United States
Department of
Agriculture

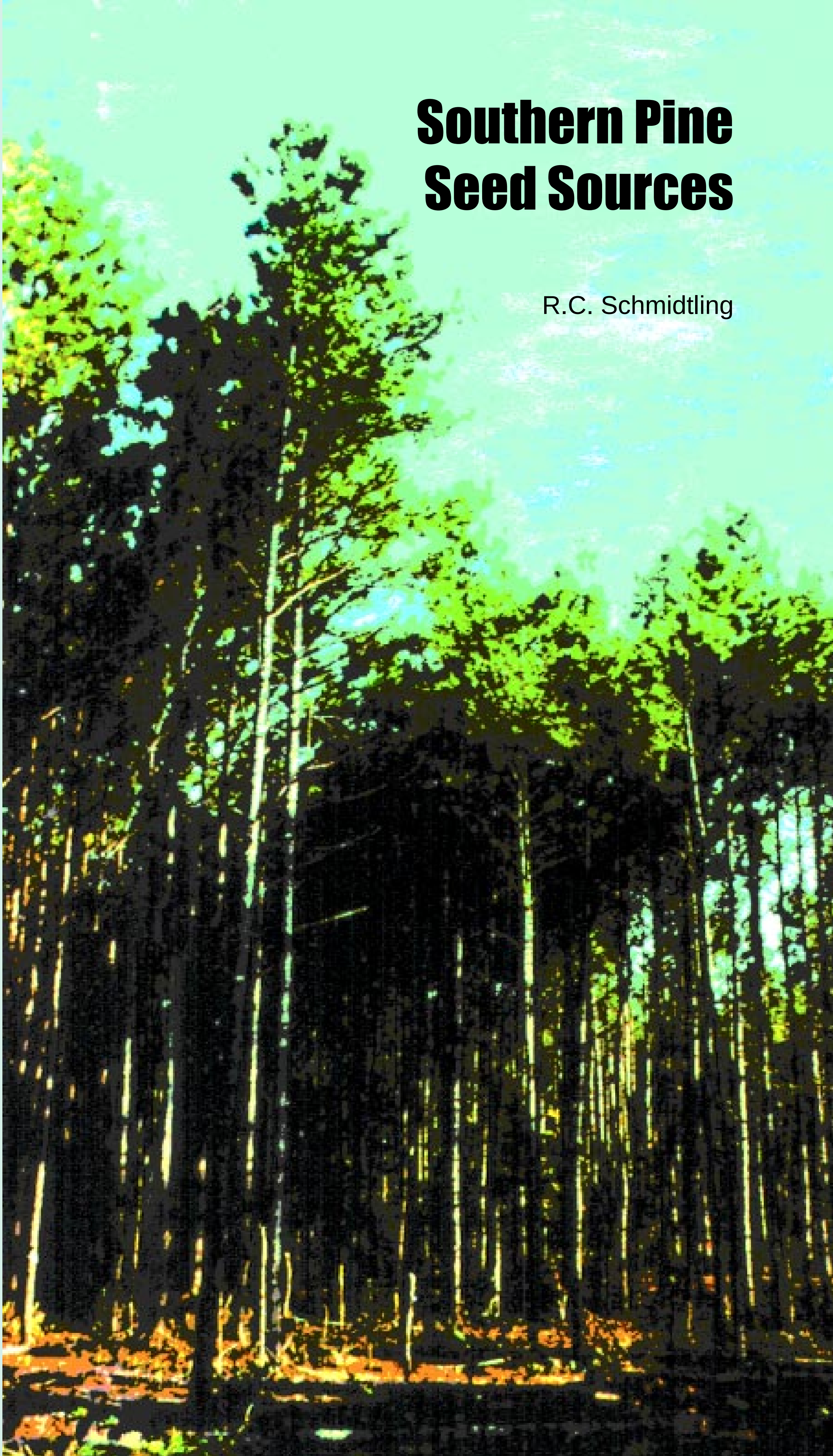
Forest Service

**Southern
Research Station**

General Technical
Report SRS-44

Southern Pine Seed Sources

R.C. Schmidtling



The Author

R.C. Schmidtling, Research Geneticist, U.S. Department of Agriculture, Forest Service, Southern Research Station, Saucier, MS.

Front cover: A provenance test in southern Arkansas at age 25 years (Wells and Lambeth 1983). The trees on the right are from the nearby, southeast Oklahoma seed source; those on the left are from the Coastal Plain of South Carolina.

Back cover: The Southeastern portion of the U.S. Department of Agriculture (1990) Plant Hardiness Zone Map to be used to more accurately determine minimum temperatures for seed transfer.

August 2001

Southern Research Station
P.O. Box 2680
Asheville, NC 28802

Southern Pine Seed Sources

R.C. Schmidtling

Foreword

The purpose of this handbook is to guide landowners and consulting foresters in selecting appropriate seed sources for planting southern pines. It replaces the booklet "*A Guide to Southern Pine Seed Sources*" written by Clark Lantz and John Kraus (1987). Both are now retired from USDA Forest Service. Important changes based on more recent research have been made. The biggest changes are in the seed movement guidelines themselves. The new guidelines avoid the term "zones" because it implies distinct boundaries. North-south variation in growth and survival traits is considered continuous (clinal), and east-west movement to areas of similar climate is generally permissible, with some major exceptions for loblolly pine.

The Geographic Variation and Seed Movement Subcommittee of the Southern Forest Tree Improvement Committee guided the writing of this handbook. The subcommittee is a cooperative of Federal, State, university, and industrial foresters organized in 1950 to foster information exchange in genetics and breeding of forest trees. Members of the subcommittee who guided the development of this handbook, supplied information, and reviewed drafts are:

Ron Schmidtling, Chairman, USDA Forest Service, Southern Research Station, Southern Institute of Forest Genetics, Saucier, MS;

Steve McKeand, North Carolina State University Tree Improvement Cooperative, Raleigh, NC;

Tim LaFarge and George Hernandez, USDA Forest Service, Southern Region, Atlanta, GA;

Clem Lambeth and Mike Waxler, Weyerhaeuser Company, Hot Springs, AR;

Bill Lowe and Tom Byram, Western Gulf Forest Tree Improvement Program, Texas Forest Service, College Station, TX;

Siroos Jahromi and Richard Bryant, International Paper Company, Southlands Experimental Forest, Bainbridge, GA;

George Rheinhardt, Arkansas Forestry Commission, Little Rock, AR; and

Tim White (ex officio), University of Florida Cooperative, Forest Genetics Research Program, Gainesville, FL.

Sponsored Publication Number 49 of the Southern Forest Tree Improvement Committee.

Table of Contents

Southern Pine Seed Sources

R.C. Schmidtling

Abstract

The selection of an appropriate seed source is critical for successful southern pine plantations. Guidelines for selection of seed sources are presented for loblolly (*Pinus taeda* L.), slash (*P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), Virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand [*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.] pines. Seed movement guidelines in this handbook are based on climatic similarities between the seed source origin and the planting site. Because yearly average minimum temperature is the most important climatic variable related to growth and survival, it has been used to define the rules of seed movement. This variable, which defines plant hardiness zones, has been used for many years by horticulturists to guide the transfer of plant materials. East-west movement to areas of similar climate is permissible, with the exception of loblolly pine.

Keywords: Fusiform rust, geographic variation, loblolly pine, longleaf pine, provenance tests, sand pine, seed movement, seed sources, shortleaf pine, slash pine, Virginia pine.

Introduction

Establishing a forest plantation is hard work and expensive. The site must be properly prepared for planting. Seedlings must be bought, cared for before they are planted, and carefully placed in the ground, one at a time. Finally, as it develops, the plantation must be protected from insects, disease, fire, and competing vegetation. The cost of the seedlings is only a small part of the total expense. Yet a poor choice of planting stock frequently reduces the productivity of plantations and sometimes causes outright failures.

Choosing the proper species for the planting site is only the first of several choices. Among southern pines, the most commonly planted species in the Southern United States, seed source is also important. If you are in coastal South Carolina, should you plant stock from local, Virginia, or Louisiana seeds? This handbook can help you to make these critical choices for southern pines and hybrids. It also gives specific guidelines for the six most common pine species: loblolly *(Pinus taeda* L.), slash *(P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), Virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand [*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.].

Research shows that seed source can govern survival and subsequent growth of southern pines. Perhaps the most important early results came from Philip C. Wakeley's 1927 Bogalusa planting. He showed that through age 22, loblolly pines grown from local seeds (Livingston Parish, LA) produced about twice the wood volume as those grown from Arkansas, Georgia, and Texas seeds. These differences persisted through age 35 (Wakeley and Bercaw 1965). Following Wakeley's pioneering study, much work was done to learn about geographic variation in southern pines, including the Southwide Southern Pine Seed Source Study (SSPSSS) initiated in 1951 by the Southern Forest Tree Improvement Committee to discover the patterns of geographic variation in the southern pines (Dorman 1976; Schmidtling 1995; Schmidtling and White 1990; Wakeley 1961; Wells 1969, 1983; Wells and Wakeley 1966).

These studies showed that southern pine species react to differences in environmental conditions by developing different traits in different places through the process of natural selection. Therefore, some races of southern pines may grow faster in certain areas, whereas others may be more resistant to disease or more tolerant of cold. The recognition of these patterns of geographic variation was the first step in the genetic improvement of the southern pines. All successful southern pine breeding programs take into account geographic variation before utilizing within-population genetic variation. Important gains in growth and disease resistance can result from simply selecting the best seed source for a given planting location. With many species, additional gains can result from using the improved stock developed by tree breeding programs.

Planting seedlings from a seed source that is poorly adapted to the site and climatic conditions can cause devastating losses. Even if the trees survive, their reduced growth will mean lower yields throughout the timber rotation. Postponing planting for a year would be more profitable than risking the results of planting ill-adapted seedlings.

Select the Best Species for Your Site

Choosing the species for site regeneration is often your most critical decision. If healthy, fast-growing trees are abundant on the site, the safest choice is usually to replant the same species. However, faced with no trees or with only a few trees that are slow growing, poorly formed, and obviously not well suited to the site, you will be wise to consider another species or possibly another seed source of the same species. Avoid the common mistake of planting a single species over a large area without considering the variation in site quality within the area (Balmer and Williston 1974). The best indicator for success on a particular site is a healthy, vigorous plantation growing on a similar site. Good survival and growth through at least half the rotation usually is a reliable predictor of success.

Other important considerations are the primary product desired, secondary uses such as hunting or grazing, and local fire and disease hazards.

The following checklist may be helpful in choosing a species:

Are pines already growing in the area?

What species are they?

Are these trees healthy and fast growing?

What products do you desire?

Will the land be hunted or grazed?

Is the area prone to local disease hazards?

Is the land vulnerable to wildfire or arson?

What is the likelihood of flooding, extreme drought, or ice storms?

Careful consideration of these questions should help you select the best species to plant, as should the classic textbooks on species selection by Balmer and Williston (1974) and Dorman (1976).

What Causes Geographic Variation in Southern Pines?

In general, the natural distribution of southern pine species is limited to the north by low temperature and to the west by low rainfall. Within these limits, native races have developed that are adapted to the local climate. This adaptation to local climatic variation is generally referred to as geographic variation.

Geographic variation of the major southern pine species has been well studied. Seed collected from different geographic areas vary greatly in their potential for growth and survival, depending upon where they are planted. Although a conservative approach would be to rely on locally obtained seed, native sources are not always the best, especially for economically important traits. For instance, seed source studies of forest tree species often show that seed sources from warmer climates tend to grow faster than local sources, if the difference in climate is not great. In loblolly pine, this is at least partly due to the warm-climate sources growing longer in the fall than the sources from colder climates (Jayawickrama and others 1998).

Climatic modeling of data from many southern pine seed source studies has shown that the most important factor influencing growth and survival within natural ranges is average yearly minimum temperature at the seed source (Schmidtling 1997). Horticulturists have used this climatic variable, not coincidentally, to determine plant hardiness zones (U.S. Department of Agriculture 1990). These zones help predict the probable success of planting ornamentals. They are also the basis of the seed transfer guidelines in this publication.

For the three southern pine species that occur naturally on both sides of the Mississippi River, only one—loblolly pine—has important differences between eastern and western sources. This difference between loblolly pine and other species is probably rooted in the Pleistocene geologic era. During the last ice age, which lasted 100,000 years and ended 15,000 years ago, the South was covered by a boreal forest and the southern pines grew south of their present location. Patterns of genetic variation in allozymes indicate that longleaf resided in one refugium in south Texas and or north Mexico and migrated northward and eastward when the ice retreated (Schmidtling and Hipkins 1998). Loblolly pine probably originated from two isolated refugia, one in southeast Texas and or northeast Mexico, and the other in south Florida and or Caribbean (Schmidtling and others 1999). The 100,000-year isolation of the two populations in differing environments resulted in the differences we see today.

Soil has little effect on seed source variation in southern pines. For instance, longleaf stands from deep sand sites do not differ in adaptive traits from nearby stands on heavier soils (Schmidtling and White 1990). Similarly, wet-site ecotypes in loblolly pine do not seem to exist, although some individual genotypes are well adapted to wet sites.[1] This lack of ecotypic differentiation, which is not surprising in light of studies showing extensive long-distance pollen flow in southern pines (Friedman and Adams 1985), simplifies seed transfer.

Fusiform Rust

Fusiform rust [*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. f*usiforme*] is a disease that inflicts heavy damage on loblolly and slash pines. It has also been known to infect longleaf pine, but so rarely that it is not considered a problem. In areas of high rust hazard, landowners and

[1] Personal communication. 1999. C.G. Williams, Associate Professor, Genetics Department, Texas A&M University, College Station, TX 77843.

foresters often had to choose between unimproved seedlings with some natural resistance to fusiform rust and susceptible but faster growing seed orchard seedlings.

Fortunately, seed orchards are now producing enough seeds of fast-growing, rust-resistant sources to satisfy most planting requirements throughout the South. In high-hazard areas where local shortages of resistant, improved seedlings exist, it may still be necessary to choose between seedlings from rust-susceptible orchards that have been genetically improved for growth rate and form or to use seedlings from unimproved but resistant woods-run seeds, e.g., Livingston Parish or east Texas loblolly. Ideally, the decision should be made by integrating several factors: degree of improvement in traits expected from orchard seeds (other than resistance), degree of improvement expected in resistance from woods-run seeds, and the hazard rating of the area to be planted. Research aimed at quantifying this decision is now underway. Growth-and yield-models incorporating fusiform rust can be used in this effort (Nance and others 1983) as well as economic analyses (Bridgwater and Smith 1997).

