The Southern Forest

Geography, Ecology, and Silviculture

Laurence C. Walker
Brian P. Oswald

The Southern Forest

Geography, Ecology, and Silviculture

Laurence C. Walker, Ph.D.
Brian P. Oswald, Ph.D.

CRC Press
Boca Raton London New York Washington, D.C.

Library of Congress Cataloging-in-Publication Data

Walker, Laurence C., 1924-
The southern forest: geography, ecology, and silviculture / Laurence C. Walker and Brian P. Oswald.
p. cm.
Includes bibliographical references and index.
ISBN 0-8493-1307-4 (alk. paper)
1. Forests and forestry—Southern states. 2. Forest ecology—Southern states. I. Oswald, Brian P. II. Title.
DNLM/DLC
SD144.A15 W36 1999
634.9′0975—dc21 99-044932
CIP

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

International Standard Book Number 0-8493-1307-4
Library of Congress Card Number 99-044932
Printed in the United States of America 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

Foreword

This book describes the geography of the forests of the South as it once was and as it is today. For some lands, history has altered the course of ecological transition, and this has been noted. Never has the use of land been modified so rapidly by mankind in so short a period as within the past century. As the story of mankind continues to be written, so too will changes in land use and the nature of forests be noted.

Man's use of the land and its resources often sets in motion natural processes that cause permanent change. Frequently, the results are destructive—sometimes catastrophic. Erosion from cleared slopes removes topsoil developed over thousands of years and gullies from poorly engineered roads lower the moisture regime of the soil and degrade forest sites. Although the forests of the South have shown remarkable ability to reoccupy lands clearcut for timber, burned, or cleared for agriculture, new stands are usually of different species than were those under virgin conditions. Pines, sweetgum, yellow-poplar, or scrub oaks may now dominate rehabilitated sites where once vigorous stands of beech–birch–maple, chestnut, or oak–hickory covered the land. Hence, the forests in much of the region have been modified more or less severely by previous land use.

Forest practices, as well as the vegetative composition of the forest, will continue to be affected by land-use transition. Conversion of timber-producing forest lands to residential communities, factories, and reservoirs; or withdrawal of forests for watersheds, game preserves, parks, and scientific studies of the environment will necessitate intensifying practices on remaining lands to supply the nation's fiber needs. Site changes, and the necessity for highest production, will rarely permit reversion to original timber types. These managed forests will, however, be subjected to the same biota, edaphic, geographic, and climatic influences as their predecessors; foresters who manage them will be most successful when they are guided by wise consideration of the ways these factors are expressed in the native forest cover types.

So it is that I commend this textbook to a serious student. Its authors have field experience and education to justify that recommendation. Professor Laurence Walker, Ph.D., with five decades of the practices of forestry as researcher, national forest manager, and instructor, preceded me, once-removed, as dean of this college. Professor Brian Oswald, Ph.D., brought to the task experiences from beyond the South to the southern forest.

R. Scott Beasley, Dean
Arthur Temple College of Forestry
Stephen F. Austin State University
Nacogdoches, Texas

Preface

America’s 754 million acres of forest constitute more than a major physical asset: they are intricately involved in the national economy and culture. Forests provide a fifth of the nation’s industrial raw material (in terms of monetary value), protect and regulate its watersheds, provide grazing range for a sizeable portion of its livestock, produce most of its game and much of its non-sport wildlife, and annually attract millions of recreation visitors. The national forests and some other public lands are, by law, managed for all of these purposes. The public, some believe, may have a right also to expect these benefits from the 400 or more million acres in private ownership. The obligation, legal or implied, to provide these amenities subjects forest managers to multifaceted, and often contradictory, public scrutiny. This applies to the rapidly urbanizing and industrializing South, no less than to other regions of the country.

Consequently, administration of forests involves the accommodation of widely varying viewpoints. In some instances, these are essentially irreconcilable. Thus, the preservation of wilderness, though compatible with many watershed and wildlife management objectives, precludes timber harvest and domestic cattle grazing. Protection may even necessitate limiting recreation use, often the motivating reason for wilderness designation. How much potentially productive land the nation can devote to a use in which only a few participate—say in the year 2020—requires decisions now. Decisions adverse to preservation tend to be relatively irreversible: What we do today may set permanent limits on the acreage available for wilderness tomorrow.

But not always. Lands across the South that lay barren in the 1930s, following the cut-and-get-out harvests of the migrating lumbermen, were purchased for as little as $2.80 an acre in national forest acquisitions during the Great Depression years. So quickly did the stands of trees that regenerated naturally take on the pristine beauty of old growth that, in the 1980s, thousands of acres were set aside as statutory wilderness. Never again, unless a future U.S. Congress decides otherwise, will loggers utilize these areas for lumber and for pulp.

Some uses of forest land are compatible, or can be accommodated by allocating limited acreages, with a single use. But as no management system is optimum for all uses, the compromises by which a particular forest is managed involve economic considerations, objectives of ownership, and complex ecological relationships. To manage the 187 million acres of national forest lands for “the greatest good of the greatest number in the long run” takes the wisdom of a Solomon. More sagacity may be essential for handling the 164 million acres of privately owned and commercially useful woodlands in the South.

Altruism will continue to be a motivation for foresters as they oversee the southern woodlands. Carl Schenck, founder of America’s first forestry school, in the Pisgah Mountains of North Carolina in 1898, expressed this concern to his students with the phrase, “Excelsior, the higher good.” Others call this interest biophilia, implying a fondness for living things.

Perhaps for no other natural resource is the relevance of stewardship more appropriate than for the practice of forestry. Most people in the profession take seriously the Genesis directive of Hebrew–Christian persuasion to “replenish and subdue the earth.” To subdue is to control, but to replenish implies the restoration of exploited sites as well as the care of those being used to provide for the needs of people. Foresters, the original professional ecologists, remain responsible for the care of the wildland estate. Sustained yields of goods and services must come from these lands.

Wood, the principal product of the forest, is a renewable raw material (along with products of agriculture and fisheries and in contrast to oil, gas, and minerals). Its production requires only soil—with its nutrients and organisms—rainfall, and sunlight. So plentiful are woodlands that forest regeneration—whether natural or by planting seeds or seedlings—has not been particularly significant in the world of abundance from which Americans are emerging. But in a world of diminishing resources, wood is one of the few materials that can be produced in perpetuity at modest energy costs.

Wood is versatile. It is readily converted into products like wallboard, newsprint, and rayon, and to substitutes for petrochemicals. Once our chief fuel, wood is again considered an energy source: Between 5% and 20% of the country's forest area could supply its electrical demands, and gas and liquid fuels like ethane and ethyl alcohol can be produced from wood.

Structural materials that substitute for wood are chiefly steel and aluminum. Both metals increasingly depend for raw material on imported ores or on low-grade ores refinable at great energy costs. The amount of wood used in construction or for furniture can be lessened only by substituting more-expensive or less-satisfactory materials. Suitable substitutes for paperboard shipping containers or wooden railroad ties are unavailable at any cost. (Concrete and steel ties are expensive and, because they do not "give" under the heavy loads borne by the wheeled trucks of freight cars, do damage to wheels, axles, bearings, and cargo.) As the demand for wood increases significantly into the 20th century, prompt intensification of forest management on a decreasing land base becomes essential.

Society's demand for softwoods, the conifers, and their generally faster growth give them priority over broadleaf hardwoods in forestry, especially in the South. Fortunately, there they grow profitably on sites where better-quality hardwood species often do not. Concentration of a large portion of the southern harvest among relatively few species tends, however, to obscure the complexity of forest resources and their management. Fifteen softwoods and about 35 hardwoods are commercially important in the region. Dozens of other species are important for specialized uses or for their ecological influence. Hundreds of trees, shrubs, and herbaceous plants that appear in ecological succession during a stand's rotation, but which have no economic value, present the forester with baffling managerial problems.

For the reader to better grasp some of these dilemmas encountered by professional managers of the woodland estate is a major purpose for the preparation of this book. The authors hope the words of these pages do that.

Laurence C. Walker
Brian P. Oswald
Nacogdoches, Texas, 1999

Authors

Laurence C. Walker, as a research forester for government, universities, and industry, worked extensively on herbicide use, nutrient fertilization, and policy matters. For 13 years, he was dean of the school of forestry (now the Arthur Temple College of Forestry) at Stephen F. Austin State University. Subsequently, he served as the Lacy Hunt professor of Forestry, retiring with emeritus rank in 1988.

Dr. Walker held degrees from Pennsylvania State, Yale, and Syracuse universities. Consulting assignments on every forested continent included association with the U.S. Forest Service, Peace Corps, private environmental agencies, the Conservation Foundation, the National Plant Food Institute, the National Park Service, colleges, forest landowners, the wood-suing industry, attorneys, and state agencies.

Among his honors were Fellow, American Association for the Advancement of Science; Fellow, SAF; Fellow, the American Scientific Affiliation; and Distinguished Eagle Scout (for service to one's profession for men who were Eagle Scouts as youths). His publications included eight books and more than 150 journal articles and textbook chapters.

His most recent interest was forest history: *The Southern Forest: A Chronicle* (University of Texas Press), *Excelsior: Memoir of a Forester* (SFASI Axes, Oxen and Men (Free Press), and *North American Forests* (CRC Press), are among his books.

During the final preparation for this book, on July 28, 1999, Dr. Laurence C. Walker, its senior author, died. His knowledge of southern forestry, his dedication to his profession, and the joy he took in the education of future foresters, were an inspiration to all who knew him. The forestry profession lost a great teacher and friend. It is hoped that these pages would meet with Dr. Walker's approval.

Brian P. Oswald is Associate Professor of Fire Ecology, Silviculture, and Range Management at the Arthur Temple College of Forestry, Stephen F. Austin State University. He earned a BS in Forestry from Michigan State University, an MS in Forestry from Northern Arizona University, and a Ph.D in Forestry, Wildlife, and Range Sciences from the University of Idaho.

Prior to joining the faculty at SFA, he was Assistant Professor of Forest Ecology and Silviculture at Alabama A&M University, and spent five years teaching forestry and range management at a community college on the Navajo Reservation. Dr. Oswald has published some 10 refereed articles and more than 10 proceedings manuscripts.

Acknowledgments

The writers must recognize their indebtedness to Dean R. Scott Beasley of the Arthur Temple College of Forestry, Stephen F. Austin State University; to Bret Gentzler for technical assistance, and to a host of colleagues across the South who have been a source of inspiration, knowledge, and encouragement. Their professional abilities and altruistic motivation have assured the wise use of the woodlands entrusted to their care. We also thank our wives, Anne and Tina, and our offspring for their support along the way.

—LCW & BPO

Dedication

For Stefanie Sinclair Page
Jessica Lammon Oswald
and
Rebecca Irene Oswald—
little ones for whom we tend the forests today
so that they will have them to enjoy tomorrow.

TABLE OF CONTENTS

1 Geography of the Forest: An Overview

Those born beyond the forests of the tall pines and broad-beamed hardwoods of the South must acquire a taste for the region, just as they would acclimate to its ribbon cane syrup, corn pone, and breakfast grits.

