. Carter. 1981. Sand pine performance on South Carolina sandhills. South. J. Appl. Forestry 5(2):84-88.

35. Nance, W. L., R. C. Froelich, T. R. Dell, and E. Shoulders. 1982. A growth and yield model for unthinned slash pine plantations infected with fusiform rust. Pages 275-281 *In* Proc. 2nd Biennial Southern. Silviculture Research Conference (E. Jones, Jr., ed.). Atlanta, Ga. 503 p.

36. Nance, W. L., R. C. Froelich, and E. Shoulders. 1981. Effects of fusiform rust on survival and structure of Mississippi and Louisiana slash pine plantations. U.S.D.A. Forest Serv., South. Forest Exp. Sta., New Orleans, La. Res. Pap. SO-172. 11 p.

37. Outcalt, K. W. 1984. Direct seeding versus planting for establishment of pines on west Florida sandhills. Pages 122-127 *In* Proc. 3rd Biennial Southern Silviculture Research Conference (E. Shoulders, ed.). Atlanta, Ga. 577 p.

38. Pait, J. A., III. 1989. Unpublished data, Container Corporation of America, Callahan, Fla.

39. Pait, J. A., III, and L. Draper, Jr. 1983. Fifth-year performance of wide ranging loblolly pine provenances. Pages 245-252 *In* Proc. 17th Southern Forest Tree Improvement Conference. Athens, Ga. Southern Forest Tree Improvement Committee Sponsored Publ. 39.

40. Pait, J. A., III, L. Draper, Jr., and R. A. Schmidt. 1985. Third year comparisons of loblolly and slash pine seed sources for fusiform rust resistance and growth potential in north central Florida. Pages 314-320 *In* Proc. 18th Southern Forest Tree Improvement Conference. Long Beach, Miss. Southern Forest Tree Improvement Committee Sponsored Publ. 40.

41. Parker, J. A., and L. W. Haines. 1981. Longleaf pine seedling survival studies. Pages 16-19 *In* Proc. 1st Biennial Southern Silviculture Research Conference (J. P. Barnett, ed.). Atlanta, Ga. U.S.D.A. Forest Serv., South. Forest Exp. Sta., New Orleans, La. Gen. Tech. Rep. SO-34.

42. Payne, T. L. (n.d.). Life history and habits. Pages 7-28 *In* The Southern Pine Beetle (R. C. Thatcher, J.L. Searcy, J.E. Coster, and G.D. Hertel, eds.). U.S.D.A. Forest Serv., Washington, D.C. Tech. Bull. 1631.

43. Powers, H. R. Jr., and J. F. Kraus. 1986. A comparison of fusiform rust-resistant loblolly pine seed sources. South. J. Appl. Forestry 10:230-232.

44. Pritchett, W. L., and N. B. Comerford. 1983. Nutrition and fertilization of slash pine. Pages 112-130 *In* Proc. The Managed Slash Pine Ecosystem (E.L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Spring Symposium, Univ. of Florida, Gainesville.

45. Ralston, C. W. 1978. The southern pinery: forests, physiography, and soils. Pages 6-13 *In* Proc. A Symposium on Principles of Maintaining Productivity of Prepared Sites (T. Tippin, ed.). March 21-23, 1978. Mississippi State Univ., Starkeville.

46. Ross, E. W. 1973. Important diseases of sand pine. Pages 199-206 *In* Proc. Sand Pine Symposium. Dec. 5-7, 1972, Panama City Beach, Fla. U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. Gen. Tech. Rep. SE-2.

47. Rounsaville, M. G. 1985. Techniques for successful artificial regeneration of longleaf pine. Pages 75-77 *In* Proc. 18th Southern Forest Tree Improvement Conference. Long Beach, Miss. Southern Forest Tree Improvement Committee Sponsored Publ. 40.

48. Ruehle, J. L., and W. A. Campbell. 1971. Adaptability of geographic selections of shortleaf pine to littleleaf sites. U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. Res. Pap. SE-87. 8 p.

49. Schmidt, R. A., R. C. Holley, and M. C. Klapproth. 1984. Results from operational plantings of fusiform rust resistant slash and loblolly pines in high rust. incidence areas in Florida and Georgia. Pages 33-41 *In* Proc. Rust of Hard Pines Working Party Conference (J. Barrows-Broaddus and H. R. Powers, eds.). Sponsored by IUFRO and U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. S2.06-10.