Capitalizing on Genetic Improvement

Tree improvement programs have been initiated all across the South and have been successful in securing substantial genetic gains in growth and form. In many programs, second- and third-generation breeding cycles are in progress. Seed orchards established to supply genetically improved seeds are now producing enough seeds to satisfy most planting needs in the South.

A tree is selected for seed orchard use on the basis of its performance in competition with its neighbors on specific sites for a specific period of time. Although the majority of these sites are on the Coastal Plain, some may not be typical sites. Planting a sufficiently large number of trees in the orchard ensures some degree of variation in the selection process. The resulting natural cross-pollination within the orchard will create many new genotypes that should be adapted to a wide range of planting sites.

Progeny tests estimate the breeding value of the selected trees. If the progeny of certain selections do not perform well, the grafts of those selections will be rogued (removed) from the orchard. If the test sites are a good representation of regeneration sites, the progeny tests will save the expense of planting the poorly adapted families.

If the progeny of a select tree performs well on one site but poorly on another site compared with other seedlings, the cause is often a genotype X environment interaction. These genotype X environment interactions have usually been small in most southern pine progeny tests, suggesting that seed orchards are producing trees with a wide range of adaptability (Li and McKeand 1989, McKeand and others 1997).

Risks and Benefits of Moving Seeds and Seedlings

Moving seeds or seedlings to an area where they have not been tested involves some degree of risk, whether the source is orchard seeds or woods-run seeds. Drought, ice, or extreme cold can devastate trees from seed lots that are not adapted to that specific hazard. The decision to plant fast-growing seedlings that may not be adapted to local hazards should only be made after comparing the potential gain with the risk of loss.

Some have elected to accept some risk in the belief that the additional wood produced by fast-growing sources will outweigh the possible loss (fig. 1). For example, loblolly seedlings from North Carolina coastal seed orchards have prospered for many years in Oklahoma and Arkansas (Lambeth and others 1984). In addition, a 25-year study in a south Arkansas plantation showed that a South Carolina source outperformed an Oklahoma source by 10 to 20 feet (ft) (Wells and Lambeth 1983). Gains have been reported with other Atlantic coastal loblolly sources (Lantz and Hofmann 1969, Wells and Switzer 1971). Likewise, Livingston Parish loblolly seedlings planted over hundreds of thousands of acres in the southern Coastal Plain have exhibited both substantial rust resistance and good growth rates (Wells 1985).

Specific seed orchard families of nonlocal and distant sources that grow faster in their new environment than many local families may also have an acceptable level of adaptation. If adaptation risk is significant, avoid the use of the nonlocal family until progeny tests have shown at least 15 years of excellence in survival and growth.

A related, more philosophical, issue in seed transfer risk is how nonlocal genotypes will affect the native gene pool. Even if these trees are harvested completely in a pulpwood rotation, their pollen will affect the seed produced in surrounding native stands. Certainly, the resulting increase in genetic diversity would add value. Recent studies suggest new characteristics are being introduced into native stands in Arkansas, perhaps from the Atlantic coastal seed sources being planted there (Schmidtling and others 1999). Arkansas seed sources are naturally resistant to fusiform rust; Atlantic coastal sources are not. Could the transfer of Atlantic coastal sources to Arkansas result in increased rust in

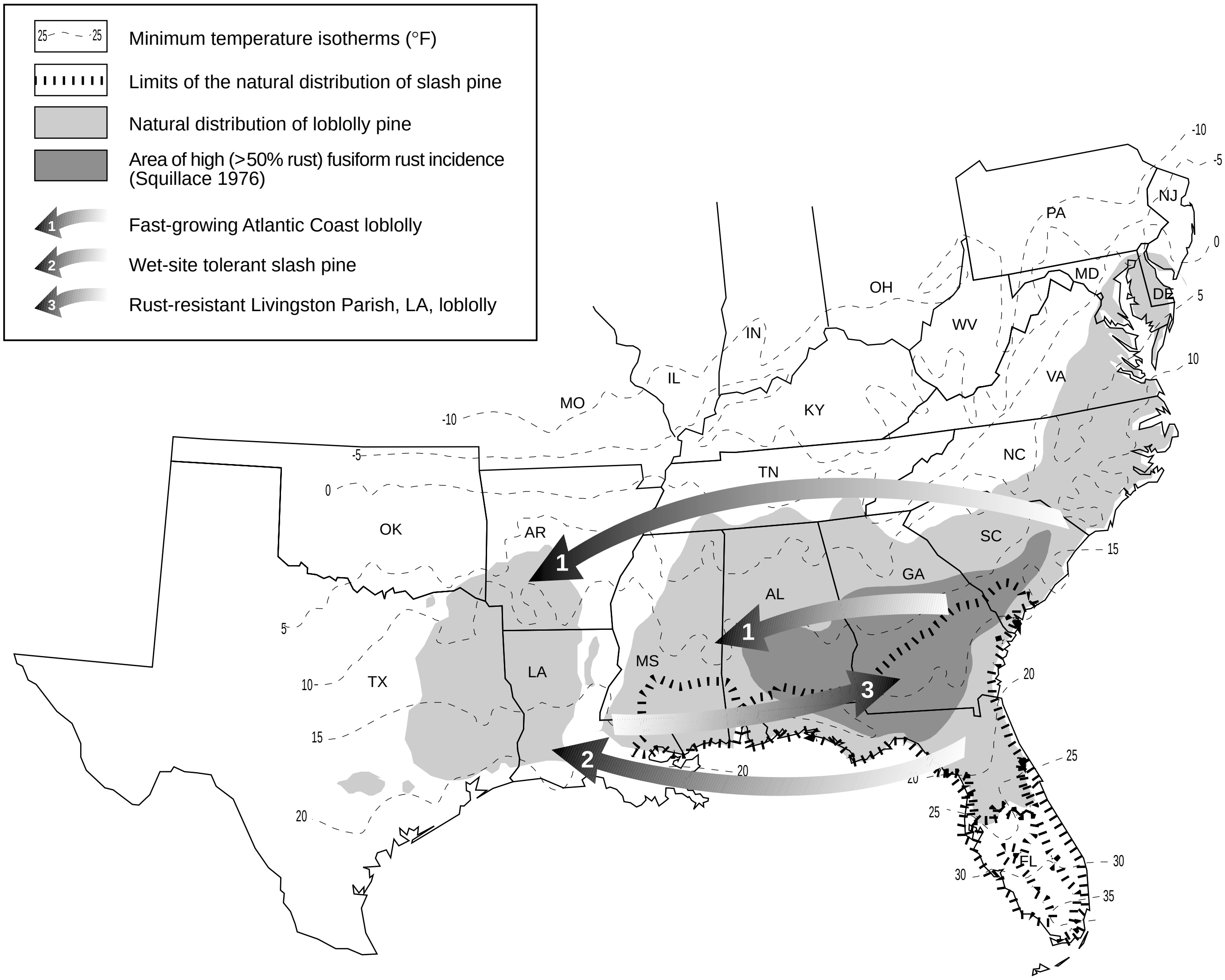


Figure 1—Major seed movement of southern pines since the Great Depression. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

naturally regenerated native stands? Certainly the susceptibility of the native stands could be increased, but one of the reasons there is little fusiform rust in Arkansas is its dry climate. The high humidity required at the time of infection (Snow and Froelich 1968) is rare in Arkansas and is likely to become rarer because most global change scenarios predict that the climate in Arkansas will be drier in the future (Prentice and others 1992). Countering the rust threat would be the positive effect of increasing genetic variability in the native stands. Genes conferring poor adaptability would eventually be eliminated by natural selection.

Planting nonlocal seeds or seedlings can have long-term as well as immediate consequences. Even well-established plantation programs encounter new hazards, for example, Dothistroma needle blight (*Mycosphaerella pini*) in Monterey pine (*P. radiata* D. Don.) plantings in Brazil, South Africa, and New Zealand (Zobel and Talbert 1984). In addition, new pathogens or disastrous weather patterns can radically change survivability and productivity. Witness the growing concern over pitch canker in the South and recently on the west coast (Storer and others 1994) and the frequent hurricane damage on the gulf coast.

Getting Help

Because they serve a diversity of interests, State forestry organizations take a more conservative approach to seed acquisition than forest industry. Few nonindustrial private forest landowners have access to advice on the specific seed sources that would be suitable for their own land. Because far too few service foresters are in a position to work with individual landowners, most State nursery programs provide seedlings from local or nearby sources. In the past, however, several States have grown loblolly seedlings from Livingston Parish seed because of their good fusiform rust resistance and fast growth.

With the exception of industry seed orchards that include clones from nonlocal seed sources, the genetic quality of clones in State seed orchards is equal to that in industry seed orchards. All Southern State forestry agencies are members of large cooperative tree improvement programs and, thus, share genetic resources with industry cooperators. While slight differences may exist in the choice of clones for inclusion into seed orchards, the clones are selected from a common genetic base.

If nonlocal genotypes prove to be well adapted over a range of sites and are superior to local genotypes based on long-term trials, then both State agencies and industry will usually use them. To illustrate, for sites in Alabama and the lower gulf coast (Sierra-Lucero 1999), tree improvement foresters now recognize that loblolly seedlings from the Atlantic Coastal Plain provide a high-return, low-risk alternative to seedlings from the lower gulf coast. In the lower gulf Coastal Plain, future orchards will include a mix of the best clones whether they come from the Atlantic coast or from the lower gulf.

Seed and Seedling Certification

Certification programs identify and control the quality of forest tree seeds and seedlings (Barber 1975). Most States in which southern pines are major species have laws to certify forest tree seeds. Under these laws, certification is available for seeds originating in natural stands, seed production areas, or seed orchards. Some seed orchard certifications include the expected amount of improvement in growth and disease resistance.

Certified seeds must also meet established standards of purity, percentage of filled seed, and germination. These requirements protect the buyer and encourage the seller to offer only seeds of known origin and quality.

Most States have established three levels of seed certification:

1. Certified tree seeds (blue tag). These seeds are produced from trees of proven genetic superiority using methods that assure genetic identity. They are usually from seed orchards in which the selected trees have been progeny tested and the poorest trees removed on the basis of the test results.

2. Selected tree seeds (green tag). These tree seeds are from untested but rigidly selected trees or stands that have potential, but not proof, of genetic superiority.

3. Source-identified seeds (yellow tag). These seeds may be from natural stands, plantations of known provenance, or seed production areas of known geographic origin. Only the geographic location is certified.

The international certification of forest reproductive material is governed by the Organization for Economic Cooperation and Development (Rudolf 1974).

Gene Conservation

Much has been written in recent years about conservation of gene pools in breeding programs. With the exception of a few isolated populations, none of the southern pines are threatened or endangered. However, longleaf pine has been placed on a list of vulnerable species (Farjon and Page 1999), because the occurrence of the species has been greatly diminished since the turn of the century.

In general, southern pines are highly variable and widely adapted. Forests in the South contain a rich gene pool that is not likely to be depleted by tree breeding. Although tree improvement programs concentrate on genes and gene complexes that are only a sample of the entire gene pool, they also conserve genetic resources in clone banks, seed orchards, and genetic tests. They create new genetic variability by breeding trees from widely separated areas and using their offspring for reforestation. Much of the natural gene pool of southern forest species is also preserved in the preponderance of stands that are regenerated by natural methods.

A successful program for encouraging the preservation of existing southern gene pools and assuring a wide genetic diversity for the future would

1. promote the use of genetically sound practices for all forest stands regardless of how they are regenerated;

2. discourage practices, such as high grading and diameter-limit logging that promote the regeneration of genetically inferior seedlings;

3. encourage landowners to leave enough of the highest quality seed trees during natural regeneration to maintain gene pool diversity;

4. keep the public informed about the risks of planting poorly adapted seeds or seedlings; and

5. monitor status of minor, threatened, and endangered forest species; establish natural areas for the preservation of these species if necessary; and plant these species whenever suitable sites are available.

General Seed Movement Guidelines

Southern pine species vary widely in natural range, economic value, and degree of genetic improvement. This section describes the natural range, geographic variation, genetic improvement, and recommended planting areas and seed sources for the southern pine species that are commonly used in forest plantations: loblolly, slash, longleaf, Virginia, shortleaf, and sand.

Local conditions such as soils, slope, and competing vegetation must be carefully considered in any site analysis. The planting recommendations in this section are based on the majority of sites within the area, but it is important to be aware of local exceptions.

The seed movement recommendations in this handbook are based on the degree of climatic similarity between the seed source origin and the planting site. Because climatic modeling using provenance test data from a number of southern pine species has shown that the most important climatic variable related to growth and survival is the yearly average minimum temperature, the minimum temperature isotherms shown on the map on the back cover of this report have been used to define the rules of seed movement. The isotherms define plant hardiness zones that, for many years, have guided horticulturists in transferring plant materials (U.S. Department of Agriculture 1990). Although they delineate approximately 5 °F intervals, they are purposely shown in dotted lines to emphasize that minimum temperatures vary continuously from south to north and from coastal to inland areas (see back cover).

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

Loblolly Pine

Loblolly pine is the most widely planted southern pine, producing over half of the total softwood volume (Dorman 1976) and accounting for about 80 percent of all southern pine seedling production in the United States (Boyer and South 1984). It is also commonly planted in China, South America, Australia, and southern Africa.

Within its natural range, which extends from southern New Jersey to southeast Texas (fig. 2), loblolly pine occupies a great diversity of sites. It grows faster than any of the other southern pines on well-drained, productive sites. It is not the best choice, however, on poor sites such as very dry sands or on wet flatwoods (Shiver and others 2000).

Geographic Variation

Geographic variation in loblolly pine is more complex than in the other southern pines because of important differences between eastern and western seed sources. Geographic variation has been well documented for growth rate, disease resistance, cold tolerance, drought resistance (Dorman 1976), and stem form (Schmidtling and Clark 1989). Loblolly pines from west of the Mississippi River are usually slower growing than east coast varieties, but they are more resistant to fusiform rust and drought (Wells 1985) and more tolerant of crowding (Schmidtling 1988, Schmidtling and Froelich 1993).