When entering the forest from the west, one passes from the wide, flat space of the prairies into rooms bounded by green and brown vertical walls. Light sifts from above through the tree canopies as long, bright shafts. Sleepy swamps, covered with vines, branches, roots, and buttressed butts of baldcypress and broadleaf species, seem to come alive upon their entry by the sojourner. Indeed, to encounter for the first time the tall pines and widespreading hardwoods may seem somewhat like an initial visit to the narrow streets of Manhattan—one sees the same amount of light. Someone from the plains might be claustrophobic; another from the city homesick for the concrete jungle. It is in this, the South's environment, that the forester endeavors to grow trees for humanity's use and enjoyment.

Foresters refer to the characteristics of any particular locale that determine which species grow there and how fast they grow as "site factors." The four factors—physiographic, climatic, edaphic (referring to the soil), and biotic—interact to form ecosystems. The interrelationships of living things to each other and to their environment, called ecological processes or relationships, depend on these factors.

Early explorers and pioneers entered the South's forests without much understanding of overall climatic patterns for the region. They knew even less of the hills and swamps to be encountered; and beyond the pigmentation of the soil, observation was of little value. The smell or feel of the soil provided some recognition of land productivity. Geographic concepts, however, were well developed by the time of the migrating lumbermen. Foresters later capitalized on that information in formulating management plans for the vast pineries and hardwood uplands and bottomlands.

Boundaries of the southern forest depend on the surveyor. Some limit the region to the principal range of the hard pines, 10 species growing on various sites between New Jersey and Texas. Others exclude the Appalachian Mountains with two additional hard pine species (pitch and table-mountain) and a variety of northern hardwoods and the near-boreal coniferous red spruce and Fraser fir. Still, an observer could choose to map as part of the southern forest the hardwood timber types of the Ozark Plateau in Missouri and the Post Oak Belt in Texas, both areas sometimes considered part of the Central Hardwoods Region. All of these peripheral zones are included for our purposes as a part of the southern forest. Their contiguousness, the continuity of settlement and development of the land, and the interrelationships of species' range and timber harvests suggest the propriety of this boundary.

The southern forest thus comprises the area east of the prairies of Texas and Oklahoma and south of the Missouri, Ohio, and Potomac rivers, plus a northern extension along the Atlantic coast to central New Jersey. It embraces the range of the commercial southern pines, the productive sites of the southern river bottoms, and extensive forests of upland hardwoods. In addition to these three broad forest cover types—the term categorizing the composition of vegetation in the forest—southern silviculturists classify many lesser ones. The most important of the minor types are red spruce and Fraser fir, eastern white pine, eastern hemlock, eastern redcedar, baldcypress (and its pondcypress variety), and Atlantic white-cedar. Each has its niche in a biome, patterns of occurrence for each

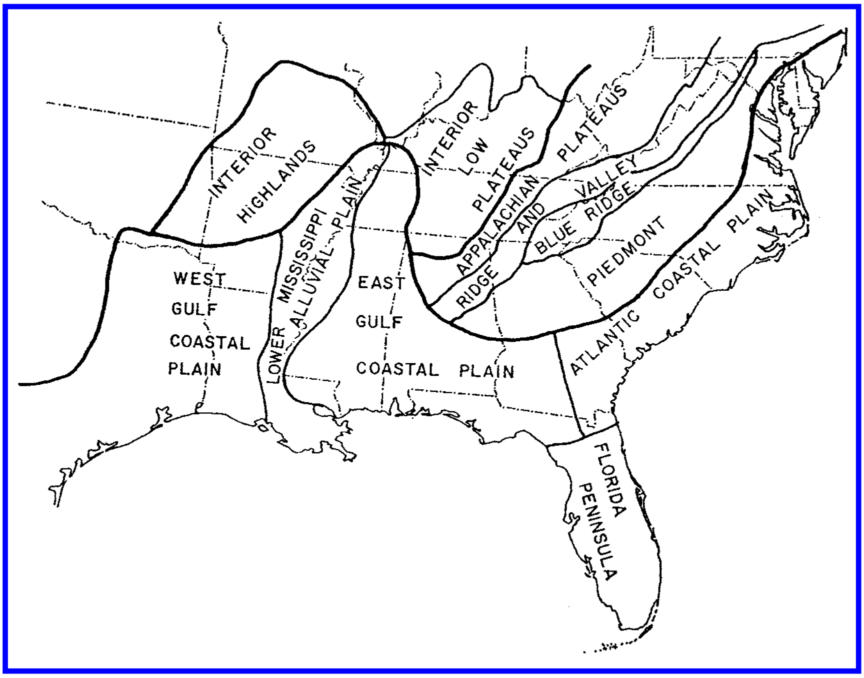

Figure 1.1 Physiography of the Southern Forest Region. (after N. Fenneman, 1938)[1]

being a matter of the previously named geographic factors—physiographic, climatic, edaphic, and biotic.

Physiographically, the southern forest includes the lower elevations and relief of the Coastal Plain bordering the Atlantic Ocean and the Gulf of Mexico, the irregular to mountainous slopes of the Appalachian provinces, the interior highlands of Arkansas and Missouri, and the interior low plateaus of Kentucky and Tennessee. Each of these components is further divided on the topographer's charts. The Piedmont of the Appalachians and the lower alluvial valley of the Mississippi River, dissecting the Coastal Plain of the Gulf of Mexico, are examples of subregions explicitly noted here because of their significance to forestry. The Florida peninsula of the Coastal Plain, the Blue Ridge Mountains, and the Ridge and Valley zones of the Appalachians are slightly less obviously associated with the occurrence of timber types.

The Region's Climate

Most of the southern forest is within the zone of Humid Subtropical climate, characterized by high temperature and abundant precipitation. The mountains are exceptions to this rule: At the colder upper reaches of the Southern Appalachians in North Carolina, the Fraser fir forest is similar to the balsam fir forests of coastal Maine.

Growing seasons are 180 days or longer in all but a few mountain sections, increasing to 320 days in southern Florida. High temperatures over these long growing seasons provide abundant energy for tree growth. For instance, loblolly pine in South Georgia may have as many as six flushes of height growth in a season, in contrast to three in the cooler part of the species' range.

The South lies mostly sunward of the isotherm that marks a 50°F mean annual temperature. The region's boundary approximates the 77°F summer isotherm—from northeastern North Carolina to northwestern Tennessee and, skirting the Ozark Mountains, to central Oklahoma. (This isotherm generally delimits the "land of cotton" of an earlier generation.)

For an area as vast as the South, and considering the influence of the large continental air mass that is confronted by ocean currents on two sides, precipitation is relatively constant throughout

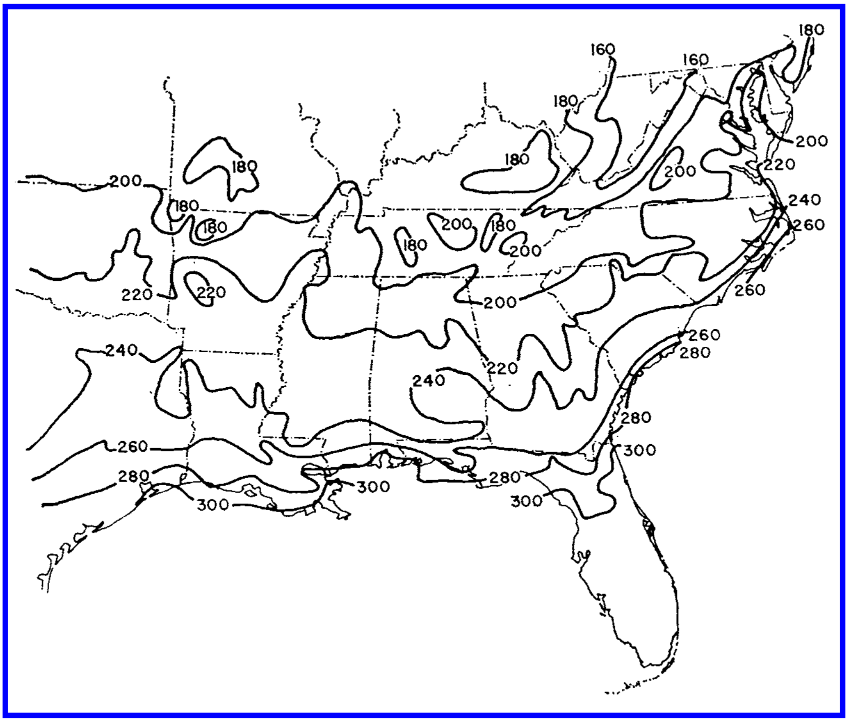

Figure 1.2 Average length of the growing season, in days. (USDA, 1941)[2]

the region. It averages 40 to 60 inches annually except in the higher, more southerly mountains where an excess of 80 inches may fall. At the upper reaches of the Appalachians along the North Carolina–Georgia line, precipitation often exceeds 120 inches in a 12-month period. That volume of rain and snow approaches the amount of precipitation received by the coniferous rain forest of the Olympic Peninsula of the Pacific Northwest and the tropical rain forests of Central America.

Not only is precipitation evenly spread throughout the region, it is also rather evenly distributed throughout the year. Some exceptions occur. More rain usually falls in winter than in summer in the western edge of the southern woodlands, as in the longleaf pine and loblolly pine forests of the Big Thicket in southeastern Texas. Even there, the difference between growing-season and dormant-season totals is not appreciable. Because southern Florida receives 60% of its rain in the summer, planting pines during the warmer months may be appropriate.

Annual and seasonal rainfall and snowfall tallies, together accounting for precipitation, suggest well-watered woods. However, the South is subject to the not infrequent "dry spell" which, during the growing season, can be disastrous to the forest. Seedlings die, fires rage, and beetles attack during these droughts that can last for more than a month. The 1995–1996 winter and the 1998 summer were notable examples.

The intensity of rain affects its availability for tree growth. Thunderstorms of high intensity and short duration may be experienced 50 or more days a year in all but the eastern and extreme southwestern parts of the region. Since these storms occur while the forest is in full foliage, the canopy intercepts some of the rainfall, wetting the leaves, stems, and trunks. Considerable moisture is so utilized before water begins to reach the forest floor by throughfall, by dripping from foliage, or by flowing down the trunks of the tree. Water held in the canopy is subject to rapid evaporation by free-flowing air. This interception may amount to 10 to 25% of the rainfall measured in adjacent open areas. It intensifies the effects of evaporation loss and the seasonal distribution of rainfall to make the already xeric southwestern part of the region drier than other climatic indicators might suggest.