50. Schmidtling, R. C. 1984. Co-evolution of host/pathogen/alternate host systems in fusiform rust of loblolly and slash pines. Pages 13-19 *In* Proc. Rust of Hard Pines Working Party Conference. (J. Barrows-Broaddus and H. R. Powers, eds.). Sponsored by IUFRO and U.S.D.A. Forest Serv., Southeast. Forest Exp. Sta., Asheville, N.C. S2.06-10.

51. Schultz, R.P. 1983. The original slash pine forest - an historical view. Pages 24-47 *In* Proc. The Managed Slash Pine Ecosystem (E.L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Spring Symposium, Univ. of Florida, Gainesville.

52. Sheffield, R. M., H. A. Knight, and J. P. McClure. 1983. The slash pine resource. Pages 4-23 *In* Proc. The Managed Slash Pine Ecosystem (E.L. Stone, ed.). June 9-11, 1981. Society of American Foresters - School of Forest Resources and Conservation Annual Spring Symposium, Univ. of Florida, Gainesville.

53. Shoulders, E., and W. L. Nance. 1987. Effects of fusiform rust on survival and structure of Mississippi and Louisiana loblolly pine plantations. U.S.D.A. Forest Serv., South. Forest Exp. Sta., New Orleans, La. Res. Pap. SO-232. 11 p.

54. Society of American Foresters. 1975. Forest Cover Types of North America. Society of American Foresters, Bethesda, Md. 67 p.

55. Sprague, J., J. B. Jett, and B. J. Zobel. 1978. The management of southern pine seed orchards to increase seed production. School of Forest Resources, North Carolina State Univ., Raleigh. 17p.

56. Squillace, A. E. 1967. Effectiveness of a 400' isolation strip around a slash pine orchard. J. Forestry 65:823-824.

57. Squillace, A. E. 1989. Tree improvement accomplishments in the South. Pages 9-20 *In* Proc. 20th Southern Forest Tree Improvement Conference. June 26-30, 1989, Charleston, S.

C. Southern Forest Tree Improvement Committee Sponsored Publ. 42.
58. Sternitzke, H. S., and T. C. Nelson. 1970. The southern pines of the United States. Econ. Bot. 24:142-150.
59. Talbert, J. T., and R. J. Weir. 1979. Improved loblolly pine of northern Piedmont source does well in the northern Coastal Plain. Tree Planters' Notes 30(3):33-35.
60. Texas Forest Service. 1955. Third progress report: forest tree improvement program of the Texas Forest Service. Texas Forest Serv., College Station, Tex. Circ. No. 51.13 p.
61. Van Buijtenen, J. P. 1969. Sixteenth progress report of cooperative forest tree improvement programs. Texas Forest Serv., College Station, Tex. Circ. No. 200.14 p.
62. Wakeley, P. C. 1944. Geographic source of loblolly pine seed. J. Forestry 42:23-32.
63. Wells, O. O. 1969. Results of the southwide pine seed source study through 1968-69. Pages 117-129 *In* Proc. 10th Southern Forest Tree Improvement Conference. Houston, Tex.
64. Wells, O. O. 1983. Southwide pine seed source study: loblolly pine at 25 years. South. J. Appl. Forestry 7(2):61-71.
65. Wells, O. O. 1985. Use of Livingston Parish, Louisiana loblolly pine by forest products industries in the. Southeast. South. J. Appl. Forestry 9(3):180-185.
66. Wells, O. O., and C. C. Lambeth. 1983. Loblolly pine provenance test in southern Arkansas - 25th year results. South. J. Appl. Forestry 7(2):71-75.
67. Wells, O. O., and G. L. Switzer. 1971. Variation in rust resistance in Mississippi loblolly pine. Pages 25-30 *In* Proc. 11th Southern Forest Tree Improvement Conference. Atlanta, Ga.
68. Wells, O. O., and P. C. Wakeley. 1966. Geographic variation in survival, growth, and fusiform rust infection of planted loblolly pine. Forest Sci. Monogr. 11.40 p.
69. Wells, O. O., and P. C. Wakeley. 1970. Variation in shortleaf pine from several geographic sources. Forest Sci. 16:415-423.
70. Werner, M. 1975. Location, establishment, and management of seed orchards. *In* Seed Orchards (R. Faulkner, ed.), IUFRO Working Party on Seed Orchards. Forestry Commission Bull. 54, London. 149 p.
71. White, T.L. 1987. A conceptual framework for tree improvement programs. New Forests 1:325-342.
72. Wright, J. W. 1976. Introduction to Forest Genetics. Academic Press, Inc., New York. 463 p.
73. Zobel, B., and J. Talbert. 1984. Applied Forest Tree Improvement. John Wiley & Sons, New York. 505 p.