The slower growth of the western sources is undoubtedly part of an evolved drought-avoidance tactic. The slower relative growth of shortleaf and longleaf pines may also be a manifestation of this tactic, as those two species often grow on droughty sites (deep sand in the case of longleaf, shallow and rocky soils for shortleaf). The natural ranges of shortleaf and longleaf pines, however, do not extend as far west into the drought-prone regions of Texas as loblolly pine, explaining why loblolly has a higher drought tolerance. Dendrochronological analyses of loblolly provenance tests have shown that the western seed sources cease growth immediately at the onset of a drought, whereas the eastern varieties tend to keep growing (Grissom and Schmidtling 1997).

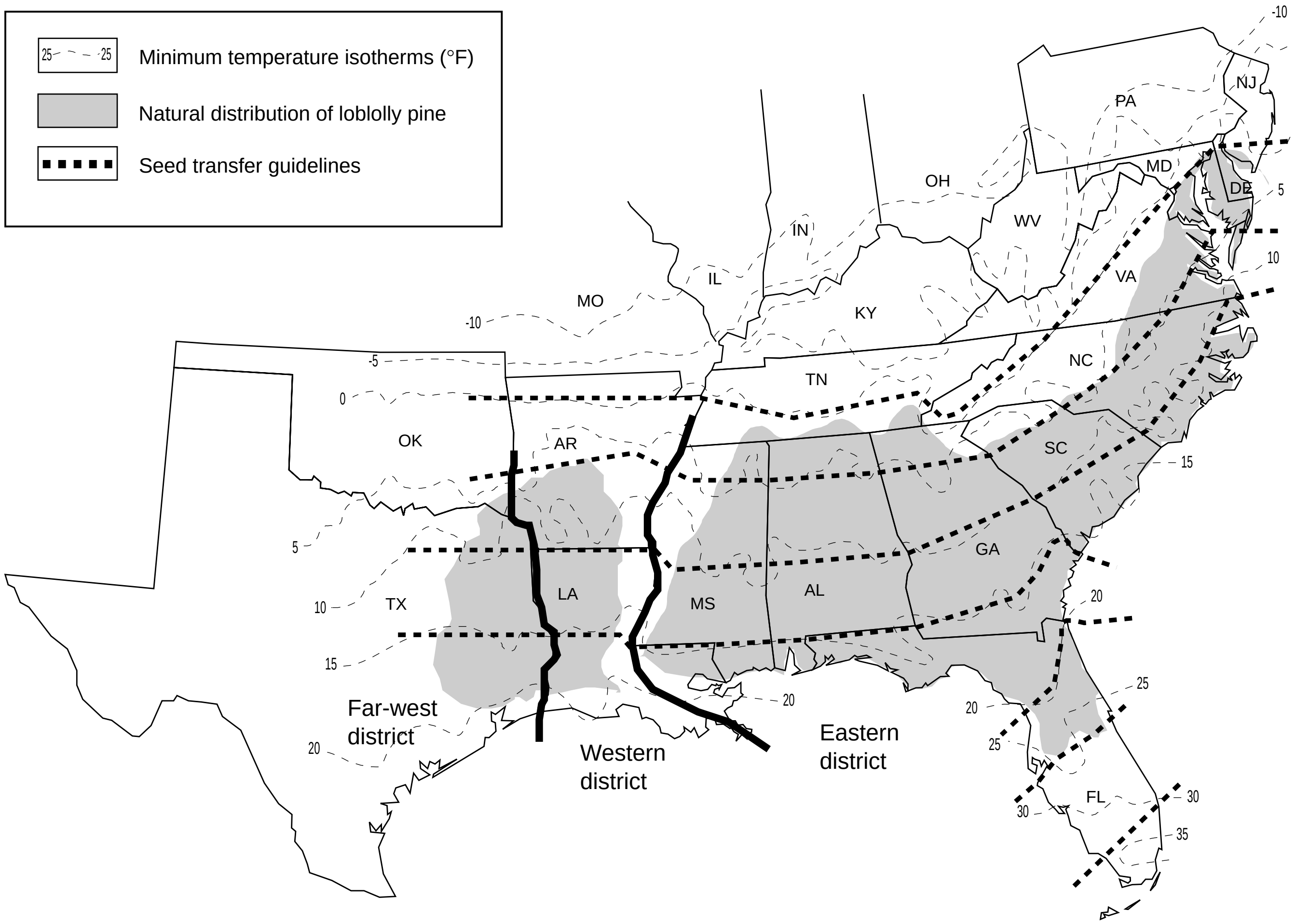


Figure 2—Loblolly pine distribution with seed transfer guidelines. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

Loblolly pines from west of the Mississippi River and from the northeastern extremity of their range (Maryland and Virginia) are the most resistant to fusiform rust. Seed sources from just east of the Mississippi River, in southeast Louisiana and southwest Mississippi, centered around Livingston Parish, LA (Wells and others 1991), are moderately resistant. All other loblolly populations are generally susceptible, with the exception of resistant families (McKeand and others 1999). Of the rust-resistant seed sources, only Livingston Parish produces loblolly pines that grow as fast as the populations from the Atlantic and gulf coasts. Livingston Parish seedlings are prone to cold and ice damage, however, and tend to exhibit poor form if planted north of the 10 °F minimum temperature isotherm (Wells 1985, Wells and Lambeth 1983).

The loblolly pine planting areas have been divided into three districts to reflect the complexity of that species' geographic variation (fig. 2). The eastern district is east of the Mississippi River, and the Texas and or Louisiana-Arkansas border separates the western and far-western districts somewhat arbitrarily. Because it is more likely to experience drought, the far-western district produces seedlings that are more drought tolerant (Long 1980).

Genetic Improvement

Because of loblolly pine's commercial importance, its breeding and planting programs are the largest in the world. Genetic improvement of loblolly pine started in the mid-1950s with the establishment of seed production areas and seed orchards. Seed production areas were high-quality natural stands thinned to the best 10 to 20 trees per acre and managed for cone production. Although the genetic gain calculated from seed production areas was small (Easley 1963), they were convenient sources of seeds from above-average trees in known geographic areas.

Seed orchards of loblolly pine were established primarily by grafting. The parent trees were selected for fast growth, good form, high-quality wood, and no insect or disease symptoms. Progeny tests indicate first-generation gains of from 10 to 20 percent in volume and up to 32 percent in value (Talbert and others 1985) as well as significant gains in the second and third generations (Li and others 1999). Although fusiform rust losses can still be high, breeding programs and the use of western seed sources have decreased the incidence of fusiform rust in the South (Pye and others 1997) and seeds from first- and second-generation seed orchards are currently available on the open market.

Information from progeny tests is especially important in assessing the suitability of improved seed. For instance, orchard selections from the lower gulf area of the North Carolina State University Cooperative have performed below expectations (Sierra-Lucero 1999). These selections are from southern Alabama and adjacent Mississippi between 5 and 15 °F in minimum temperature (fig. 2), and should perform about the same as selections from the Coastal Plain of North and South Carolina. The reason for their disappointing performance is not known but it may be related to clearcutting practices that started around the turn of the century or gene flow from slower growing western populations (Schmidtling and others 1999). Selections from nearby Livingston Parish, however, do perform well compared to Atlantic coastal sources (Schmidtling and Nelson 1996, Wells and Wakeley 1966).

Recommended Sources

Unless you intend to practice intensive management, your safest choice would be to use seed sources from within your district. Transferring seed sources from the eastern to the western district would introduce danger of losses due to drought and fusiform rust damage. By the same token, transferring seed from the west to the east may be warranted for droughty sites or areas with high fusiform rust incidence (see General Guidelines). Keep in mind, however, that the western sources generally grow slower.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

Within a district, the same General Guidelines apply for transferring improved seed and unimproved seed although seedlings from progeny-tested seed orchards are always preferred. If advanced generation selections have been derived from controlled crosses of superior trees from areas of different minimum temperature, use the average of these two temperatures to assess the suitability of the seed sources.

High-rust-hazard sites—The first choice for high-rust-hazard sites would be seedlings from progeny-tested and rogued seed orchards, which include exposure to a high-rust-hazard site. If improved seed are not available, sites with minimum temperatures above 10 °F would be hospitable for seeds from Livingston Parish or east Texas. On Coastal Plain sites, longleaf pine would be an excellent alternative.

Sandhills sites—Sandhills sites are a real challenge for reforestation. Often the key to success is the correct analysis of the site followed by the correct choice of species and seed source. Species alternates include longleaf pine (Dennington and Farrar 1983), Choctawhatchee sand pine (Outcalt and Brendemuehl 1985), and drought-hardy loblolly pine from Texas (Jett and Guiness 1992).

Carolina sandhills sites have traditionally been planted with either longleaf pine or slash pine even though slash pine seedlings often begin well on deep sand sites only to stagnate later. Choctawhatchee sand pine and drought-hardy loblolly seedlings from Texas survived and grew better than other loblolly sources and other species on South Carolina sandhills sites after 17 years (Jett and Guiness 1992). The drought-hardy Texas loblolly source grew well and had very little fusiform rust. Longleaf pine was the original species on these sites and should be the preferred species for the long term, if products beyond pulpwood are desired. These results, however, provide some new alternatives for regenerating sandhills sites.

Western sites—Several long-term tests have shown that the eastern district produces faster growing loblolly pine than the western and far-western districts (Wells 1983, Wells and Lambeth 1983). Trees from some eastern sources have grown about 8 ft taller than western trees in 25 years (Wells and Lambeth 1983) (see front cover). Since the results of these studies became well known, forest products manufacturers have transferred substantial amounts of Atlantic coastal seed sources to sites ranging from southern Arkansas and southeastern Oklahoma to the Ouachita Mountains (Lambeth and others 1984).

Seed source movement entails a certain amount of risk but just how much is not certain. In the Wells and Lambeth (1983) long-term tests, certain eastern sources suffered heavy mortality at about age 20 compared to local sources, which survived well. Survival was poorest for coastal Florida sources that came from the mildest climates, but other randomly distributed eastern sources were also hard hit. The researchers suggested that the damage was caused by a combination of very high stand densities and bark beetle attack. Their results show that Atlantic coast sources of loblolly can successfully grow in Arkansas and Oklahoma if they are restricted to soils with good water retention and if stands are kept thrifty by judicious thinning, competition control, and fertilization. However, the level of management required is generally available only in large industrial holdings.

Planting loblolly from the Atlantic Coastal Plain is probably not a viable strategy for nonindustrial landowners west of the Mississippi River. Doing so requires the careful assessment of the geographic location and site quality, with emphasis on moisture-holding capacity. It also requires the resources to carry out thinnings for as long as necessary and the ability to absorb losses in severe drought years.

Northern sites—Loblolly pine has grown successfully north of its natural range if planted according to the General Guidelines. In western Kentucky and western Tennessee, Barbour (1980) showed that loblolly seedlings from northern Mississippi, northern Alabama, and northwestern Georgia perform much better than other sources, and that sources from eastern Virginia, northern North Carolina, and central Arkansas also perform well.

In a provenance test in southern Illinois, a coastal South Carolina source grew well and had satisfactory survival after 5 years (Wisehuegel 1955) and 10 years (Zarger 1961). By 35 years, however, only 3 percent survived, compared to between 33 and 42 percent for the seed sources that originated in Tennessee, northern Alabama, and northern Georgia (Wells and Rink 1984). The southern Illinois site was 7 or 8 °F cooler than the Tennessee seed source. Height differences were not significant.

Minckler (1950) established a similar experiment in two colder southern Illinois locations. After 27 years, survival of sources from Maryland, Virginia, and Arkansas was about 60 percent compared to about 40 percent for Carolina and Mississippi sources (Gilmore and Funk 1976). After 37 years, survival averaged only 14 percent (Rink and Wells 1988). Height differences were not significant. The Maryland source in this experiment was from the most northern extreme of the loblolly range, 11 to 15 °F warmer than the two Illinois locations. The other sources were from even warmer locations.

Gilmore (1980) recommended that loblolly pine not be planted north of the 180-day contour of frost-free days in Illinois. As evidence, he cited a 30-year-old planting of a Maryland source just 60 miles north of this contour that suffered almost complete mortality in the record freeze of 1977. The fact that mortality was freeze-related reinforces guidelines that stress average minimum temperatures rather than growing season length. In Illinois, the 180-day isoline is just north of the -10 °F minimum temperature isotherm, 15 °F colder than the Maryland seed source. For even the most cold-hardy sources this represents a more drastic change than recommended in the General Guidelines.

Slash Pine

Slash pine has the southernmost natural range of any of the southern pines, extending from coastal South Carolina west to eastern Louisiana and south to the Florida Keys (fig. 3). The two recognized varieties are the South Florida slash pine (*P. elliottii* var. *densa* Little & Dorman) and slash pine (typical) (*P. elliottii* Engelm. var. *elliottii*), which occur from central Florida northward. Commercially, the typical variety is more important, as many active breeding and planting programs worldwide are based on trees selected from this variety.