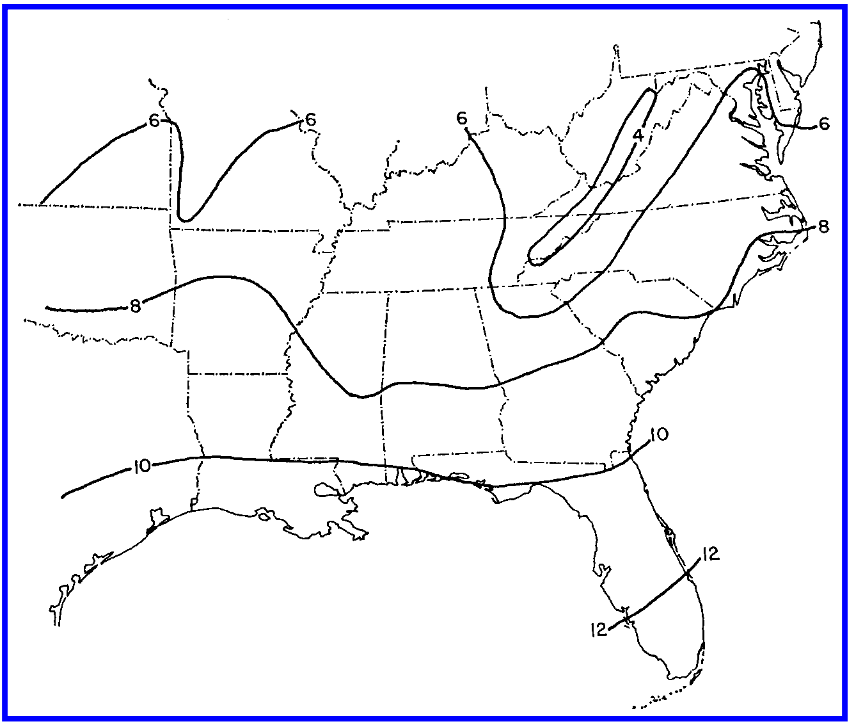

Figure 1.3 Average temperature effectiveness provides a measure for quantifying climate that suggests the rate of plant growth. It is computed by adding together, for each day of the growing season, the difference between its mean temperature and 40°F. The line of 800 units approximately bisects the southern forest. In contrast, New England measures 300 units and the Rocky Mountains, 600. The numbers represent hundreds of units. A day with an average temperature of 41°F. produces 1 unit a day with an average temperature of 42°F. produces 2 units, and so on. (after Livingston and Shreve, 1921)[3]

The Region's Soils

Varied edaphic materials and inconsistent slopes in the Coastal Plain's physiographic regions and subregions under the influence of climate, vegetation, and microorganisms have resulted in soils classed mainly as red-yellow ultisols. These are sediments in which iron and aluminum are slowly leached from the surface soil into the subsoil. Movement of iron is particularly noticeable, as the soils in which podzolization is advanced are lighter-colored at the surface and darker red below. Oxidation of the leached iron results in the red color, exemplified by the rust of a safety pin or jackknife left out in the weather. As the pin or knife soon will not open and close because of the rust of oxidation, so too subsoils are stiffer—the particles "rusted" together—than those at the surface. When a spade is thrust into the ground, it is suddenly impeded when the tool meets the denser subsoil somewhere between 4 and 40 inches below the surface.

Classifiers refer to the soils of the Appalachian Mountains as gray-brown alfisols. True podzols occasionally interrupt the surface strata of these podzolic soils at the higher elevations. Gray color at the surface indicates their presence, for the word *podzol*, from the Russian, means ash-white. (Soils like the true podzols occur in cold, moist climates throughout the world.)

Podzolics are in the process of becoming true *podzols* as iron and aluminum oxides leach from the surface to the lower horizons of the soil. It is the loss of those elements that gives the light color to the soil particles. With podzolics, leaching is never complete, so the reddish color of iron oxide does not disappear. *Lithosols*, denoting shallow soils containing many weathered rock fragments, even at the surface, are relatively recently derived and are usually found on ridges of the South's mountainous areas. Calcareous black soils are called *rendzinas*. These are found on the

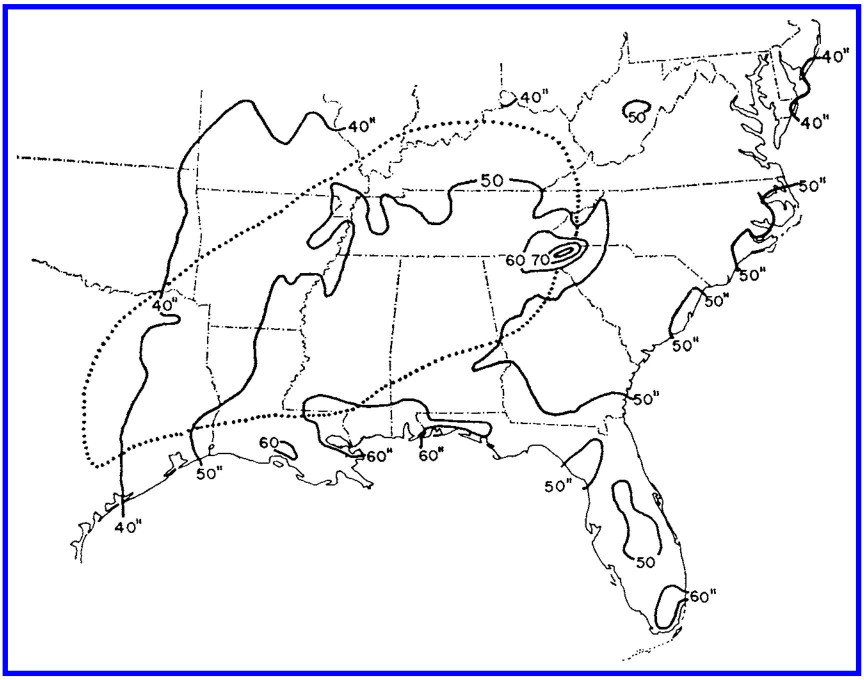

Figure 1.4 Average annual precipitation. Within the area outlined by the dotted line, summer rainfall is 40 to 50% of the annual total; elsewhere it is 50 to 60%. (after USDA, 1941; and G. Trewartha, 1961)[4]

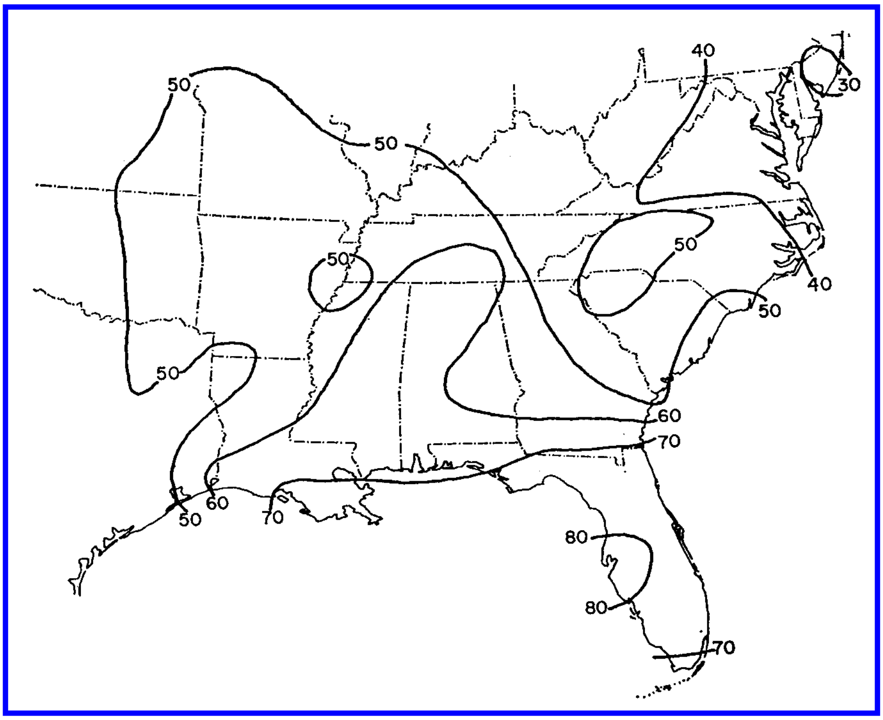

Figure 1.5 Average annual number of days with thunderstorms. (after USDA, 1941)[5]

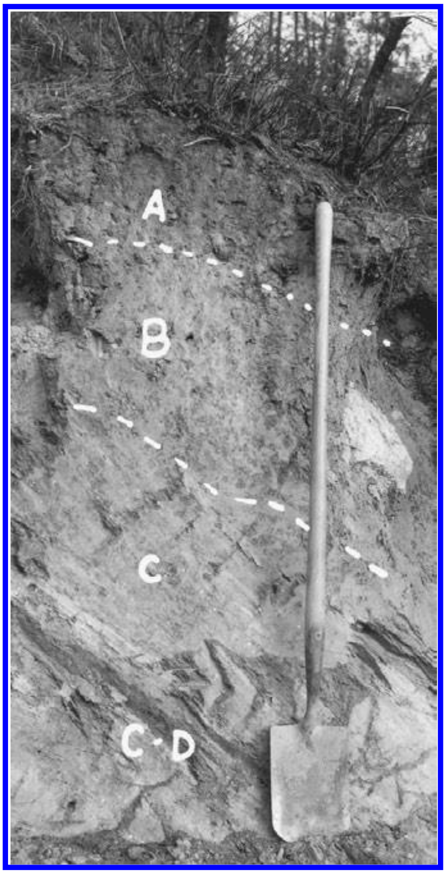

Figure 1.6 Horizons of virgin forested soils in the Piedmont province. The upper A horizon contains perhaps 5% organic matter. The B consists of more compact clay, while the C is mineral parent material from which the soil was derived through weathering and dissolution. Here the D zone of bedrock contains partially weathered material.

non-forested prairies that occur as a crescent in Alabama's midsection and the finger-like intrusions into Texas from Oklahoma at the western edge of the southern forest. Old seabeds of marl or chalk encourage the development of these soils in humid zones.

As the South escaped glaciation, its soils lack the accumulation of the many nutrient-supplying minerals released from the rocks that were carried and ground into powder by the massive movement of the ice sheet, as in the Northeast and Lake States.

The Region's Forests

Biotic factors influencing the forest involve animals (insects, birds, mammals, etc.), plants (fungi, competing vegetation, etc.), and, of course, the trees themselves. In this book, trees are our principal concern, though other biotic components play significant roles in the development of forests.

More than 60 forest-cover types have been recognized by the Society of American Foresters as occurring in the South. These are generally grouped into nine classes. The oak–hickory–pine type, the most widespread, covers 21.7 million acres.