The most important characteristic that distinguishes South Florida slash pine variety from the typical variety is its early delayed height growth, often referred to as a grass stage, a term that is used to describe the early development of longleaf pine. Although delayed height growth is probably an adaptation to frequent fires in both species, their growth patterns are quite different. Squillace (1966) found that 1-year-old seedlings from north Florida averaged around 10 inches (in.) in height, while those from south Florida averaged around 4 in. in height. Longleaf pine seedlings, on the other hand, do not grow in height at all the first year, unless hybridization with other southern pines is involved (Lott and others 1996). The difference between longleaf pine and slash pine of all races is evident very early. Germinating longleaf seedlings have no hypocotyl, whereas all slash pine have distinctive hypocotyls. Figure 3 implies a distinct transition between the two varieties that is not really accurate. In central Florida where the two varieties overlap,

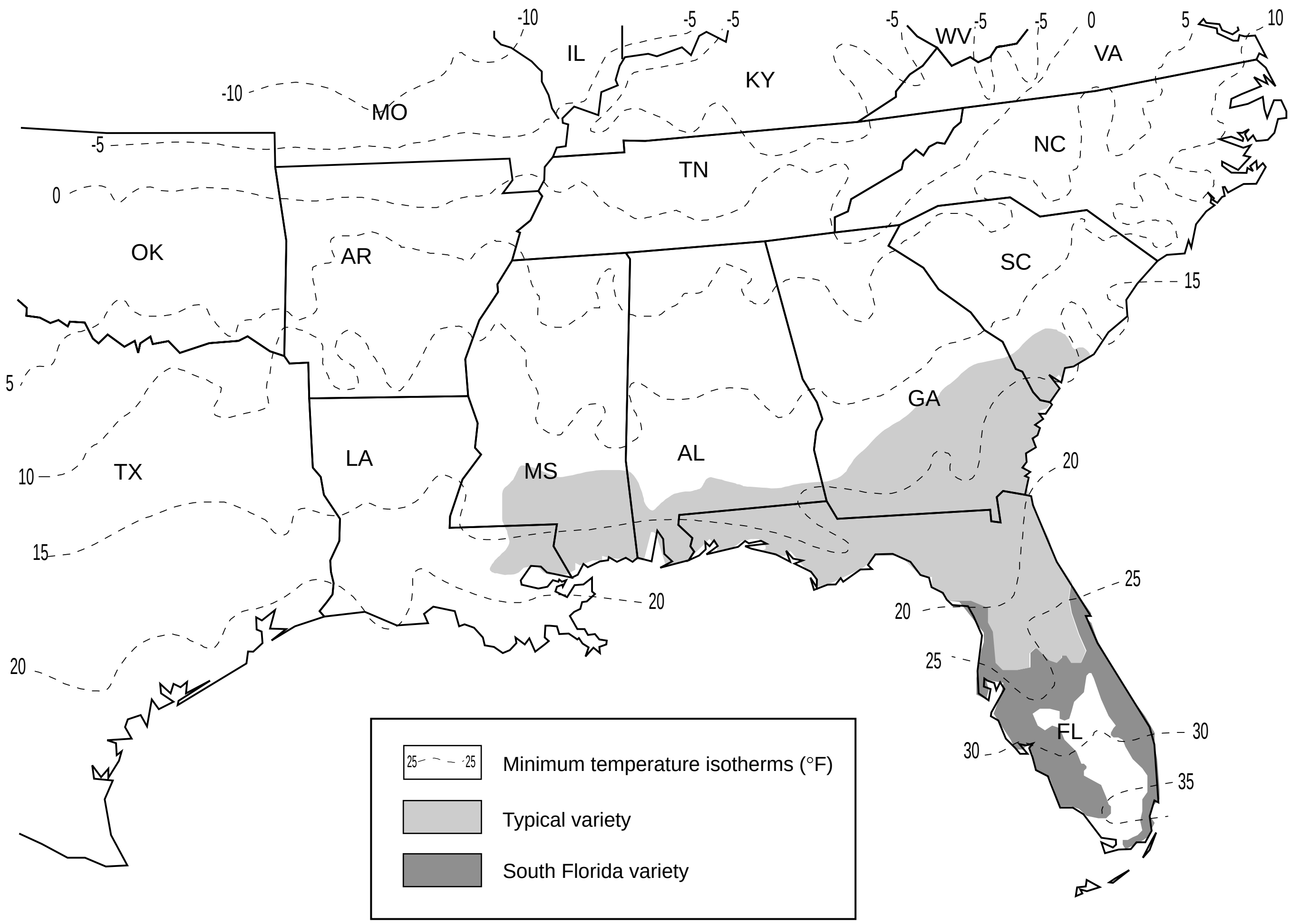


Figure 3—Natural range of slash pine showing minimum temperature isotherms. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

all traits vary in a clinal pattern (Fisher 1983, Nikles 1966, Squillace 1966) making it difficult to classify populations. The southernmost source of the SSPSSS slash pine phase was collected in the transition zone, but specifically identified as a representative of the typical variety. However, this source proved to have more characteristics in common with the South Florida variety (Wakeley 1961). Cold adaptation could certainly be a factor in varietal differences. The 25 °F minimum temperature isotherm (fig. 3) approximates the transition between the two varieties. This isotherm corresponds almost exactly to Squillace's (1966) 8-in. isoline for first-year seedling height growth, which is used to distinguish the two varieties.

Geographic Variation

Typical variety—The major differences among slash pine populations can be traced to the traits of the two varieties. Differences within the more commercial typical variety are small and difficult to detect. This is not surprising since most of it is in an area where minimum temperatures vary by little more than 5 °F. Goddard and others (1983) tested a number of seed sources for geographic differences in two plantings at the northern extreme of the slash pine range at age 10. The sources from a narrow area running from coastal South Carolina to southeastern Louisiana produced the tallest trees, but the differences were small enough to be obscured in tree improvement programs.

Predicting seed source success in warmer temperate climates requires examining plantings outside the United States. Barrett (1973) established extensive provenance tests of slash pine in Argentina. In his tests, the best performing sources were from an area just north of the transition to the South Florida variety. Rockwood and others (in press) and Schmidtling and others (1997) echoed these findings. Even though the range of minimum temperatures within the natural distribution of the typical variety is small, South American tests show that the minimum temperature has the same relationship with slash pine growth[2] as other southern pines (Schmidtling 1997) and that the same General Guidelines apply for transferring seed sources. However, these guidelines are really only relevant for seed sources from peninsular Florida or in plantings outside the United States, because of the small range in minimum temperatures elsewhere.

South Florida variety—The South Florida variety was named densa partly because of the higher specific gravity of its wood (Little and Dorman 1952). This must have been an environmental effect, however, since in common garden studies the wood of the typical variety has higher specific gravity (Saucier and Dorman 1969). The most important morphological traits distinguishing the two varieties are seedling traits such as a thicker stem and delayed height growth (Little and Dorman 1954).

When planted within the natural range of the typical variety, the South Florida variety has much lower productivity than the typical variety (Snyder and others 1967), showing that movement of seed sources from warmer climates does not always produce faster growth. Keep in mind, however, that moving the South Florida variety northward to where most of the provenance tests were located usually involved a minimum temperature change move of more than 10 °F.

Unfortunately, definitive studies involving the South Florida variety planted in south Florida are lacking. Squillace's (1966) planting near Ft. Meyers was destroyed by fire at an early age, as was the SSPSSS planting near Tampa (Wakeley 1961). The best trials involving the South Florida variety are in Africa, where Mullin and others (1978) showed that although the typical variety had superior growth and productivity in the highlands, the South Florida variety performed best in the lowlands. Anecdotal evidence also supports the view that the South Florida variety does as well as, or better than the typical variety in southern Florida.[3]

Fusiform rust—No clear geographic pattern of fusiform rust resistance has been identified within the natural range of the typical variety (Goddard and others 1983). Much less natural resistance exists in slash pine than in loblolly pine. Doudrick and others (1996) showed that the South Florida variety is even more susceptible to fusiform rust than the typical variety, a trait it shares with its closely related neighbor, Caribbean pine (P. caribaea Morelet).

Genetic Improvement

Typical variety—Slash pine seedlings from first- and second-generation seed orchards are available on the open market. In addition to improved growth rate, an important regeneration need is for improved resistance to fusiform rust. Kraus and LaFarge (1984) found that seedlings from first-generation slash pine seed orchards demonstrated substantial growth gains, but that fusiform rust infection rates were higher than expected even though selection for rust-free phenotypes was incorporated in all programs. All tree improvement programs test their selections for susceptibility to rust at the Resistance Screening Center (Anderson and Powers 1985), as well as in progeny tests. Rust-resistant slash pine seedlings are usually available for planting in high-hazard areas.

South Florida variety—A small tree improvement program for the South Florida variety was established, but the orchard location was not conducive to seed production (see footnote 3). A better location has been selected, but seed will not be available for some time.

Recommended Sources

Within the natural range of typical slash pine, guidelines for seed movement are not very critical. Most of the commercial range of typical slash pine above peninsular Florida hardly varies by more than 5 °F in minimum temperature. The same General Guidelines apply for transferring either seed orchard or unimproved seed. Because of the limited distribution of slash pine, the guidelines make little difference except at the edges of the distribution. The most important seed source recommendation is to avoid the South Florida variety for plantings north of Tampa, FL. The typical variety will perform much better. The South Florida variety should be considered for planting south of Tampa, however.

The most common commercial seed source of slash pine—encompassing southern Georgia and northern Florida—shares a few characteristics with the South Florida variety in that it is less drought hardy and less cold resistant than slash pine from the northern or western extremities of the range (Snyder and others 1967), located north of the 15 °F minimum temperature isotherm (fig. 3). These characteristics are of little importance if the plantings are to be made within the natural range of slash pine where drought and cold do

[2] Schmidtling, R.C. Geographic variation in the southern pines. Manuscript in preparation. U.S. Department of Agriculture, Forest Service, Southern Research Station, Saucier, MS.
[3] Personal communication. 2000. Jim Bryan, Manager, Forestry Division, Lykes Brothers Forestry, P.O. Box 102, Palmdale, FL 39574.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

not reach critical levels, but could become important if plantings are north or west of the natural range. When planting north or west of the species' natural range, choose seeds from South Carolina, Mississippi, or Louisiana or from areas north of the 15 °F minimum temperature isotherm. For well-drained sites, improved loblolly pine may grow and survive better and should be considered.

The Civilian Conservation Corps planted many thousands of acres of slash pine west of the Mississippi River during the Great Depression. More recently, the Western Gulf Forest Tree Improvement Program and USDA Forest Service, Southern Region Tree Improvement Program have used selections from these old plantings to develop a land race of improved slash pine suitable for planting west of the Mississippi River. Planting of slash pine west of the river is usually limited to wet (flatwoods) sites, however.[4]

Considering the lack of definitive provenance-test data from central Florida southward, sources from within 5 °F temperature are safest. Dorman (1976) had limited data to support his recommendation that seeds from the latitude of Alachua County (Gainesville) were best suited for sites south of Tampa. Certainly, plantings of the typical variety within the range of the South Florida variety have been successful, but the long-term value of this transfer is in question, especially given the high incidence of pitch canker (*Fusarium moniliforme* Sheld. var. *subglutinans* Wollenw. & Reink) observed when more northern seed sources were planted in southern Florida (Dorman 1976). Considering the strong ecosystem restoration movement in south Florida, the local variety would probably be a prudent choice. The South Florida variety appears to be more susceptible to fusiform rust (Doudrick and others 1996), but this disease is not a problem in south Florida plantations.

Fusiform rust—When regenerating sites with a high fusiform rust hazard, select seeds and seedlings according to the following descending order of preference:

1. seed orchards specifically established for increased rust resistance or rogued for increased rust resistance;

2. seed production areas established in highly infected stands where selection of disease-free trees was intensive; and

3. seed orchard cone collections restricted to the most rust-resistant clones in the orchard.

Pitch canker—Natural stands in areas with a high incidence of pitch canker have experienced strong selection pressure against susceptible trees. Collecting seed from the best trees in these local natural stands appears, therefore, to be the best procedure for establishing stock with some resistance to the disease (Goddard and others 1983). Another alternative is to collect seeds from the most resistant clones in established seed orchards (McRae and others 1985).

High gum yield—Tapping trees for gum naval stores is a practice that has largely disappeared in the United States. Currently, products formerly derived from gum are now obtained from tall oil, a by-product of the pulping process. If high gum yield were to become a primary management objective again, seedlings would be available from State seed orchards established for high gum yield. Most of these orchards were established with plant material from the USDA Forest Service naval stores breeding program at Olustee, FL. These seedlings should produce about 50 percent higher gum yields than nursery-run seedlings, with some improvement in growth rate and yield of tall oil (Squillace 1965).

Longleaf Pine

Longleaf pine is adapted primarily to Coastal Plain sites from southeastern Virginia to east Texas (fig. 4), where originally it was the predominant species. The area of longleaf pine in the South has declined from 12.2 to 3.8 million acres over the past 30 years (Kelly and Bechtold 1990). It is the preferred species on sandy sites and in many ways the most valued of the southern pines (Croker 1990), and there is now a concerted effort to restore longleaf to its historical and

[4] Personal communication. 2000. Tom Byram, Geneticist, Western Gulf Forest Tree Improvement Program, Texas Forest Service, College Station, TX 77843.

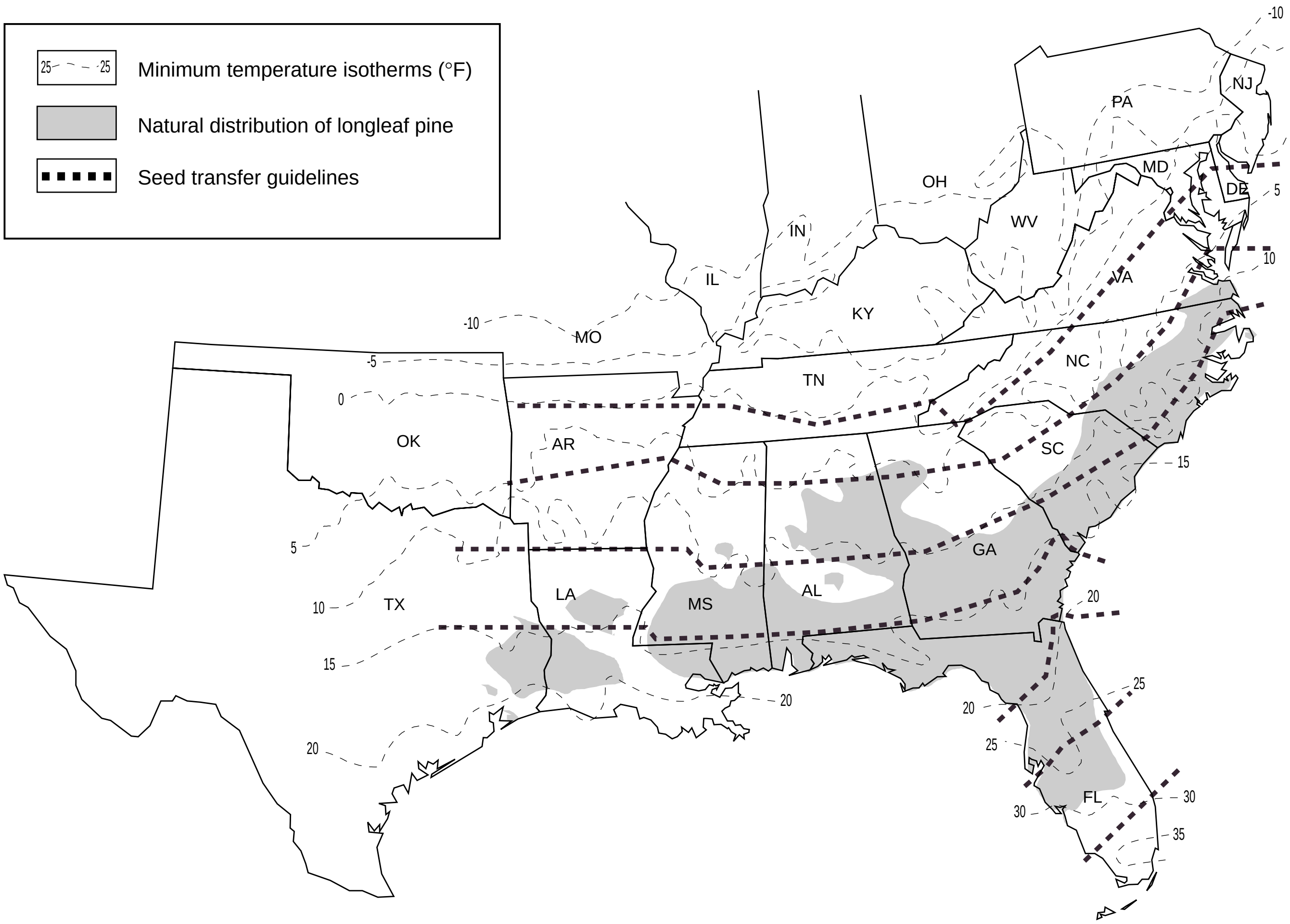


Figure 4—Longleaf pine distribution with seed transfer guidelines. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

ecological prominence. Longleaf planting programs are also being expanded by a number of organizations because the species has excellent form, high-quality wood, and natural resistance to fusiform rust.

Survival has long been a problem with planted longleaf. The delayed height growth (grass stage) of this species is unique. Seedlings need to be grown at low density in the nursery and they require special care in storage, transportation, and planting. However, more recent silvicultural research has made the planting of longleaf pine much more successful (Farrar 1990) and the use of containerized seedlings has been very effective.

Geographic Variation

Although longleaf, like loblolly pine, grows on both sides of the Mississippi River, geographic variation in longleaf pine is less complicated and differences between eastern and western sources are minor. Longleaf from west of the Mississippi River is more susceptible to brown-spot needle blight (*Mycosphaerella dearnessii* Barr) than longleaf from the gulf coast east of the Mississippi River (Henry and Wells 1967), but this difference has had no impact on final yields (Schmidtling and White 1990).

Growth of longleaf in provenance tests is well described by the same seed transfer model as loblolly, with the lack of east-west differences producing an even better statistical fit. The longleaf pine model originated from a provenance test that sampled the entire latitudinal range of seed sources and planting sites from south Florida to north Georgia (Schmidtling and Sluder 1995). Its results were verified with 25-year data from the rangewide SSPSSS longleaf phase (Schmidtling 1997), as well as data from a north-south transect in Alabama (data from Duba and others 1984, reanalyzed in Schmidtling 1997).

Some of the sampling for the SSPSSS longleaf phase was specifically designed to determine if seed sources from deep sand sites were better adapted to these sites than sources from nearby sites with heavier soils (Schmidtling and White 1990). No differences were found. Similarly, the north-south transect in Florida and Georgia (Schmidtling and Sluder 1995) showed no differences attributable to physiographic province.

Genetic Improvement

Although 443 acres of first-generation longleaf pine seed orchards were established in the South by 1982 (Dennington and Farrar 1983), very few improved seedlings are currently available for sale, because of poor early seed production in the orchards. This should change in a few years. Primary emphasis has been on breeding for fast initial height growth (a shorter grass stage) and resistance to brown-spot needle blight, as these traits are very important in early survival. Seeds from seed production areas are sometimes available. The recommended seed movement guidelines should be observed with seeds from either wild stands or orchards and seed production areas.

Recommended Sources

The recommendations for seed transfer in longleaf pine follow the General Guidelines.

Longleaf pine is seldom planted outside of its natural range and is unlikely to succeed if planted west of its natural range. Planting north of its natural range should be successful if you follow the minimum temperature General Guidelines.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

Shortleaf Pine

Shortleaf pine has the most extensive natural range of any southern pine, but its southern component produces only half the wood volume of loblolly pine (Dorman 1976). The natural range of the species extends from New York to Oklahoma and Texas (fig. 5) over a very wide range of sites. Shortleaf pine is resistant to all common southern pine diseases except for littleleaf disease (Phytophthora cinnamomi Rands).

Geographic Variation

The only rangewide provenance test in shortleaf pine is the shortleaf phase of the SSPSSS (Wells 1979, Wells and Wakeley 1970). Analysis of 25-year data showed that the relationship between climate at the seed source and growth was stronger than for any other southern pines, but that east-west differences were not important (Schmidtling 1995). Seed transfer guidelines are, therefore, based on the General Guidelines.

Genetic Improvement

Primarily Southern State forestry organizations and the USDA Forest Service have established clonal seed orchards of shortleaf pine. The few orchards that forest industries have established bring the total acreage to 667 (Kitchens 1987).

In recent years, the planting of shortleaf pine has decreased because loblolly pine survives better and grows faster on many former shortleaf sites (Lambeth and others 1984). In an encouraging development, however, shortleaf survival was 22 percent higher for seed orchard than for nursery-run seedlings on the Ouachita and Ozark National Forests (Kitchens 1987).

Of the average of 22,600 acres planted annually to shortleaf pine in the South, 18,500 are on national forests (Kitchens 1987) primarily in Arkansas, Georgia, Kentucky, and Tennessee.

Seeds from shortleaf pine seed orchards are available from a number of organizations. The same geographic restrictions should be applied with seed orchard seeds as with wild seeds. Genetic improvement is of little value if the seeds are not well adapted to the planting site.

Recommended Sources

The recommendations for seed transfer in shortleaf pine follow the General Guidelines.

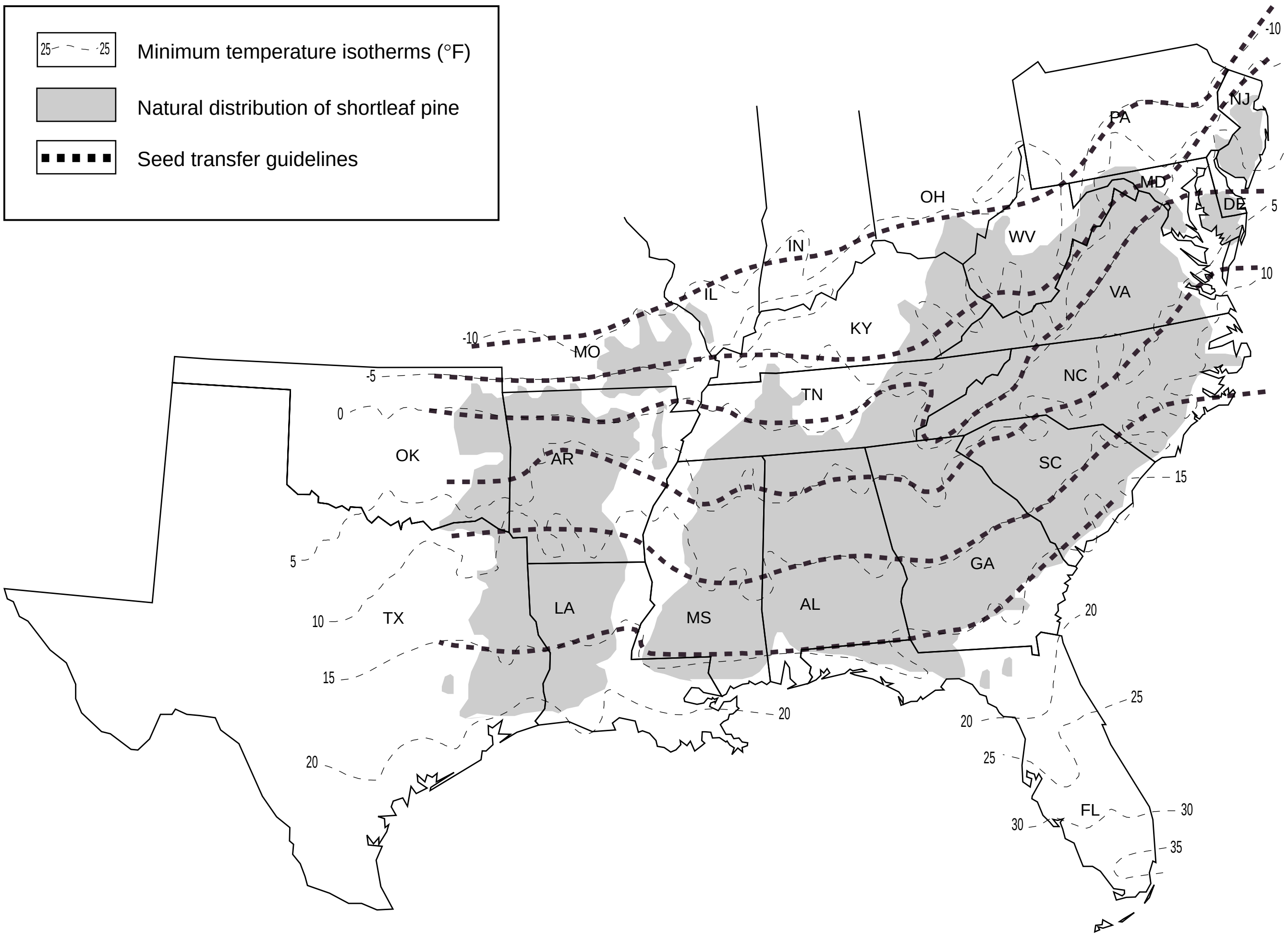


Figure 5—Shortleaf pine distribution with seed transfer guidelines. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

Littleleaf disease is the only disease of any importance that affects survival of shortleaf pine. Because of the erratic nature of infection, resistance is difficult to incorporate into a breeding program. In a seed source study of shortleaf pine planted on littleleaf sites in Georgia, South Carolina, and Virginia, Ruehle and Campbell (1971) found that upland sources had fewer disease symptoms than coastal sources. The Prince Edward County area in Virginia, an area characterized by high incidence of littleleaf disease, was the best overall source for all test plantings. The Prince Edward source may have benefited from natural selection for disease resistance similar to that cited by Goddard and others (1983) in their recommendations for improving the resistance of slash pine to pitch canker.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

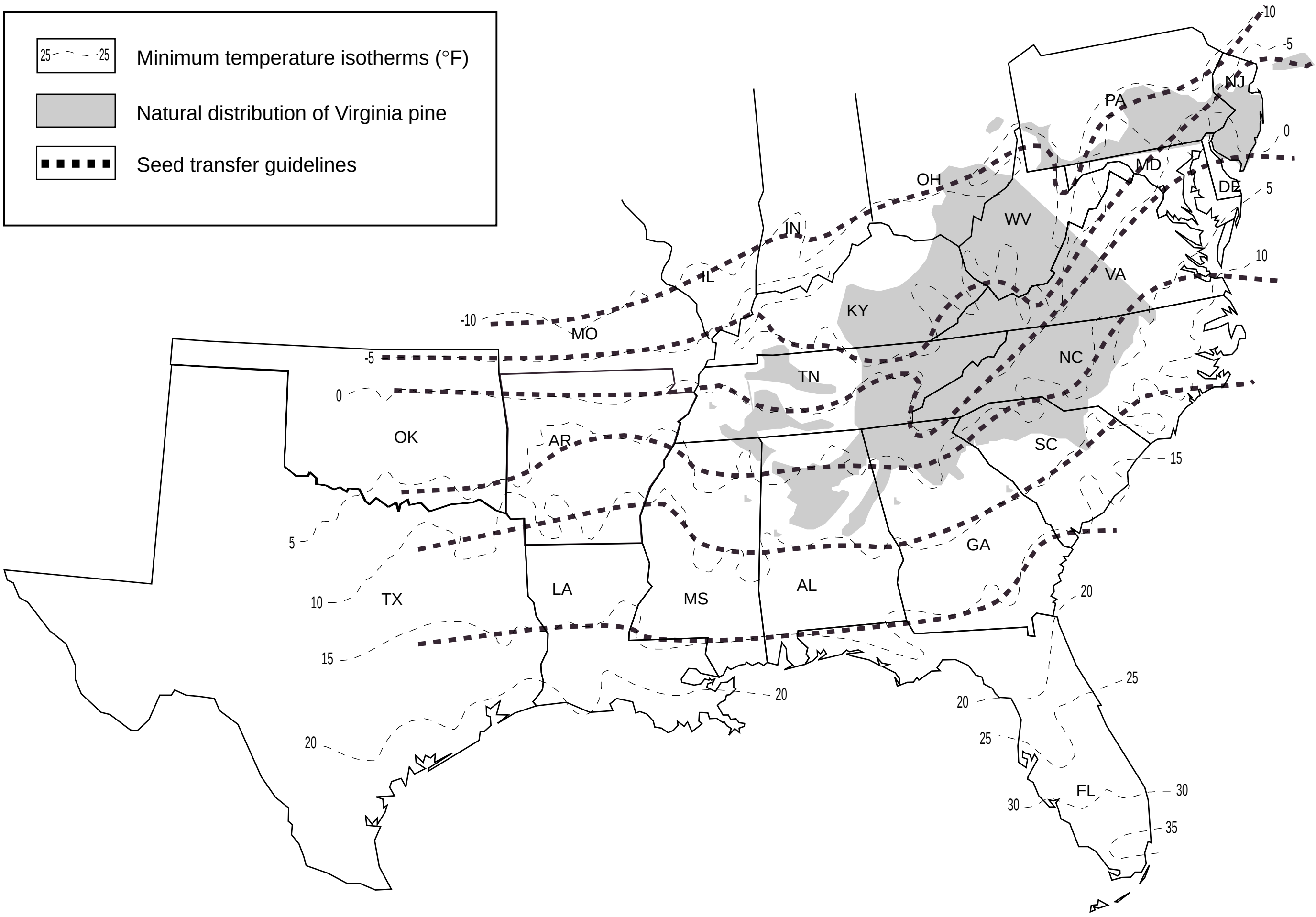


Figure 6—Virginia pine distribution with seed transfer guidelines. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

Virginia Pine

Virginia pine occupies a wide range from New York south to Alabama and Mississippi (fig. 6) and is widely planted for pulpwood and Christmas trees.