Acreages garnered from survey records of the U.S. Forest Service show the four principal southern pines (longleaf, slash, loblolly, and shortleaf) to be the primary species on more than 69 million acres. Most of this acreage is in the Coastal Plain, some 70% covered by loblolly or shortleaf pines. The lesser southern pines (pond, Virginia, sand, pitch, spruce, and table-mountain) occur on

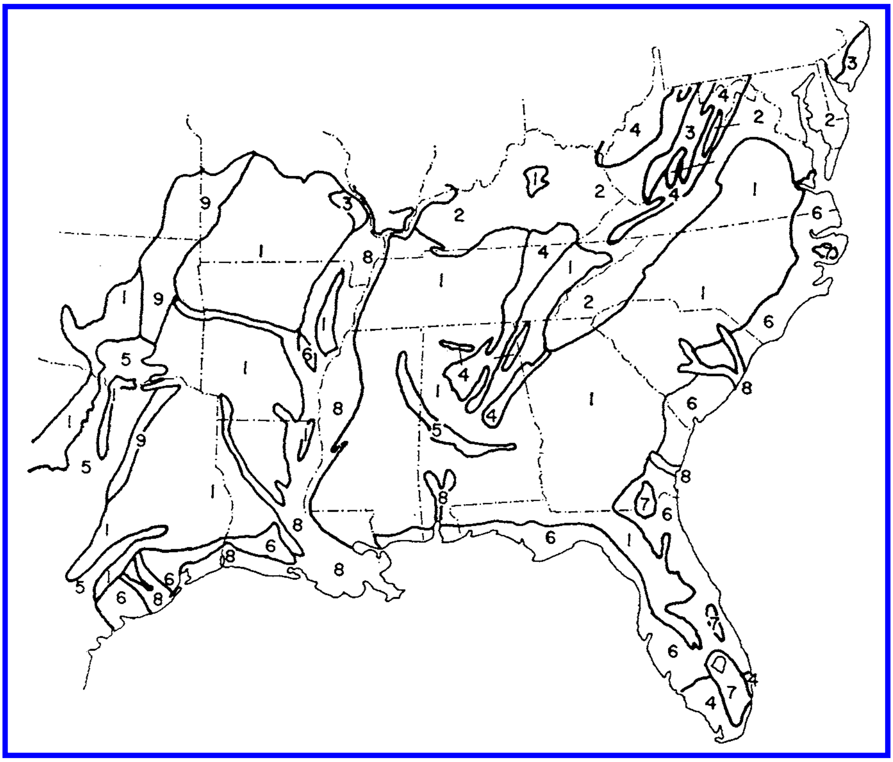

Figure 1.7 Soil regions of the southern United States: (1) red and yellow podzolics, (2) grey-brown podzolics, (3) podzols, (4) lithosols, (5) rendzina, (6) weisenboden, ground-water podzol, and half-bog, (7) bog, (8) alluvium, and (9) planosols. More recently a highly technical International Classification System has been developed. (after USDA, 1957)[6]

5.5 million acres in the Coastal Plain, Piedmont, and Appalachian provinces. The oaks and pines together are tallied on 30 million acres and the oaks and hickories on 86 million acres. Baldcypress stands, with their associated gums and oaks, comprise 34.3 million acres in the South. The elm–ash–cottonwood type of the wet areas and the beech–birch–maple predominate on 4 million and 3.2 million acres, respectively. The latter type predominates on the midslopes of the mountains and occasionally along the edges of the rivers of the Coastal Plain. White pines and hemlocks, the latter the climax species under pioneer white pines, are mapped on about a third of a million acres; the spruce and fir forests, exclusively in the upper reaches of the Appalachians, occur on another 42,000 acres.

Eastern redcedar (a juniper) spreads out rather evenly in all provinces, totaling about 2.5 million acres, excluding the Nashville Basin and the Ozark Cedar Glades. Eastern redcedar and bunch grass together dominate the cedar glades of the Nashville Basin in Tennessee. In the Ozarks, where redcedar once was a predominant species, its presence is now much less frequent. In the cedar brakes of the Hill Country of central Texas, Ashe and Pinchot junipers, appearing as redcedars to the inexperienced, honor in their names a dendrologist and the father of American forestry, respectively. Mesquite, an import from South Texas and Mexico brought northward as seeds in the stomachs of cattle during their long drives to market stockyards or kept low in numbers by frequent surface fires, now accompanies the junipers, as do post oaks and other scrub oaks, on many sites. The juniper trees, with their red-colored fragrant wood, may form pure stands.

The totals, allowing for generous rounding of figures, indicate that about 128 million forested acres occur in the Coastal Plain, 33 million in the Piedmont province, 39 million in the Appalachian Mountains, 10 million in the Interior Low Plateaus of Kentucky and Tennessee, and 25.5 million

Figure 1.8 Sampling tubes enable study of the soil to depths of several feet below the surface of the ground. Extracted from the pipe onto a tray, texture, color, and structure can be observed and samples from various depths carried to a laboratory for chemical, physical, and biological analysis.

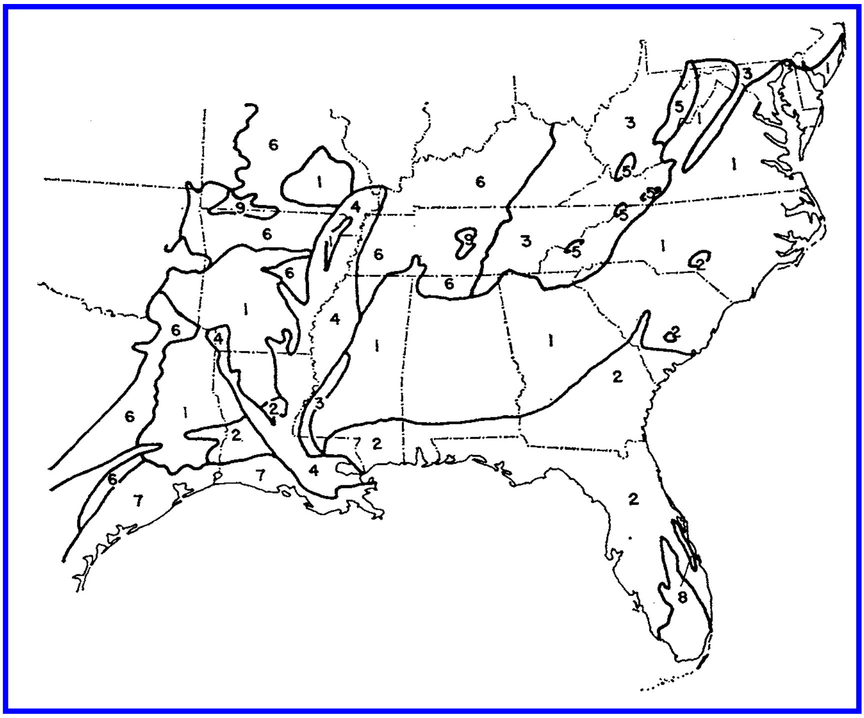

Figure 1.9 Potential vegetation types of the Southern Forest Region: (1) oak–hickory–pine, (2) longleaf–loblolly–slash pines, (3) oak–ash–hickory–yellow-poplar–maple–basswood–Buckeye–beech, (4) oak–sweetgum–baldcypress–tupelo, (5) beech–birch–maple–hemlock, (6) oak-hickory, (7) coastal prairie, (8) Everglades grasses, and (9) redcedar–bunch grass (cedar glade). (after USDA, 1963; and A.W. Kuchler, 1964)[7]

in the Interior Highlands of Arkansas and Missouri. The grand total of the southern forests, changing daily as land is reclaimed to woodlands and converted from timberlands to other uses, now approximates 235.5 million acres, or 368 thousand square miles. That is the equivalent of the gross area of the five New England states plus the three large Lake States (Michigan, Wisconsin, and Minnesota), plus Indiana and another some two thousand square miles. The pre-Columbian forests of the South could have encompassed 400,000 square miles.

The late-successional climax oak–hickory forests were most frequently found by the explorers and pioneers as they roamed these woods in the Piedmont and in the upper Coastal Plain from East Texas to New Jersey. This cover type also predominates in the Missouri Ozarks. The oaks and hickories (without the pines) are the common species of the forested biomes of western Kentucky and Tennessee, of the higher elevations in the Ozarks, and of the Post Oak Belt's ecotone; often called the tension zone, just west of the pineries of East Texas.

Longleaf pine–loblolly pine–slash pine form the overstory vegetation in the lower Coastal Plain, extending from southern South Carolina into the pineries of Texas. Often fire climax, and certainly present because of fire history, in the absence of fire, these stands give way to the oak–hickory climax cover type.

In the rolling hills from Maryland to the Bluffs of Mississippi, a complex forest often develops. It may consist of mixtures of several oaks, ash, several hickories, yellow-poplar, maple, basswood, buckeye, and beech. Among these species are both climax trees, such as the oaks and hickories, and intolerant pioneer plants like yellow-poplar. The stands are thus uneven-aged as well as mixed. Openings created by man or nature in a climax stand provide conditions that encourage light-demanding hardwoods to germinate and survive.

The river bottoms, often spreading out for miles as a fan from both sides of water courses, exhibit mixtures of oaks, sweetgum, baldcypress, and tupelo. While these predominate, perhaps a hundred lesser species also occur. (Heartwood from the sweetgum trees growing in these lowlands, in contrast to those on high, dry hills, is a rich reddish-brown; hence, the tree is often referred to as redgum. When used for furniture and millwork, the wood is marketed by lumbermen as figured gum, along with tupelo found on similar sites.) About 25% of the Coastal Plain forests originally were bottomland types. Higher-value use of the land, especially for agricultural crops like cotton and soybeans, has lately diminished the bottomland acreage growing fine hardwoods and bald-cypress trees.

Among the unusual wet-site forests are the pond pines in the *pocosins*—Indian for "swamp-on-a-hill"—that survive repeated wildfires raging through the organic soils when the fibrous surface stratum dries out. Normally too waterlogged for good tree growth, when dry the accumulation of pine needles is highly flammable. Atlantic white-cedar also occurs as dense, pure stands in pocosin swamps. These wetlands, covering a few to several thousand acres in area, may have developed where dunes along shorelines have affected waterflow, the ponds filling with organic matter that decomposes into soft black muck and brown fibrous peat.

Domes of baldcypress—another unusual wet-site biome—occur in lower peninsular Florida. These islands, with the taller trees in the center (the opposite of conventional isolated stands of trees), range in size from less than one to more than 100 acres. Variously attributed to fire, grazing, and drainage, the domes are surrounded by grassy savannas or by water.

Spruce pine, growing on the moist fringes surrounding longleaf pine stands not far inland from the Gulf of Mexico, is also associated with loblolly pine and hardwoods in the drainages of the Coastal Plain. Acreages and volumes available for harvest and marketing are so small that the species has had only minor attention. Little is known about its silvical characteristics.

Coastal prairies, frequently joining coastal estuaries of broadleaf trees and shrubs, are influenced by the storms that develop in the Gulf of Mexico. Cyclone winds and fire keep them treeless. Everglades, the extensive acreages of grasses at the southern tip of Florida, like the coastal prairies, also are generally without forests.

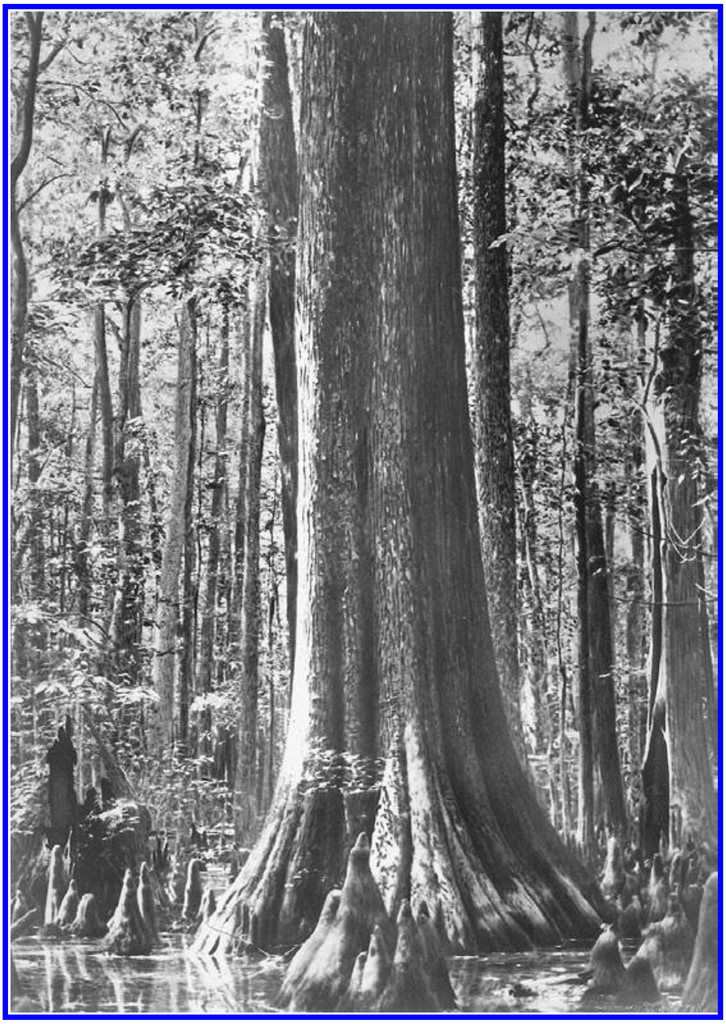

Figure 1.10 Periodically flooded estuary. Fluctuating water levels in coastal "lakes" like this one supporting baldcypress trees have become a major concern of the federal government with passage of the Coastal Zone Management Act.

Coastal *savannas* (treeless grassy plains) should not be confused with grassland types with scattered trees occurring farther west or the blackland prairies developed on calcareous parent material inland from the Gulf Coast. These latter dry savannas also interrupt the forests; such sites today find use as improved pastures.

Among the unusual dry-sites are the pine barrens of southern New Jersey that lie on the edge of the southern forest. Such xeric areas include vast acreages of sprout-reproduced, short-boled pitch pines in extensive zones called "plains." Scrub oaks and shortleaf pines compete with pitch pines on these excessively drained sites. The low-value hardwoods must be controlled if a new pine stand of any commercial value is to be regenerated. However, many prefer the barrens left for aesthetic reasons in their present condition. To accommodate that preference limits management intensity and, thus, the commercial value of these forests.

West Florida sandhills, covered with pure stands of low-grade longleaf pine prior to the harvest of the virgin forest, are also difficult xeric regeneration sites. Before seedlings are planted, sites should be prepared by removing the invading drought-hardy scrub hardwoods. Slash pine, which was also abundant in the droughty sandhills virgin forest, has been the preferred species for planting

Figure 1.11 Remnant virgin longleaf pine–scrub oak forest cover type in the west Florida sandhills. Many such stands naturally regenerated to slash pine following the initial lumberman's harvest; other sites were planted to the latter species. Only recently has an interest in reestablishing longleaf pine on these lands become significant. (USDA Forest Service photo by E. A. Hebb, 1955)

on these deep, coarse, sandy soils in the Panhandle of Florida, but longleaf pine is gaining in appeal as planting knowledge increases.

We now consider the zones of the region in some detail.

Coastal Plain

Physiography—The Coastal Plain, a 320,000-square-mile zone that extends east from the western limits of the southern forest in Texas to the Atlantic shore, supports the most extensive and productive pine forests of the South. A happy combination of the four factors of site makes this so. Geologically young, the underlying sediments of the region are mainly sands, gravels, clays, and marls, in strata that drop toward the coast. Older sediments are exposed in the interior, younger ones seaward. Elevations rarely reach 1000 feet, and local relief is seldom more than 500 feet.

Along the eastern sector of the Gulf of Mexico, the Plain is characterized by a series of terraces oriented almost parallel to the present coastline. In contrast, the western Gulf Coastal Plain consists of alternating low ridges and valleys, again approximately parallel to the shore, that give rise to a belted topography. The Florida peninsula and the Great Alluvial Valley of the lower Mississippi River interrupt these patterns.

From central North Carolina northward, the Atlantic Coastal Plain is indented by bays and estuaries penetrating halfway or more to the Piedmont section of the Appalachians, thus dividing the land surface into a series of peninsula-like extensions. Long barrier beaches and islands separated from the mainland by sleepy lagoons are an attraction for wildlife and saltwater enthusiasts.

Sand dunes and salt-spray sites commonly occur at the fringes of these barrier islands as well as on strips of mainland up to a mile inland along either coastline. (Where winds constantly move beach sands, few woody plants become established until grasses and sedges first capture the site.) Though deep, the soils are infertile and frequently flooded by storm-blown salt spray or seawater. Some pines seem to resist frequent salt-spray damage; such especially persist on the barrier islands off the Mississippi Coast. Some salt-tolerant trees, like live oak, wax myrtle, and yaupon, endure the harsh environment of saltwater coasts.

Figure 1.12 Mature stand of sand pine in the Big Scrub of central peninsular Florida. Trees of this serotinous species of poor form mature at about 35 years of age. They persist for another 25 years, gradually falling apart. The stand shown is 50 years old.

From the Delaware River southward to the Georgia shoreline, the Atlantic Coastal Plain is characterized by a series of broad marine and fluvial step-like terraces roughly paralleling the ocean. These zones are separated by low escarpments, each of slightly greater seaward slope. So distinct are the terraces in the southern section that travelers may observe tide-washed boulders on either side of a road as it dips toward the sea, perhaps a hundred miles from where waves now buffet the shore. Deep sands, too, tell that far inland, where great forests now stand, was once the ocean's edge.

These terraces, laid down at different times, exhibit variation otherwise attributed to length of exposure for weathering and the degree of uplift above the present sea level in ages past. The innermost terraces are older, lifted higher, and exhibit more pronounced relief. Here, leaching and oxidation of nutrients and organic matter over a long period have formed thicker, weathered zones in the soil profile. Plow furrows expose a brilliant red color in the soils, thus early settlers called them redlands. Names like that persist for titles of towns in the upper Coastal Plain.

Flatwoods are important components of the forest of the lower Coastal Plain. Often they are on the low side of a terrace, immediately above where the land gives way to a swamp.

The uppermost terrace on the Atlantic Ocean side of the Coastal Plain is called the Fall Line. This sandy zone also forms the outer limit of the Piedmont province—the foot of the mountains—that lies to the northwest. The outcrops of sand extend in a belt roughly paralleling the coast, in places more than 20 miles wide, while in some zones the Fall Line appears only as a narrow strip of imperceptible width. Elevations of the hills of the Fall Line approach a thousand feet, occasionally rising higher than the adjacent Piedmont province. Longleaf pines, with an unusual resistance to brown spot disease (a seedling needle blight) and scrub oaks capture these xeric sites.

Figure 1.13 Typical scrub oak site in the Fall Line sandhills. Such stands tally 3400 stems per acre, ranging from 1/2 to 6 inches in diameter at breast height (DBH). (USDA Forest Service photo by R. Shipman, 1954)

Soils—Typically, the podzolic soils of the Coastal Plains have deep, well-developed profiles that are slightly acid and low in organic matter and soluble nutrients. Occasionally, they are saline, from salt-water intrusion; in other places alkaline, where limestone solution has played a role in their genesis. Texture of the yellowish to reddish surface materials varies from clay through silt to sand, although sandy loam and silty loam classes are common. Some of these soils contain fragments of rock.

Mottled red, yellow, and bluish-gray subsoils occur throughout the Coastal Plain. Oxidation, reduction, and hydration of iron coatings on the surfaces of the grains of soil give the particles hues of various shades. These chemical reactions also result in the development of hardpans or clay pans several feet below the surface. Spades, picks, and soil augers are impeded by this tough zone, unable to penetrate it. Sometimes subsoilers, towed by tractors, cut through this zone to improve drainage; sometimes dynamite is necessary to fracture the subsoil.

Atop the parent material or lying on former soil surfaces might be an overburden of peat (with more than 50% organic matter) or muck (between 20 and 50%). Soil scientists also classify wet mineral soils within 100 miles of the coasts of both the Atlantic Ocean and the Gulf of Mexico as *wiesenboden*. Associated with these are the *half-bogs,* a rich mixture of organic matter and silt and clay. In this broad area, too, one charts the *bogs*; they may occur in small patches or in large swamps, like the Dismal, the Okefenokee, and the Everglades. Atlantic white-cedar trees predominate in the former, baldcypress and many broadleaf species in the Okefenokee, while grasses and shrubby woody plants cover most of South Florida's Everglades.

Forests—Upland Coastal Plain forest types include mixtures of loblolly and shortleaf pines, amounting to about one-fourth of the total acreage of the zone. Longleaf and slash pines together compose 17% of the province, and the composite oak–pine forests some 33%. Pond pine, mostly along the Atlantic seaboard, accounts for 2% of the total, while sand pine, eastern redcedar, and Virginia pine amount to less than 0.3%. These values change as hardwoods encroach in pine forests with fire suppression and pine cutting, and, conversely, as abandoned farmland reverts to old-field pine forests.

The longleaf pine–slash pine mixture predominates on sandy soils within the natural ranges of these two species. This is so even where hardpans underlie the surface soil. (Longleaf pine is a deep tap-rooted tree.) Tall, straight stems, prized for poles, piling, and plywood bolts, suggest the favorable moisture-holding capacity of better soils. Turkey oak and other scrub oaks are associates of longleaf pine on more droughty soils, while blackgum and red maple accompany slash pine.

Slash pine is not found naturally west of the Mississippi River, but foresters introduced planted stands in East Texas and western Louisiana as early as the 1930s. The South Florida variety of slash pine occurs in the subtropical zone of that state along with some tropical hardwoods.

Although often considered a moist-site species, loblolly pine has wide site tolerance. It does well from the edges of wet savannas in Virginia to the xeric rocky outcrops of Central Texas.[8] It can also be found associated with longleaf pine. Indeed, where wildfire is excluded, as it has been since the 1940s throughout much of its range, loblolly pine replaces longleaf pine. Consequently, the acreage of longleaf pine rapidly declined until the 1980s. With the use of prescribed fire for stand regeneration, the area covered with longleaf pine has since increased and continues to do so. Indeed, foresters aggressively work to restore this highest-quality southern pine to much of its original range. Growing straight and tall, the wood is dense.

Upland hardwoods, including those in the Post Oak Belt in Oklahoma and Texas, constitute a fifth of the forests of the Coastal Plain. Apart from the Belt, the occurrence of broadleaf species in the region largely relates to past use of the land. Narrow bands of broadleaf trees occur along major drainages and minor streams where dampness excludes fire.

Disruptions To The Coastal Plain

The Mississippi Delta—A physiographic feature that breaks into the general pattern of the Gulf Coastal Plain is the lower alluvial valley of the Mississippi River, called the *Delta* locally and in forestry literature. It interrupts the prevailing east–west orientation of the Coastal Plain with a north–south strip of alluvial soils bearing distinctive bottomland hardwood forests.