Geographic Variation

Studies of geographic variation in Virginia pine are limited but, in general, the results follow the same pattern as in other provenance tests: sources from warmer climates tend to grow faster than local sources if they are not moved to greatly differing climates. For instance, the best sources of Virginia pine for Tennessee plantings were from areas of milder climate found in the central part of the great valley of Tennessee (Todd and Thor 1979).

In a rangewide provenance study of Virginia pine, Genys (1966) found that sources from Alabama, South Carolina, Tennessee, and Virginia had high mortality when planted in the colder climate of Pennsylvania and variable performance when planted in Maryland and Tennessee. A study with 38 seed sources planted at 5 locations in Oklahoma showed that the best growing sources were from stands located between the 0 and 5 °F isotherms of minimum temperature (fig. 6) and that the best predictor of performance in Oklahoma was the average yearly minimum temperature at the seed source (Tauer and others 1998). Analysis showed a curvilinear relationship between growth and minimum temperature at the seed source that is almost identical to loblolly pine (Schmidtling 1994).

Genetic Improvement

Federal, State, and forest industry organizations in the South have established a number of seed orchards of Virginia pine. Early flowering and heavy cone production of the species have allowed these orchards to produce commercial quantities of seeds for many years and to make rapid improvement for Christmas tree production. Some orchards have specialized in producing Virginia pine trees with the best form and color for Christmas trees to meet heavy consumer demand. Seeds and seedlings from the central Alabama source in the U.S. Alliance Corporation seed orchard are popular with Christmas tree growers because of their exceptional form and good growth rates.

Recommended Sources

The recommendations for seed transfer in Virginia pine follow the General Guidelines.

Virginia pine is often planted west and south of its natural range, mainly for Christmas trees. For plantings west of its natural range, the General Guidelines should be followed. South of the natural range, central Alabama and other southernmost sources should be the best for establishing plantings. Pitch canker has caused problems[5] when Tennessee sources were planted in coastal Mississippi. These problems, similar to those of north Florida slash pine planted in south Florida (Dorman 1976), did not appear until well after the normal Christmas tree rotation age.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

[5] Observations (1976 to 1990) by personnel at the USDA Forest Service, Southern Research Station, Southern Institute of Forest Genetics, Saucier, MS.

Sand Pine

The natural range of sand pine is restricted to deep sands in Florida and the gulf coast of Alabama east of Mobile Bay (fig. 7). The Ocala variety (var. *clausa*) is found in the central part of peninsular Florida and the Choctawhatchee variety (var. *immuginata* D.B. Ward) is located in the western end of the Florida panhandle and southern Alabama. The primary characteristic that distinguishes the Ocala variety from the Choctawhatchee variety is its serotinous cones, which can remain on the tree for many years, until a wildfire causes them to open.

Geographic Variation

The few studies of geographic variation in sand pine have been limited to comparisons of the two varieties. In field tests, Choctawhatchee sand pine generally had higher planting survival, higher resistance to root rot, superior form, and greater tolerance to freezing (Burns 1973, 1975).

Genetic Improvement

Clonal seed orchards of Choctawhatchee sand pine have been established by several organizations in the South, primarily in Georgia and Florida. The USDA Forest Service operates a seedling seed orchard of Ocala sand pine on the Ocala National Forest (Lewis and others 1985).

Recommended Sources

Planting of sand pine should be limited to deep sand sites. On heavier soils, the root rot fungi (*Phytophthora cinnamomi* Rands) and *Clitocybe tabescans* (Scop.: Fr.) Bres. cause massive mortality (Ross 1973).

Choctawhatchee sand pine has grown and survived well 17 years after being planted on sandhills sites as far north as South Carolina, at its northern limit for seed movement (Jett and Guiness 1992). This variety had the highest volume of all other species and no fusiform rust. It also performed better than any other pine species tested in the Georgia sandhills (Outcalt and Brendemuehl 1985).

The South Carolina planting site would seem to be very far north of the natural distribution of Choctawhatchee sand pine. This move, however, represents a transfer to a colder climate of only 5 °F (fig. 7). These results, plus those of Burns (1973), support the use of the General Guidelines for seed sources of sand pine.

Planting the Ocala variety of sand pine should be restricted to peninsular Florida. Direct seeding of Ocala sand pine has

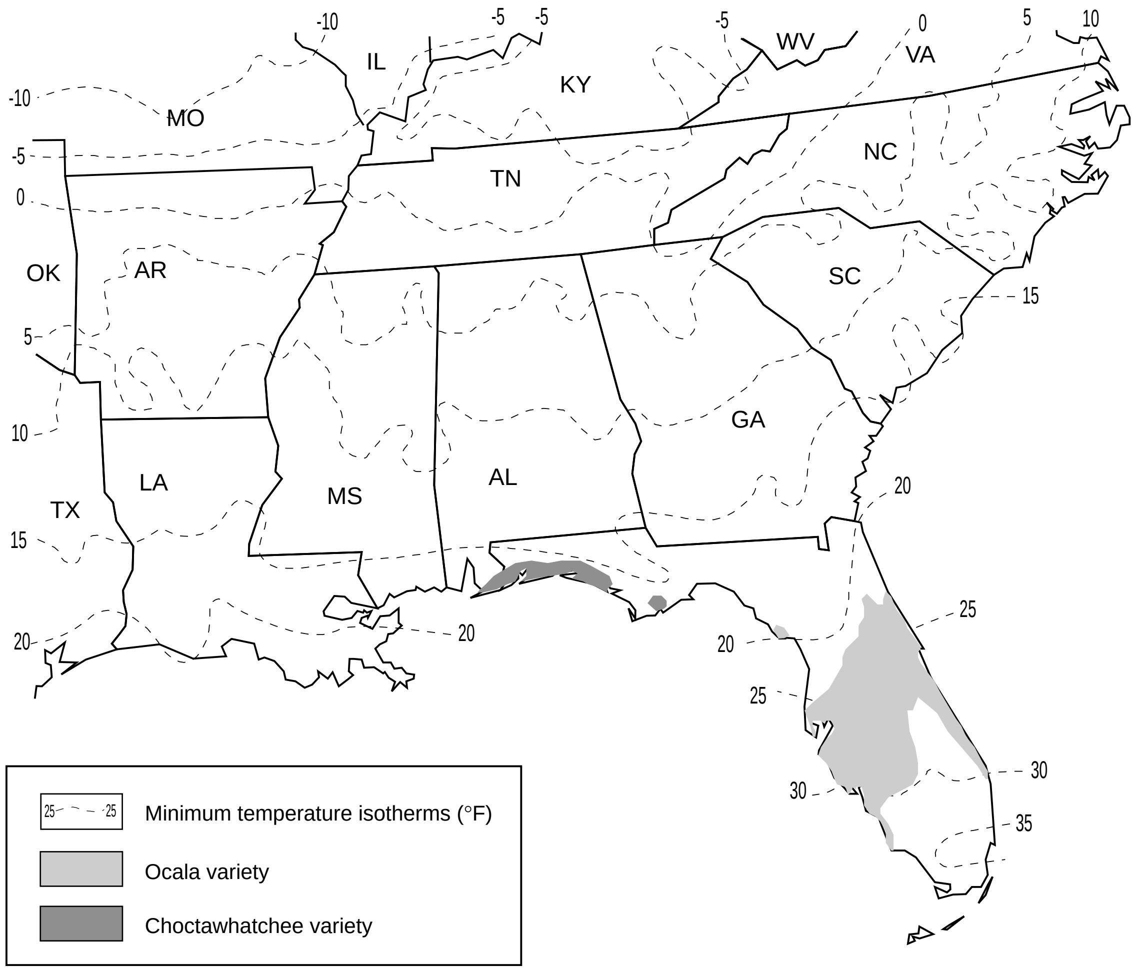


Figure 7—Natural range of sand pine showing minimum temperature isotherms. Natural distributions of species adapted from Critchfield and Little (1966); minimum temperature isotherms from USDA (1990).

been successful on some sites on the Ocala National Forest, but the survival of planted seedlings has usually been poor.

General Guidelines

Seedlings will survive and grow well if they come from any area having a minimum temperature within 5 °F of the planting site's minimum temperature. Seedlings from an area with warmer winters will grow faster than seedlings from local sources; seedlings from an area with cooler winters will grow slower (Schmidtling 1994). The difference in winter lows can be as much as 10 °F, but with increased risk of damage at the cold end of the range and growth loss at the warm end. East-west transfers within districts are usually successful, and in some instances may be desirable if improved stock is available.

Other Species and Hybrids

Dorman (1976) is the source of the scant information available on the minor southern pine species: pitch pine (*P. rigida* Mill.), pond pine (*P. serotina* Michx.), spruce pine (*P. glabra* Walt.), and Table Mountain pine (*P. pungens* Lamb.). Certainly, using local sources would be the safest. However, there is no reason to believe that the General Guidelines would not apply to the minor species, especially considering that they all occur east of the Mississippi River, and that east-west population differentiation is unlikely for any of them.

The southern pine species often hybridize in areas where different species occupy the same sites. The most common natural hybrids are a longleaf X loblolly pine called Sonderegger (Chapman 1922), a loblolly X shortleaf pine

(Zobel 1953), and a loblolly X pond pine (Saylor and Kang 1973).

The pitch X loblolly pine hybrid has been produced artificially in Korea for many years (Hyun 1970) and is currently planted on cold, dry sites on the Cumberland Plateau (Little and Trew 1976).

The hybrid of slash pine with Caribbean pine has been very successful in tropical and subtropical climates, especially in Queensland, Australia. Because it combines the continuous growth of Caribbean pine with slash pine's tolerance of poorly drained soils (Nikles 1995), this hybrid has promise for south Florida.

Research in the South has indicated that shortleaf X slash pine hybrids often outgrow the parental species (Nelson 1991, Wells and others 1978). Research on loblolly X shortleaf pine hybrids indicates the potential for improved fusiform rust resistance in offspring (LaFarge and Kraus 1980). However, using hybrids as a source of rust resistance may no longer be cost-effective, considering the advancements made in breeding for resistance in standard (nonhybrid) stock.

The successful planting of hybrids requires a very careful site analysis, since hybrid stock is likely to be considerably more expensive than standard stock. Both the pitch X loblolly hybrid and the shortleaf X loblolly hybrid will perform well when the planting sites are properly selected. Additional information on southern pine hybrids may be found in Dorman (1976).

Literature Cited

Anderson, R.L.; Powers, H.R., Jr. 1985. The resistance screening center - screening for disease resistance as a source for tree improvement programs. In: Proceedings IUFRO rust of hard pines working party conference; 1985 June; Athens, GA. Athens, GA: University of Georgia, Georgia Center for Continuing Education: 59–65.

Balmer, W.E.; Williston, H.L. 1974. Guide for planting southern pines. Atlanta: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area. 17 p.

Barber, J.C. 1975. Seed certification. In: Faulkner, Roy, ed. Seed orchards. For. Comm. Bull. 54. London: Her Majesty's Stationery Office: 143–149.

Barbour, H.F. 1980. Loblolly seed sources for west Kentucky. In: Lantz, Clark W., comp. Proceedings of the 1980 southern nursery conference; 1980 September 2–4; Lake Barkley, KY. Tech. Publ. SA–TP–17. Atlanta: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 15–23.

Barrett, W.H. 1973. Variación geográfica en *Pinus elliottii* Engelm. y *P. taeda* L. II. Cinco años de crecimiento en el nordeste argentino. (Geographical variation in *Pinus elliottii* and *P. taeda*. II. Five years of growth in northeastern Argentina). Idia: Supplemento Forestal. 8: 18–39. In Spanish.

Boyer, J.N.; South, D.B. 1984. Forest nursery practices in the South. Southern Journal of Applied Forestry. 8: 67–75.

Bridgwater, F.E.; Smith, W. 1997. Economic impact of fusiform rust on the value of loblolly pine. Southern Journal of Applied Forestry. 21: 187–192.

Burns, R.M. 1973. Comparative growth of planted pines in the sandhills of Florida, Georgia, and South Carolina. In: Sand pine symposium, Proceedings; 1972 December 5–7; Panama City Beach, FL. Gen. Tech. Rep. SE–2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 124–134.

Burns, R.M. 1975. Sand pine: fifth-year survival and height on prepared and unprepared sandhill sites. Res. Note SE–217. Asheville, NC: U.S, Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 5 p.

Chapman, H.H. 1922. A new hybrid pine (*Pinus palustris* X *Pinus taeda*). Journal of Forestry. 20: 729–734.

Critchfield, W.B.; Little, E.L., Jr. 1966. Geographic distribution of the pines of the world. Misc. Publ. 991. Washington, DC: U.S. Department of Agriculture, Forest Service. 97 p.

Croker, T.C., Jr. 1990. Longleaf pine - myths and facts. In: Proceedings, symposium management of longleaf pine; 1989 April 4–6; Long Beach, MS. Gen. Tech. Rep. SO–75. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 2–10.

Dennington, R.W.; Farrar, R.M., Jr. 1983. Longleaf pine management. For. Rep. R–8–FR3. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region. 17 p.

Dorman, K.W. 1976. The genetics and breeding of southern pines. Agric. Handb. 471. Washington, DC: U.S. Department of Agriculture, Forest Service. 407 p.

Doudrick, R.L.; Schmidtling, R.C.; Nelson, C.D. 1996. Host relationships of fusiform rust disease: I. Infection and pycnial production on slash pine and nearby tropical relatives. Silvae Genetica. 45: 142–149.

Duba, S.E.; Goggans, J.F.; Patterson, R.M. 1984. Seed source testing of Alabama loblolly pine: implications for seed movement and tree improvement programs. Southern Journal of Applied Forestry. 8: 189–193.

Easley, L.T. 1963. Growth of loblolly pine from seed produced in a seed production area vs. nursery-run stock. Journal of Forestry. 61(5): 388–389.

Farjon, A.; Page, C.N., comps. 1999. Conifers: status survey and conservation action plan. International Union for Conservation of Nature and Natural Resources/Species Survival Commission (IUCN/SSC) conifer specialist group. Gland, Switzerland; Cambridge, UK: International Union for Conservation of Nature and Natural Resources. 121 p.

Farrar, R.M., ed. 1990. Proceedings, symposium management of longleaf pine; 1989 April 4–6; Long Beach, MS. Gen. Tech. Rep. SO–75. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 294 p.

Fisher, R.F. 1983. Silvical characteristics of slash pine (*Pinus elliottii* Englem. var *elliottii*). In: Stone, E.L., ed. The managed slash pine ecosystem: Proceedings of a symposium; 1981 June 9–11; Gainesville, FL. Gainesville, FL: University of Florida, School of Forest Resources and Conservation: 48–55.

Friedman, S.T.; Adams, W.T. 1985. Estimation of gene flow into two seed orchards of loblolly pine (*Pinus taeda* L.). Theoretical & Applied Genetics: 69: 609–615.

Genys, J.B. 1966. Geographic variation in Virginia pine. Silvae Genetica. 15(l): 72–76.

Gilmore, A.R. 1980. Extending the range of loblolly pine in the Mississippi River Valley: factors relating to growth and longevity. In: Lantz, Clark W., comp. Proceedings, 1980 southern nursery conference; 1980 September 2–4; Lake Barkley, KY. Tech. Publ. SA–TP–17. Atlanta: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 8–14.

Gilmore, A.R.; Funk, D.T. 1976. Shortleaf and loblolly pine seed origin trials in southern Illinois: 27-year results. In: Proceedings of the 10th Central States forest tree improvement conference; 1976 September 22–23; West Lafayette, IN. [Place of publication unknown]: [Publisher unknown]: 115–124.

Goddard, R.E.; Wells, O.O.; Squillace, A.E. 1983. Genetic improvement of slash pine. In: Stone, E.L., ed. The managed slash pine ecosystem: Proceedings of a symposium; 1981 June 9–11; Gainesville, FL. Gainesville, FL: University of Florida, School of Forest Resources and Conservation: 56–68.

Grissom, J.E.; Schmidtling, R.C. 1997. Genetic diversity of loblolly pine grown in managed plantations: evidence of differential response to climatic events [Abstract]. In: Proceedings of the 24th southern forest tree improvement conference; 1997 June; Orlando, FL: 410. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Henry, B.W.; Wells, O.O. 1967. Variation in brown-spot infection of longleaf pine from several geographic sources. Res. Note SO–52. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Hyun, S.K. 1970. The growth performance of pitch-loblolly hybrid pine produced by different geographic races of loblolly pine in their early age. In: Second world consultation on forest tree breeding; 1969 August 7–16; Washington, DC. Rome: Food and Agriculture Organization of the United Nations: 803–814. Vol. 1.

Jayawickrama, K.J.S.; McKeand, S.E.; Jett, J.B. 1998. Phenological variation in height and diameter growth in provenances and families of loblolly pine. New Forests. 16: 11–25.

Jett, J.B.; Guiness, W.M. 1992. Growth and wood properties in a Carolina sandhills pine seed source study. Southern Journal of Applied Forestry. 16: 164–169.

Kelly, J.F.; Bechtold, W.A. 1990. The longleaf pine resource. In: Proceedings symposium on management of longleaf pine; 1989 April 4–6; Long Beach, MS. Gen. Tech. Rep. SO–75. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 11–22.

Kitchens, R.N. 1987. Trends in shortleaf pine tree improvement. In: Murphy, Paul A., ed. Symposium on the shortleaf pine ecosystem; 1986 March 31–April 2; Little Rock, AR. Fayetteville, AR: University of Arkansas, Cooperative Extension Service: 89–100.

Kraus, J.F.; LaFarge, T. 1984. Early results of a slash pine variety trial. Southern Journal of Applied Forestry. 8(l): 41–43.

LaFarge, T.; Kraus, J.F. 1980. A progeny test of (shortleaf x loblolly) x loblolly hybrids to produce rapid-growing hybrids resistant to fusiform rust. Silvae Genetica. 29(5–6): 197–200.

Lambeth, C.C.; Dougherty, P.M.; Gladstone, W.T. [and others]. 1984. Large-scale planting of North Carolina loblolly pine in Arkansas and Oklahoma: a case of gain versus risk. Journal of Forestry. 82(12): 736–741.

Lantz, C.W.; Hofmann, J.C. 1969. Geographic variation in growth and wood quality of loblolly pine in North Carolina. In: Proceedings of the 10th southern forest tree improvement conference; 1969 June 17–19; Houston, TX: 175–188. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Lantz, C.W.; Kraus, J.F. 1987. A guide to southern pine seed sources. Gen. Tech. Rep. SE–43. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 34 p.

Lewis, R.A.; LaFarge, T.; McConnell, J.L. 1985. A seven-year-old Ocala sand pine seedling seed orchard. In: Proceedings of the 18th southern forest tree improvement conference; 1985 May 21–23; Long Beach, MS: 204–207. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Li, B.; McKeand, S.E. 1989. Stability of loblolly pine families in the Southeastern U.S. Silvae Genetica. 38: 96–101.

Li, B.; McKeand, S.E.; Weir, R.J. 1999. Tree improvement and sustainable forestry impact of two cycles of loblolly pine breeding in the U.S.A. Forest Genetics. 6(4): 229–234.

Little, E.L., Jr.; Dorman, K.W. 1952. Slash pine (*Pinus elliottii*), its nomenclature and varieties. Journal of Forestry. 50: 918–923.

Little, E.L., Jr.; Dorman, K.W. 1954. Slash pine (*Pinus elliottii*), including south Florida slash pine. Nomenclature and description. Pap. 36. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 82 p.

Little, S.; Trew, I.F. 1976. Breeding and testing pitch x loblolly pine hybrids for the Northeast. In: Garrett, Peter W., ed. Proceedings of the 23rd northeastern forest tree improvement conference; 1975 August 4–7; New Brunswick, NJ: 71–85. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Long, E.M. 1980. Texas and Louisiana loblolly pine study confirms importance of local seed sources. Southern Journal of Applied Forestry. 4(3): 127–132.

Lott, L.A.; Schmidtling, R.C.; Snow, G.A. 1996. Susceptibility to brown-spot needle blight and fusiform rust in selected longleaf pine and hybrids. Tree Planters' Notes. 47: 11–15.

McKeand, S.E.; Eriksson, G.; Roberds, J.H. 1997. Genotype by environment interaction for index traits that combine growth and wood density in loblolly pine. Theoretical & Applied Genetics. 94: 1015–1022.

McKeand, S.E.; Li, B.; Amerson, H.V. 1999. Genetic variation in fusiform rust resistance in loblolly pine across a wide geographic range. Silvae Genetica. 48: 255–260.

McRae, C.H.; Rockwood, D.L.; Blakeslee, G.M. 1985. Evaluation of slash pine for resistance to pitch canker. In: Proceedings of the 18th southern forest tree improvement conference; 1985 May 21–23; Long Beach, MS: 351–357. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Minckler, L.S. 1950. Effect of seed source on height growth of pine seedlings. Journal of Forestry. 48: 430–431.

Mullin, L.J.; Barnes, R.D.; Prevôst, M.J. 1978. A review of the southern pines in Rhodesia. Res. Bull. 7. Harare, Zimbabwe: Rhodesia (Zimbabwe) Forestry Commission. 331 p.

Nance, W.L.; Froelich, R.C.; Dell, T.R.; Shoulders, E. 1983. A growth and yield model for unthinned slash pine plantations infected with fusiform rust. In: Jones, Earle P., Jr., ed. Proceedings of the second biennial southern silvicultural research conference; 1982 November 4–5; Atlanta. Gen. Tech. Rep. SE–24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 275–282.

Nelson, C.D. 1991. Fusiform rust incidence and volume growth in a first-generation backcross population. (shortleaf X slash) x slash. In: Proceedings of the 21st southern forest tree improvement conference; 1991 June 17–21; Knoxville, TN: 152–159. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Nikles, D.G. 1966. Comparative variability and relationship of Caribbean pine (*Pinus caribaea* Mor.) and slash pine (*Pinus elliottii* Engelm.). Raleigh, NC: North Carolina State University. **201 p.** Ph.D. dissertation.

Nikles, D.G. 1995. Hybrids of the slash - Caribbean - Central American pine complex: characteristics, bases of superiority and potential utility in South China and elsewhere. In: Shen, Xihuan, ed. Forest tree improvement in the Asia-Pacific region. Beijing: China Forestry Publishing House: 168–186.

Outcalt, K.W.; Brendemuehl, R.H. 1985. Growth of Choctawhatchee sand pine plantations in Georgia. Southern Journal of Applied Forestry. 9(1): 62–64.

Prentice, I.C.; Cramer, W.; Harrison, S.P. [and others]. 1992. A global biome model based on plant physiology and dominance, soil properties, and climate. Journal of Biogeography. 19: 117–134.

Pye, J.M.; Wagner, J.E.; Holmes, T.P.; Cubbage, F.W. 1997. Positive returns from fusiform rust research. Res. Pap. SRS–4. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 55 p.

Rink, G.; Wells, O.O. 1988. Productivity comparisons of 37-year-old loblolly-shortleaf pine seed sources in southern Illinois. Northern Journal of Applied Forestry. 5: 155–158.

Rockwood, D.L.; Huber, D.A.; White, T.L. [In press]. Provenance and family variability in slash pine grown in southern Brazil and northeastern Argentina. New Forests.

Ross, E.W. 1973. Important diseases of sand pine. In: Sand pine symposium, Proceedings; 1972 December 5–7; Panama City Beach, FL. Gen. Tech. Rep. SE–2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 199–206.

Rudolf, P.O. 1974. Tree-seed marketing controls. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture: 153–166.

Ruehle, J.L.; Campbell, W.A. 1971. Adaptability of geographic selections of shortleaf pine to littleleaf sites. Res. Pap. SE–87. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 8 p.

Saucier, J.R.; Dorman, K.W. 1969. Intraspecific variation in growth and wood characteristics of two slash pine varieties grown in south Florida. In: Proceedings of the 10th southern forest tree improvement conference; 1969 June 17–19; Houston TX: 49–57. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Saylor, L.C.; Kang, K.W. 1973. A study of sympatric populations of *Pinus taeda* L. and *Pinus serotina* Michx. in North Carolina. Journal of Elisha Mitchell Scientific Society. 89(1 & 2): 101–110.

Schmidtling, R.C. 1988. Racial variation in self-thinning trajectories in loblolly pines. In: Proceedings International Union of Forest Research Organizations forest growth modeling and prediction; 1987 August 23–27; Minneapolis. SAF–87–12. Washington, DC: Society of American Foresters: 134–142. Vol. 1.

Schmidtling, R.C. 1994. Using provenance tests to predict response to climatic change: loblolly pine and Norway spruce. Tree Physiology. 14: 805–817.

Schmidtling, R.C. 1995. Seed transfer and genecology in shortleaf pine. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1–3; Auburn, AL. Gen. Tech. Rep. SRS–1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 373–378.

Schmidtling, R.C. 1997. Using provenance tests to predict response to climatic change. In: Ecological issues and environmental impact assessment. Houston, TX: Gulf Publishing Co.: 621–642. Chapter 27.

Schmidtling, R.C.; Carroll, E.; LaFarge, T. 1999. Allozyme diversity of selected and natural loblolly pine populations. Silvae Genetica. 48: 35–45.

Schmidtling, R.C.; Clark, A., III. 1989. Loblolly pine seed sources differ in stem form. In: Miller, James H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1–3; Memphis, TN. Gen. Tech. Rep. SO–74. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 421–426.

Schmidtling, R.C.; Froelich, R.C. 1993. Thirty-seven year performance of loblolly pine seed sources in eastern Maryland. Forest Science. 39: 706–721.

Schmidtling, R.C.; Hipkins, V. 1998. Genetic diversity in longleaf pine (*Pinus palustris* Mill.): influence of historical and prehistorical events. Canadian Journal of Forest Research. 28: 1135–1145.

Schmidtling, R.C.; Marcó, M.; LaFarge, T. 1997. A slash pine progeny test in Argentina and USA. In: Proceedings of the 24th southern forest tree improvement conference; 1997 June 9–11; Orlando, FL: 384–386. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Schmidtling, R.C.; Nelson, C.D. 1996. Interprovenance crosses in loblolly pine using selected parents. Forest Genetics. 3(1): 53–66.

Schmidtling, R.C.; Sluder, E.R. 1995. Seed transfer and genecology in longleaf pine. In: Proceedings of the 23rd southern forest tree improvement conference; 1995 June 20–22; Asheville, NC: 78–85. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Schmidtling, R.C.; White, T. 1990. Genetics and tree improvement of longleaf pine. In: Proceedings symposium management longleaf pine. Gen. Tech. Rep. SO–75. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 114–127.

Shiver, B.D.; Rheney, J.W.; Hitch, K.L. 2000. Loblolly pine outperforms slash pine in southeastern Georgia and northern Florida. Southern Journal of Applied Forestry. 24: 31–36.

Sierra-Lucero, V. 1999. Genetic parameter estimates of loblolly pine grown in the lower Coastal Plain of the Southeastern United States. Gainesville, FL: University of Florida. 86 p. M.S. thesis.

Snow, G.A.; Froelich, R.C. 1968. Daily and seasonal dispersal of basidiospores of *Cronartium fusiforme*. Phytopathology. 58: 1532–1536.

Snyder, E.B.; Wakeley, P.C.; Wells, O.O. 1967. Slash pine provenance tests. Journal of Forestry. 65: 414–420.

Squillace, A.E. 1965. Combining superior growth and timber quality with high gum yield in slash pine. In: Proceedings of the 8th southern forest tree improvement conference; 1965 June 16–17; Savannah, GA: 73–76. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Squillace, A.E. 1966. Geographic variation in slash pine. Monogr. 10. Forest Science. 56 p.