Pioneering settlers seemed to have had an understanding of world geography, especially the similarity of the lower Mississippi Valley to the mouth of the rich Nile River of Egypt. Cairo, IL;

Figure 1.14 A Coastal Plain longleaf pine pole stand that regenerated following a blow-down 50 years earlier. Periodically burned, the stand with its "rough" (the ground cover) provides good habitat for quail. (USDA Forest Service photo)

Memphis, TN; and Alexandria, LA, remind one of the cities by the same names not far from where the Nile pours its silt-laden waters into the Mediterranean Sea. The influence upon the land of the Nile and Mississippi rivers is not dissimilar.

The Mississippi, an aggrading river, built up this alluvial plain more than 500 miles long and 25 to 125 miles wide in the large structural trough between the Appalachian and the Ozark mountains. Because of modification by silt deposition, the average valley gradient is less than 8 inches per mile; land sometimes slopes downward away from the river to lower-elevation basins within the flood plain. These flood basins range in size from a few hundred acres to major regions embracing numerous subbasins, such as those drained by the Yazoo River in Mississippi, the St. Francis and Black rivers in Arkansas, and the Tensas and Atchafalaya rivers in Louisiana. Except between Memphis and Vicksburg, the Mississippi River channel currently lies near the eastern margin of the flood plain at the foot of the Bluff Hills, which rise immediately to the east of the Delta. Over the centuries, the River has meandered throughout the plain, producing a landscape of old terraces that represent stages of valley fill. Many low ridges, and cutoff meanders forming oxbow lakes, mark the location of old natural levees along the stream channel.[9]

Average annual precipitation ranges from about 45 inches in the north to 60 inches in the Delta's south. However, dry periods have little effect on the growth of forests in the Delta's poorly drained soils.

Alluvial silts, often originating in the mountains a thousand miles or more from their present locale, fill the streams and overflow the rivers of both the Atlantic and Gulf coasts. The Mississippi provides a classic example. While continuing to build, its delta got its start from glacial silt eroded from northern precincts and deposited during the Pleistocene Period of geologic history. These soils are especially important in the Great Mississippi Delta, extending from southern Illinois to the Gulf shore below New Orleans. The fine particles making up this sediment may have traveled

Figure 1.15 Post oaks of the so-called tension zone in Texas and Oklahoma. The relatively pure stands lie just west of the pine–hardwood forests. Rainfall too low to sustain pine seedlings through a second year precludes their establishment. As a rule of thumb, two consecutive years of adequate summer and early autumn rainfall assures a new stand of loblolly and/or shortleaf pines, provided a seed source is available and the site has been prepared by fire or disturbance.

from what is now the glaciated Allegheny Mountains via the river of the same name in northwestern Pennsylvania to the Ohio River, moving with its flow to the Mississippi at Cairo, Illinois, and thence southward.

Other silts and clays have been transported to the Mississippi from as far away as the upper reaches of the Southern Appalachians, above 5000 feet, just to the west of the summit of the subcontinental divide in Tennessee. First through trickling springs, then infant streams, and then cascading down creeks to the Little Tennessee River, these suspended sediments move. Then they flow with the current to the Tennessee River, from there to race from corner to corner through northern Alabama, turning north at the Mississippi line and pushing through Tennessee and Kentucky. That water and its silts, along with the flow of the Cumberland River that drains the mid-section of the Appalachians from West Virginia and Tennessee, then funnel into the Ohio River. A hundred miles of river course and the Ohio joins the Mighty Mississippi.

Some sediments, too, have come from the east slope of the Continental Divide, high in the Rocky Mountains. They move, via the Arkansas and Missouri rivers and the tributaries that feed them, into the “Father of Waters” en route to the Gulf of Mexico.

Not all of these materials are consigned to salt the sea as the Mississippi empties its sediment loads into the Gulf. Historically, in times of flood and overflows, for 50 or more miles from the main channel, the water-carrying sediments become trapped when the River’s high water recedes behind both natural and man-made levees. These soil grains reach the delta in suspension, as sugar is held in a supersaturated glass of tea, and not in solution as salt dissolves in a bowl of hot soup. While flood waters recede, moisture moves to the air by evaporation or percolates by gravity through the ground below, in both cases leaving behind particles of silt and clay.

Figure 1.16 Cottonwood trees thrive on batture lands of the Mississippi River Delta. Plowing during the first year following planting is necessary to control vegetative competition. Later, low-level plants provide habitat for small wildlife. (USDA Forest Service photo)

Little of the sands dislodged by the erosive forces that sent the silt and clay downstream travel as far as the delta. Each sand grain is relatively large and heavy. Because it is not in suspension, its movement is by water force. After the raindrops' impact that releases sand sediments either from a river's bank, high above and far away, or a river's nearby thrust, sand particles are pushed to the side of the channel to build *new land*. On this new land, cottonwood and willow trees promptly seed in to hold the soil in place. The suspended finer materials rush on below, either to precipitate in the river's overflow or to build a new strata of sediment along the coast beneath the sea.

The soils of this alluvial plain are well supplied with nutrients other than nitrogen. Texture varies with the velocity of the flood waters by which the soils were deposited. The coarser materials, those fine sands and sandy loams that have reached the delta, are found on natural levees adjacent to present or former river channels where flood waters flow most rapidly. Progressively, the coarser sediments tend to drop out as flood waters spread from the main channel, leaving little but clay to be deposited in the black backwater swamps. Differences in aeration due to these texture gradients and to variability in surface drainage have marked effects on soil productiveness for forest tree growth. Soil patterns may be extremely complicated in areas where remnants of natural levees from old meanders are unrelated to the present channel.

Artificial levees and other engineering protection works have greatly reduced flooding in much of the Mississippi River's delta. Few major overflows of the main river have occurred since 1927, the latest occurring in 1993. This protection and, with it, improved local drainage have lowered water tables and encouraged widespread land clearing for agriculture. With less area available for forestry in protected basins, there is increased silvical interest in the unprotected lands, called

Figure 1.17 A ragged, unmanaged cottonwood stand on Mississippi River batture land. A recent sawtimber harvest had removed 1/3 of the merchantable volume of 36,000 board feet per acre. (authors' collection)

battures, that lie between the levees and the river channel. Light-textured and fertile, these sites, like new land, often support excellent stands of cottonwood and willow.

Forest types of the Delta are related to the elevation of the land; slight differences cause significant changes in species composition. Flats, fronts, new land, ridges, swales, and swamps are often characterized by certain tree groups. About 70 species of commercial importance occur, usually in mixed stands. Along a river front are eastern cottonwood and willow, while farther back, pure stands of sweetgum, water oak, white oak, or ash may be found. Mixed stands on the ridges—slight rises of a few inches to a few feet above a surrounding flat—may be predominantly of white, red, and water oaks, hickories, sweetgum, baldcypress, blackgum, and water tupelo.

Fire, tornado, logging, agriculture, flooding, sedimentation, and erosion have each played a role in determining the present mixture of species and age classes, ranging from seedlings to mature trees. Many species intolerant of shade become established in the openings; others develop in the understories of older stands. Generally, seedbeds must be moist, but not flooded, and for many species like the willow and cottonwood that seed-in on new land recently built up alongside a river during a flood, the mineral soil must be exposed.

Bluff Hills—Formed from the wind-blown silts of the Mississippi Delta, the Bluff Hills lie east of the river in the states of Mississippi and Tennessee. The bluffs stand 125 to 250 feet above the river flood plain. While the wind-deposited loess thins rapidly eastward, brown loam soils indicate the presence of aeolian deposits as far as 100 miles east of the western edge of the bluffs.

Exposed loess rapidly erodes. Yet these sites are among the most fertile in the South. They were cleared before 1860 for agriculture, but by 1930 erosion was so severe that cultivation was hopeless. In 1906, the agriculturist E.W. Hilgard noted that both industrial communities and agrarian

Figure 1.18 Gully erosion in loess (silty) soil. Congress appropriated money for the USDA Forest Service to plant trees on these privately owned, devastated and abandoned cotton fields and hay meadows in western Tennessee and northern Mississippi in the post-World War II years. Grasses had not halted these "washes;" hopefully trees would, as these sites produce quality timber. (Soil Conservation Service photo)

lands had washed down the hills.[10] Annual losses of over 100 tons per acre from cultivated land were not unusual. Here, the old southern term "gullywasher" expresses a tragic truth as it describes intense summer thunderstorms common to the area.

Travelers crossing the Mississippi River from the west at Vicksburg have an excellent view of a classical loessal bluff. Here, 100 feet above the water, Confederate troops watched the adversary on the river, readily fired upon his battle boats, and for almost 3 months stayed the federal offensive. The river has changed its course since 1863, moving slightly west, thus hiding the proximity of the guns mounted on the Bluff Hills from the vessels in the channel below.

The Mississippi had changed its course often before those eventful days, creating new alluvium and leaving the old strata to dry out and seed-in to trees. Unknown are the frequencies during the Pleistocene Period of the powerful dust blows that moved the soft silt from the dry bottomlands lying to the west. Mounded in hills, horizon upon horizon, winds gently deposited nutrient-rich sediments.[11] Sediments still blow into the Bluff Hills from plowed fields of eastern Arkansas and Louisiana. These deposits of yellowish-brown silt differ little from that of the buff-colored prairies of Iowa and the plains of Nebraska.

Bogs—We turn now to the peat and muck in the bog sites along both the Atlantic and Gulf coasts. Often these organic soils are met by sand dunes at one extreme, and by marshes at the other. The sands are usually coarse, largely coming from the mountain-forming granites and associated bedrock materials. The sands of quartz, the fourth-hardest natural mineral (after diamond, corundum, and topaz) were released in some past geologic millennia from granite rocks, also containing feldspar and mica. In contrast to the silicon dioxide quartz (like flint and sandstone), the feldspar and mica are relatively soft. These minerals are thus more readily decomposed and dissolved, their nutrient elements rather promptly released for plant growth. (The slowly soluble silicaceous mineral is not essential for plant growth.) The abundance of sand at the edge and in the bottom of the sea is related to the mineral's insolubility. It is released from the rocks of the land when the rocks are fractured by freezing and thawing and by water and acidic solution of other more-soluble components of the earth's mantle. Conversely, the sea is saline because of the solubility of the mineral-containing salts in the softer materials of the earth's rocky crust.

The marshes have an abundance of these salts, storing them for a season in the grasses and herbaceous plants that grow in savannas along the coasts from New Jersey to Texas. Like all of the sediments of the Coastal Plain except for the Bluffs, the saline soils of these wet sites are water-laid deposits. The rock beneath these soils, often at depths of hundreds of feet, has had little to do with the genesis of the soils in which trees and lesser plants grow. (In contrast, soils in areas above the Coastal Plain, as in the Piedmont and the several mountain ranges, have been formed in place. Such *in situ* development depends upon the weather, the action of plants and animals, and the nature of the parent material and time.)

Under poorly drained conditions at low elevations, groundwater podzols occur. These tend to show an organic-rich layer at the surface. Underlying that strata is a thick organic and iron-rich hardpan mottled with an array of yellow and brown colors that suggest hydration in times past. Bog sites are common from the Atlantic white-cedar swamps of New Jersey to the pocosins of pond pine in the Carolinas.