Squillace, A.E. 1976. Geographic patterns of fusiform rust infection in loblolly and slash pine plantations. Res. Note SE–232. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 4 p.

Storer, J.; Gordon, T.R.; Dallara, D.L.; Wood, D.I. 1994. Pitch canker kills pines, spreads to new species and regions. California Agriculture. 48: 9–12.

Talbert, J.T.; Weir, R.J.; Arnold, R.D. 1985. Costs and benefits of a mature first-generation loblolly pine tree improvement program. Journal of Forestry. 83(3): 162–166.

Tauer, C.G.; Shah, S.R.S.; Schmidtling, R.C. 1998. Virginia pine (*Pinus virginiana* Mill.) provenance and progeny performance in Oklahoma. Southern Journal of Applied Forestry. 22: 209–215.

Todd, D.; Thor, E. 1979. Variation and estimated gains in height, diameter, and volume growth for open-pollinated progeny of Virginia pine (*Pinus virginiana* Mill.). In: Proceedings of the 15th southern forest tree improvement conference; 1979 June 19–21; Starkville, MS: 42–57. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

U.S. Department of Agriculture. 1990. USDA plant hardiness zone map. Misc. Publ. 1475. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 1: 6,000,000 scale; 48 x 48 in.; colored.

Wakeley, P.C. 1961. Results of the southwide pine seed source study through 1960–61. In: Proceedings of the 6th southern forest tree improvement conference; 1961 June 7–8; Gainesville, FL: 10–24. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Wakeley, P.C.; Bercaw, T.E. 1965. Loblolly pine provenance test at age 35. Journal of Forestry. 63: 168–174.

Wells, O.O. 1969. Results of the southwide pine seed source study through 1968–69. In: Proceedings of the 10th southern forest tree improvement conference; 1969 June 17–19; Houston, TX: 117–129. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Wells, O.O. 1979. Geographic seed source affects performance of planted shortleaf pine. In: Proceedings: symposium management pines of the interior South; 1978 November 7–8; Knoxville, TN. Tech. Publ. SA–TP–2. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry: 48–57.

Wells, O.O. 1983. Southwide pine seed source study-loblolly pine at 25 years. Southern Journal of Applied Forestry. 7(2): 63–71.

Wells, O.O. 1985. Use of Livingston Parish, Louisiana loblolly pine by forest products industries in the Southeast. Southern Journal of Applied Forestry. 9(3): 180–185.

Wells, O.O.; Barnett, P.E.; Derr, H.J. [and others]. 1978. Shortleaf X slash pine hybrids outperform parents in parts of the Southeast. Southern Journal of Applied Forestry. 2(1): 28–32.

Wells, O.O.; Lambeth, C.C. 1983. Loblolly pine provenance test in southern Arkansas: 25th year results. Southern Journal of Applied Forestry. 7(2): 71–75.

Wells, O.O.; Rink, G. 1984. Planting loblolly pine north and west of its natural range. In: Shoulders, Eugene, ed. Proceedings of the third biennial southern silvicultural research conference; 1984 November 7–8; Atlanta. Gen. Tech. Rep. SO–54. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 261–264.

Wells, O.O.; Switzer, G.L. 1971. Variation in rust resistance in Mississippi loblolly pine. In: Proceedings of the 11th southern forest tree improvement conference; 1971 June 15–16; Atlanta: 25–30. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Wells, O.O.; Switzer, G.L.; Schmidtling, R.C. 1991. Geographic variation in Mississippi loblolly pine and sweetgum. Silvae Genetics. 40: 105–118.

Wells, O.O.; Wakeley, P.C. 1966. Geographic variation in survival, growth, and fusiform-rust infection of planted loblolly pine. Monogr. 11. Forest Science. 40 p.

Wells, O.O.; Wakeley, P.C. 1970. Variation in shortleaf pine from several geographic sources. Forest Science. 16(4): 415–423.

Wiesehuegel, E.C. 1955. Five year's results of loblolly pine geographic seed source tests. In: Proceedings of the 3rd southern forest tree improvement conference; 1955 January 5–6; New Orleans: 16–25. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Zarger, T.G. 1961. Ten-year results of a cooperative loblolly pine seed source test. In: Proceedings of the 6th southern forest tree improvement conference; 1961 June 7–8; Gainesville, FL: 45–50. Available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Zobel, Bruce J. 1953. Are there natural loblolly-shortleaf pine hybrids? Journal of Forestry. 51(7): 494–495.

Zobel, Bruce; Talbert, John. 1984. Applied forest tree improvement. New York: John Wiley. 505 p.

Glossary

adaptation: the process of evolutionary (genetic) adjustments fitting individuals or groups to their environment

allozyme: (isozyme, isoenzyme) multiple forms of a single enzyme, which catalyze the same reaction but differ in their electrical charge when separated by electrophoresis. Minor variations in allozymes are considered to be nonadaptive, but are useful in studies of population genetics.

cline: a geographical gradient of phenotype or genotype within the species' range. Determining whether a cline is genetic requires testing in at least a single environment. Usually clinal variation results from an environmental gradient. Portions of populations exhibiting such continuous (clinal) change from one area to another should not be designated as ecotypes, races, or taxa.

clone: a group of genetically identical plants derived asexually from a single individual, produced by grafting, rooting cuttings, or tissue culture

ecotype: a race adapted to the selective action of a particular climatic or soil environment. Most differences among ecotypes show up only when different ecotypes are tested in a uniform environment.

edaphic: pertaining to the soil in its ecological relationships

electrophoresis: a method to separate charged molecules in an electrical field, exploiting differences in net electrical charge, shape and size of the molecules. Electrophoretic separation in free solution is possible, but usually it is performed in a matrix (gel electrophoresis) or on filter paper.

gene: a chromosomal segment involved in producing a polypeptide chain or RNA molecule. The fundamental physical and functional unit of heredity that carries information from one generation to the next.

genotype: (1) an individual's hereditary constitution, with or without phenotypic expression of the one or more characters it underlies. Also the gene classification of this constitution expressed in a formula. The genotype is determined chiefly from performance of progeny and other relatives. It interacts with the environment to produce the phenotype. (2) Individual(s) characterized by a certain genetic constitution.

genotype-environment interaction: the failure of genotypes (families, clones, provenances) to maintain the same relative performance when tested in different environments

geographic race: the race native to a geographic area

geographic variation: the visible differences among native trees growing in different portions of a species' range. If the differences are largely genetic rather than environmental, the variation is usually specified as racial, ecotypic, or clinal.

grass stage: delayed early growth in pine seedlings in which the seedlings have very limited stem elongation and resemble grass

hypocotyl: in a freshly germinated pine seedling, the segment (stem) between the roots and the cotyledons (embryonic needles)

isoline, isotherm: a line on a map or chart along which there is constant value such as temperature, growing season, or growth potential

local seed source: source native to the locality in which the seedlings are grown; belonging to the indigenous geographic race. Its seed collection area is usually defined experimentally as being within a certain distance or elevation of the planting site.

nursery-run seedlings: seedlings from unselected trees, usually from general forest collections made in natural stands

phenotype: the plant or character as we see it; state, description, or degree of expression of a character; the product of the interaction of the genes of an organism (genotype) with the environment. When the total character expressions of an individual are considered, the phenotype describes the individual. Similar phenotypes do not necessarily breed alike.

plus stand: a stand of trees with exceptional phenotypic characteristics in growth, form, and disease resistance. These stands are usually thinned intensively to eliminate the poorer trees.

progeny test: evaluation of parents by comparing the performance of their numbers of offspring under conditions more controlled than would be possible for the parent

provenance: the geographic origin of a seed source

race: a population that exists within a species and exhibits general genetic characteristics distinct from those of other populations. When the distinguishing characteristics of a race are adaptive rather than simply phenotypic, the term is synonymous with ecotype, and the race is described by the nature of its adaptation, such as climatic or edaphic.

refugium: a place where species exist (refuge) during times of generally unfavorable climatic conditions

roguing: systematic removal of individuals not desired for the perpetuation of a population; culling

seed orchard: a plantation consisting of clones or seedlings from selected trees isolated to reduce pollination from outside sources, rogued of undesirables, and cultured for early and abundant production of seeds

seed production area: a plus stand that is generally upgraded and opened by removal of undesirable trees and then cultured for early and abundant seed production

seed source: the locality where a seed lot was collected; also the seed itself. If the stand from which collections were made was, in turn, from nonnative ancestors, the original seed source should also be recorded and designated as the provenance.

selection: often synonymous with artificial selection, which is the choice by the breeder of individuals for propagation from a larger population. Artificial selection may be for one or more desired characteristics. It may be based on the tree itself (phenotypic), or on the tree's progeny or other relatives (genotypic). Refers also to the tree selected.

serotinous: a term usually applied to cones that, though mature, remain closed for a year or more

SSPSSS: the Southwide Southern Pine Seed Source Study. A major study of geographic variation (provenance test) initiated by Phil Wakeley and the Southern Forest Tree Improvement Committee.

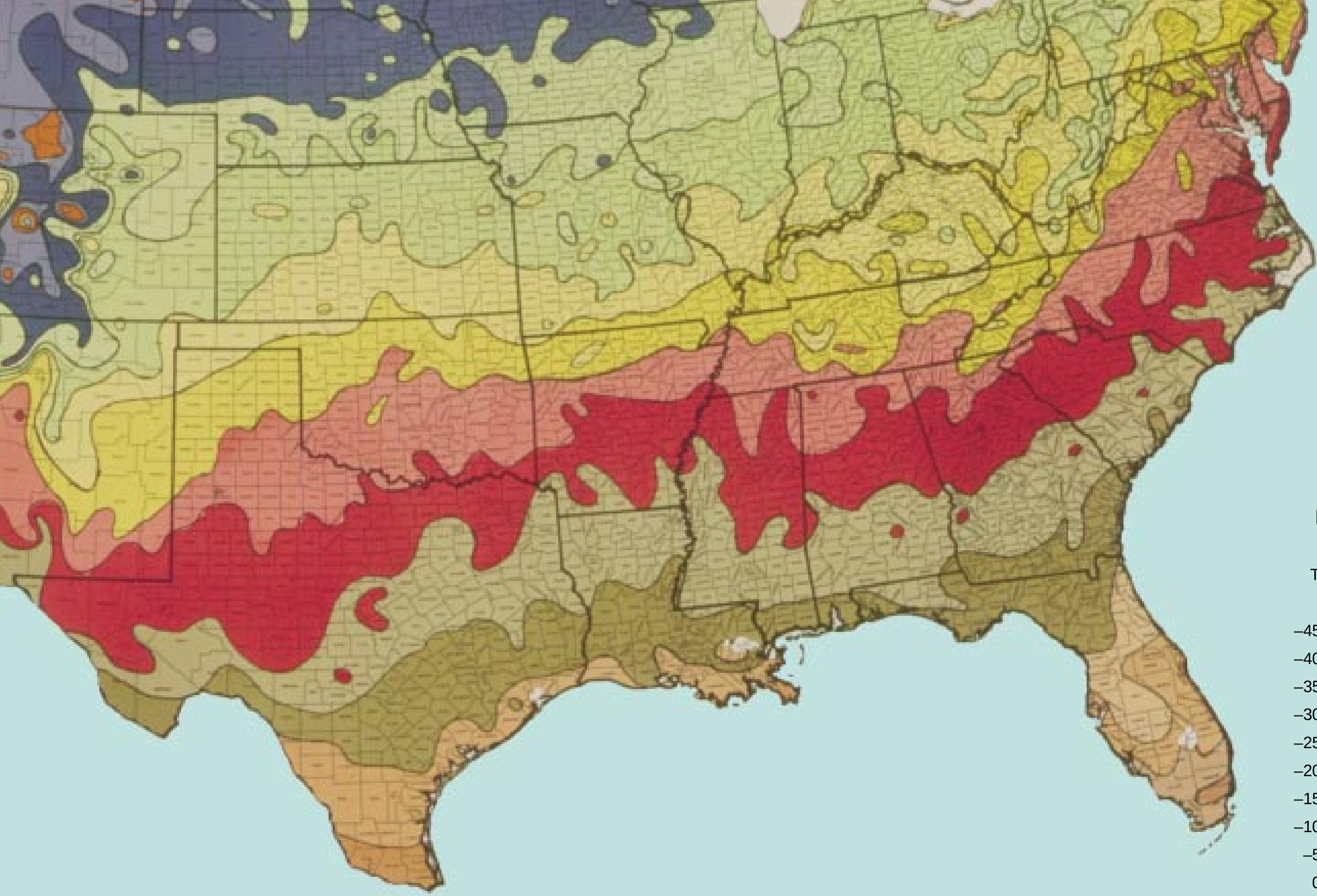
variety: a subdivision of a species, usually separated geographically from the typical, having one or more heritable, morphological characteristics which differ from the typical even when grown under the same environmental conditions

woods-run: unselected, wild, or natural stands of trees

Schmidtling, R.C. 2001. Southern pine seed sources. Gen. Tech. Rep. SRS-XX. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 25 p.

The selection of an appropriate seed source is critical for successful southern pine plantations. Guidelines for selection of seed sources are presented for loblolly (*Pinus taeda* L.), slash (*P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), Virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand [*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.] pines. Seed movement guidelines in this handbook are based on climatic similarities between the seed source origin and the planting site. Because yearly average minimum temperature is the most important climatic variable related to growth and survival, it has been used to define the rules of seed movement. This variable, which defines plant hardiness zones, has been used for many years by horticulturists to guide the transfer of plant materials. East-west movement to areas of similar climate is permissible, with the exception of loblolly pine.

Keywords: Fusiform rust, geographic variation, loblolly pine, longleaf pine, provenance tests, sand pine, seed movement, seed sources, shortleaf pine, slash pine, Virginia pine.



Average Annual Minimum Temperature

Temperature (ºF)		
Below –50		
–45	to	–50
–40	to	–45
–35	to	–40
–30	to	–35
–25	to	–30
–20	to	–25
–15	to	–20
–10	to	–15
–5	to	–10
0	to	–5
5	to	0
10	to	5
15	to	10
20	to	15
25	to	20
30	to	25
35	to	30
40	to	35
40 and above		

USDA Plant Hardiness Zones