Flatwoods—The term flatwoods is applied to a number of extensive areas of low relief within the Coastal Plain, usually limited to pine and pine–hardwood sites. Such areas occur on the lower terraces along the Atlantic and Gulf coasts. They also are found in interior belts where clays or other fine sediments result in the development of flat topography.

The coastal flatwoods, mostly at elevations below 25 feet, are poorly drained but not permanently inundated. Although soils are usually sandy, root development is often limited by high water tables or hardpans that underlie the surface horizon. Loblolly pine and numerous hardwoods are supported by these sites throughout the region. Pond pine and Atlantic white-cedar are common along the Atlantic coast, longleaf pine may be present south of Virginia, and slash pine east of the Mississippi River. The Big Thicket area, inland from the southeast Texas coast, is generally similar to the coastal flatwoods, though site quality may be higher due to lower, more favorable permanent water tables.

Interior flatwoods soils are typically fine-textured, with moderate to poor internal drainage, though often permeable for tree roots to depths of six feet or more. Plant nutrients are usually adequate, enabling good growth of a variety of species, including loblolly pine. These belts also support shortleaf pine and many hardwoods, notably red and post oaks.

Extending from central Alabama into northeastern Mississippi and terminating near the Tennessee line is another kind of flatwoods, a 6- to 12-mile-wide soil and physiographic region. At an elevation of only 200 to 300 feet, a smooth surface has developed on an outcrop of cold, gray, stiff, poorly drained clay. When wet, the soil is sticky; when dry, hard and cracked. The cracks in dry weather and the crayfish holes in wet weather enable conduction of oxygen to lower horizons. Locally this soil is called "crawfish gumbo."

Post Oak Belt—The Post Oak Belt of Texas and Oklahoma, from 50 to 100 miles wide, forms a fire-maintained transition between the pine and oak–pine types to the east and the tall-grass prairies (now mostly farmed or ranched) to the west. Stands of trees, dominated by post and blackjack oaks, may include several other oaks and hickories. Except in the most favorable sites, tree growth is slow and form is poor. Stand density declines from east to west, the border with the prairie often being a dry savanna. Rainfall diminishes about 1 inch for each 25 miles, from east to west, averaging about 30 inches for the Belt. Bluestems and prairie bunch grasses along with a rich variety of flowering annuals and perennials appear as understory plants. Generally, trees occur on the more broken terrain where soils are sandy, while flatter areas with clay soils originally covered with grass are now farmed or in pasture. Relict loblolly pine stands near the western edge of the Post Oak Belt, the results of studies with drought-hardy pine seedlings, and measurements showing adequate growth on more than 200 loblolly pine plantations within the Belt suggest that conversion to the more-valuable conifer may be an economically feasible option. But such may further diminish this endangered ecosystem.

The "Lost Pines"—Found in three "islands" totaling about 40,000 acres in the vicinity of Bastrop, TX, are loblolly pines. They occur about 75 miles west of the western edge of the East Texas pineries. Between these two coniferous forests lies the finger of post oaks here referred to.

Some consider the Bastrop pines as the nail of another finger, this one pointing southwestward from the pine–hardwood forest at the Oklahoma border. All along the finger, pines once grew with the post oaks. One now sees an occasional remnant pine tree along the roads that traverse the area. Except in the Bastrop vicinity, the conifers were harvested and the lands farmed and grazed. When abandoned by agriculture, a pine seed source was lacking, so too was adequate moisture for stand establishment which, under natural conditions, occurs infrequently. If once in a century the weather and seedfall collaborated, a new forest would develop. What of the Lost Pines at the fingernail? Those trees too were cut to supply wood for pioneer "peckerwood" mills in the 1800s, but the poor, rock-strewn soil precluded conversion of the land to other uses. The finger's nail is now an island of naturally regenerated pines in a sea of post oaks.

Swamps—Swamps occupy large areas of the Coastal Plain. Although coastal saltwater marshes and some adjacent swamplands such as the Everglades of southern Florida are essentially treeless, most inland swamps are timbered. These include the extensive Big Cypress in Florida, the Okefenokee in Florida and Georgia, and the Dismal in North Carolina and Virginia. Baldcypress occurs in nearly all deep swamps. Other species, with varying tolerance for inundation, include pond pine, blackgum, water tupelo, Atlantic white-cedar, green ash, sweetbay, and magnolia. Specially recognized types of swamps include the sharply defined elliptical depressions known as *bays* and *pocosins*. Most common on upper terraces in the Carolinas, bays vary from slightly wet depressions to deep swamps or lakes. Pocosins, waterlogged areas in lower terraces, however, range up to several thousand acres in extent. In them, soils to six-foot depths are black muck or brown peat, usually supporting stands of pond pine or Atlantic white-cedar. Prior to the 1980s' concern for maintaining wetlands, many pond pine sites had been converted by elaborate drainage systems to faster-growing and economically more valuable loblolly pine.

Certain waterlogged soils, usually adjacent to swamps, may support grassland vegetation. Such sites, called savannas in the Southeast and prairies west of the Mississippi River, become pine sites if local surface drainage is provided.

Figure 1.19 Into the 1960s, wetlands were drained for food crop production and to convert swampy sites to valuable tree species. Small ditches fed excess water into these larger canals that carried the water through locks to the sea. The locks prevented saltwater intrusion.

Areas of slow, subterranean drainage contain peat formed from hydrophytes. Better-drained areas have a more finely divided peat or muck formed from woody-plant residues, while thick beds of acid sandy loam produce half-bogs of organic surface soil and mineral subsoil. The low pH, less than 4.5, limits nutrient availability. Sometimes these swamps smell very unpleasant, the pH being so low (less than 3) and the soil so sour.

Baldcypress is found in swamps where water is too deep for competitive species. It occurs in pure, dense, even-aged stands. Where single stems are found mixed with hardwood forests, a change in the physiography of the site during the life of the stand has probably occurred. Perhaps man or nature has diked or drained the land or plowed the soil.

Florida Peninsula—Southward from southern Georgia lies an extensive flat-topped plateau rising abruptly from the sea floor. In the northern part of the exposed section of the zone, the land is a central upland that reaches elevations of about 300 feet and contains broad flats, hills, swamps, and many lakes. Underneath the sandy surface soil lie soluble calcareous materials on which has developed a surface of modified *karst*, with its limestone sinks and caverns. Terraced marine lowlands, normally less than 100 feet in elevation and containing old and new beach ridges with intervening swales, occur on either side of the central upland. These marine terraces, broader on the Atlantic than on the Gulf side, account for most of the surface area of peninsular Florida.

South of the latitude of Tampa Bay, the peninsula is a broad plain with an average elevation of less than 20 feet. Here, the surface is an almost flat marl and limestone shelf, generally overlain with a thin layer of peat and muck and a little sand. Swamps cover perhaps 80 to 85% of the surface—or did before lands were drained. The low, swampy surface is relieved by a rather continuous strip of slightly higher sandy land parallel to the east coast and a highly fragmented counterpart along the west coast. Pines cover the higher parts of these low ridges. Pure stands of short-lived and serotinous sand pine cover extensive areas near the center of the peninsula, while slash pine and its South Florida variety otherwise compose the principal forest type. Extensive forests of the peninsula are called the Big Scrub.

The Florida peninsula continues southward as a broad submerged ridge or bank surmounted by non-forested islands, called *keys*, composed entirely of calcareous materials ranging from solidified coral to clay-size particles. Maximum elevation in the southern extremity is about 15 feet. The everglades are lower.

The Fall Line

The Fall Line separates the Piedmont province from the Coastal Plain. It is the original eastern continental coast, as its sand hills attest. The zone is readily identified by the cities that later developed at the falls where water power was obtainable for manufacturing, clear water was available for industrial use, and clean water was found for human consumption. Far up the rivers that fed the coastal communities—such as Williamsburg, Wilmington, Charleston, and Savannah —malaria was rare, the “bad air” not affecting health and hindering development. A line joining Georgetown (now a part of Washington, D.C.), Richmond, Raleigh, Durham, Columbia, Augusta, Macon, and Columbus mark the route of an Indian trail joining these Fall Line present-day cities.

Tree vegetation on the Fall Line in the Carolinas consists largely of longleaf pine and its scrub oak associates. To the south, all of the southern pines compete to control these sites; but the scrub oaks have an advantage; they endure droughty soils better. Indeed, foliage on the oaks growing in the hot, solar-reflecting sands in the Carolinas gradually twist on their petioles to a vertical position at high noon. The foliage returns to the horizontal late in the day when transpiration is minimal. This phenomenon thus conserves sparse supplies of soil moisture for tree growth.

Piedmont Province

Physiography—The Piedmont province, the eastern foothills of the Appalachian Mountains, extends from north of the Potomac River south to Alabama. Narrow in the north—about 50 miles wide in Maryland, the region broadens to 125 miles in North Carolina, and then narrows to the south. Elevations range from 300 to 1200 feet above sea level. The Piedmont, from the Italian for “foot-of-the-mountains,” is often referred to as a plateau, probably because the namesake Italian formation at the foot of the Alps is relatively table-like.

The Piedmont, however, was once worn away almost to a plain by erosion. Then uplifted, the region was subsequently dissected to produce the undulating character of the present landscape. Old, metamorphosed rocks such as marble and quartzite cover much of the area, tending to form upland. Perhaps 20% of the region is underlain by granite, this rock’s resistance to erosion also tending to result in uplands and some striking formations. Thus, the North American Piedmont consists of rolling hills and isolated features. Most notable of these is Stone Mountain in Georgia, a huge regolith rather void of tree vegetation. Softer rocks occur along the eastern margin of the Piedmont, for example, the so-called Carolina Slate Belt, extending from southern Virginia to Georgia, is characterized by valleys at lower than prevailing elevations. In the Piedmont are many other unmetamorphosed and noncrystalline rocks similar to those of the Appalachian highlands that serve as parent material for the soil.

Soils—Soils of the Piedmont are mainly red-yellow podzolics, either of sandy loam or clay loam texture. They are acidic and fairly high in nutrients where not eroded.[9] Soil thickness, even if

Figure 1.20 A natural stand of yellow-poplar in a Piedmont cove. This broadleaf species has many of the same silvical characteristics for natural regeneration as do the southern pines—mineral seedbed exposed, seed source available, and full sunlight.

erosion has been minimal, varies greatly. It is thin where derived from horizontal beds of schist and thick where these mineral layers have been displaced vertically.

Few regions in the United States, and perhaps the world, have experienced such severe soil losses from erosion as has the Piedmont. Widespread clearing and continuous cultivation of row crops on sloping surfaces have left the zone depleted of its once fertile topsoil. This is aggravated by the porous surface layers that rest over heavy subsoils. Frequent and intense rainfall and little snow for protection of the soil during winter storms further encourages erosion.

Because of erosion, one commonly sees exposed the reddish clayey subsoils that once underlay the rich loam surface horizons. This plastic material cannot absorb an inch of rainfall in 36 hours. The water runs off the surface, carrying the silt and clay sediments with it to the streams. Not only do these subsoils—now exposed at the surface—inadequately absorb water, they do not contain organic matter needed for improving the physical structure of the soil and, with it, tree vigor.

Every part of the Piedmont has lost 25% of its loamy surface horizon; much has lost three-fourths or more. The whole of the region, some have suggested, is now at least one foot lower in elevation than when the pioneers entered its mesic forests. As a result, much farm land has been abandoned and returned to forests.

Forests—Encroachment of undesirable hardwood trees is a major obstacle to forest management in this region. Frequent crops of wind-blown seed, exposed mineral soil for seedbeds, and full sunlight in openings combine to favor pine establishment on old fields. The shade-tolerant hardwoods become established in the understory within a few years.

Before the intrusion of European settlers into the southern Piedmont, a mixture of pines and hardwoods covered the land. Chestnut–oak–hickory or beech–birch–maple climax vegetation eventually replaced the pines that originated following fires or catastrophic storms. Pure pine stands occasionally were climax where soils are derived from sandstone or granite.

Sweetgum is an important invader in the Piedmont; providing high-quality veneer wood when growing on moist sites but a weed to be controlled on coarse, upland soils. Dogwood, once of significance for spindles in textile manufacturing, may take over large areas. This species is a soil-builder, its foliage laden with nutrients. Dogwood anthracnose disease threatens the range of this species.

About one-third of the Piedmont forest today is in loblolly pine and shortleaf pine types. This includes vast acreages of plantations. Oaks and hickories cover another one-third of the forested area; the oak–pine group about one-fifth; and the balance in oak–gum–cypress, Virginia pine, longleaf pine–slash pine, and elm–ash–cottonwood cover types.

Annual precipitation tallies 40 to 50 inches, about a third of which falls during the summer. Growing seasons vary from 180 to 210 days, depending principally upon latitude.

THE HIGHLANDS

Physiography—Moving from east to west, upon leaving the Piedmont province one encounters the Blue Ridge and the Ridge and Valley provinces, and the Appalachian plateaus. The Blue Ridge Mountains, a belt 5 to 80 miles wide, extends from beyond the northern extremity of the southern Appalachians in Virginia southward to Georgia. This is the province through which passes the Appalachian Trail, the uninterrupted footpath from Maine's Mt. Katahdin to Springer Mountain in Georgia.[12] This is also the region of the most rugged topography east of the Rocky Mountains, ordinarily rising 1000 to 4000 feet above the Piedmont and reaching an elevation of 6684 feet at Mt. Mitchell in North Carolina. The Blue Ridge is broadest and highest at its southern extremity. A twist in the general lay of the land orients the Great Smoky Mountains in the south in an east-west direction, in contrast to the general position of North American mountain ranges. (The Ozark and Ouachita mountains are other exceptions.)

North of the Roanoke River, the province appears as a single ridge, or a major one flanked by lesser ridges. Here the Blue Ridge got its name, for the haze on the mountains, caused by the terpenes exuded from the coniferous vegetation and accompanied by natural temperature inversions, gives the air a distinctly blue tint. Settlers named the Great Smoky Mountains for a similar reason.

Southward from the Roanoke River, closely spaced ridges form a rugged topography with a prominent escarpment that overlooks the Piedmont at elevations of 1500 to 2500 feet. Here the name Blue Ridge is applied locally only to the escarpment and to the ridges forming the divide between the Atlantic and Mississippi drainages. Other names, like Shenandoah and Catoctin, more specifically delineate sections of the Blue Ridge Mountains.

The Southern Appalachian chain of highlands contributes a great measure of character and culture to the southern forest. The physiography of the zone, geologically the oldest mountains of the continent, is largely responsible for the climate and soil that resulted in the complex and diverse vegetation covering the hills and valleys. The rugged terrain, discouraging to some elements of society, was the great enticement for others, especially the Scotch–Irish, who craved the isolation of the ridges and coves. Remote in communication, the lands provide a habitation for a people preferring isolation even to this day. Their forebears had come "unto a good land," not greatly

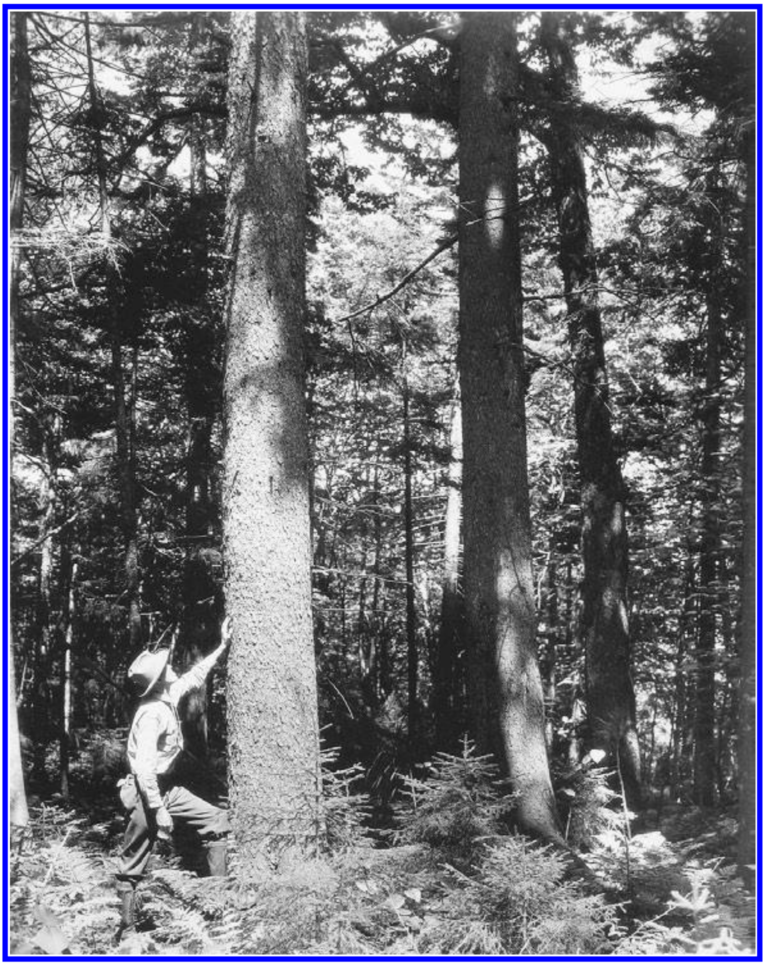

Figure 1.21 Old-growth, and probably virgin, red spruce in the higher reaches of the Southern Appalachian Mountains. Younger trees appear in the understory of this climax, uneven-aged forest. (USDA Forest Service photo by E. Shipp, 1927)

different in its physiography from that left behind on the British Isles. Here, in contrast to the long-ago cutover lands of Europe, were vast ranges of virgin, or near-virgin, forest.

From that good land the immigrants learned to utilize the varieties of wood, each for its highest use. For instance, a craftsman of the Civil War period, in making a "secretary" desk, used principally chestnut, with the desk's writing area inlaid with black cherry, the book shelves oak, and the back and hidden drawer parts basswood. The variety of woods and the soils enabled the handy settlers to be self-sufficient, so they required little contact with the world beyond the ridges.

Climate—Average precipitation for the Southern Appalachian provinces is between 40 and 60 inches, except at the highest elevations, where it exceeds 80 inches. High in the mountains, much precipitation falls as snow. The varied topography causes local precipitation patterns, rain shadows forming because of the proximity of the mountains and lesser hills. Annual precipitation within the zone may vary by more than 10 inches. Precipitation from a single storm over a two-hour period often differs by 3 inches when measured in gauges less than 100 feet apart.

For the whole of the Southern Appalachians, temperature effectiveness has been measured from less than 400 in the high-elevation reaches of the spruce and fir forests to 600 in the southerly and elevationally lower area. The spruce and fir sites occurring above 5500 feet in North Carolina and

Tennessee have growing season averages 10–15°F. cooler than at the base of the mountains. Precipitation is 50% greater in the spruce and fir habitat than at the foot of the hills. Such a cool, superhumid climate is approached at sea level in northern New England and adjacent Canadian provinces and in the coastal region of the Pacific Northwest. In the high-elevation forests of the South, vegetation similar to that of the Adirondack boreal woods of New York and the Maine coasts occurs. However, southern-grown spruce and fir trees grow faster and taller than those of the northern woods.[13]

Soils—The rocks and minerals of the Blue Ridge are primarily metamorphic, with gneiss, schist, quartzite, and slate particularly common. In the southern reaches, accumulations of sediments have formed siltstone, sandstone, and conglomerates. The soil derived from these rocks varies with the kinds of mineral formations and with the direction and degree of slope. Except on the steepest mountain sides, the acidic soils are shallow, sandy, and contain much organic matter. Nutrient levels vary greatly. The usually permeable subsoils are well-drained.

In the southern sector of the Blue Ridge province, a transition from gray-brown podzolic to red-yellow podzolic soils takes place. The fine-textured soils, whether derived from sandstone or from shale parent materials, produce crusts on the surface following rains and drying winds. This impervious layer prevents seedling emergence and reduces the infiltration of precipitation.

The lay of the land affects site quality and the occurrence of certain vegetation because of the angle at which the soil surface intercepts the sun's rays. South-facing slopes steeper than 10° intercept appreciable solar radiation during part of the day; in the summer they get the sun's rays at nearly right angles, thus receiving appreciable heat. Rainwater evaporates more rapidly, fires are more frequent, tree growth is retarded, and the more-xeric species prevail on these drier sites. As high soil temperature accelerates decomposition of organic matter, the lesser amount of decayed vegetable matter in the soil encourages erosion. This, in turn, results in shallower and less-fertile soils for tree growth. Western-facing slopes exposed to direct sunlight in the afternoon, when the air is warmer, are similarly affected. They are drier than those facing east. Better sites generally occur in these mountains, as a generality, on slopes that face north and northeast.

Forests—Perhaps the richest variety of tree species in the world's temperate zones occurs in the Blue Ridge province. Prior to the introduction of the fungus disease *Endothia parasitica*, American chestnut occurred here in pure stands on a variety of sites. Though most types at lower elevations are variations of the broad oak–hickory association, American basswood, white ash, and black cherry are also important deciduous trees.

While red spruce may occur with hardwoods at elevations as low as 3500 feet, this conifer transitions to pure stands or mixes with Fraser fir at higher elevations. The latter species is believed to be a relict population of a once-continuous fir type that included balsam fir, a tree now restricted to the northern region of North America.[14]

Oak and hickory forests cover about 70% of the Southern Appalachian provinces. Oak and pine mixtures and various conifers each cover another 10%. The pines include loblolly and shortleaf on a variety of sites, Virginia pine on cutover and burned sites, table-mountain pine at the highest elevations, and pitch pine on *scalp locks*, the summits of the hills.

Scalp locks describe the ridges where separate fires in the past have met as flames simultaneously raced up two or more sides of a mountain. Where such fires meet, explosions erupt from the heat of combustion, and whole trees are tossed like matchsticks into the air. Even though pitch pines die in the holocaust, the *serotinous* nature of the species enables its perpetuation—the tightly sealed cones open, heat having dissolved the resinous glue that seals shut their scales. After the fire has passed and the ground cools, the seeds from within the cones hanging in the tops of the now-dead trees flutter to the ground, soon to germinate in the seedbed of bare mineral soil.

Lesser species include eastern white pine and eastern hemlock, the latter invading stands of the former in ecological succession. White pine, a pioneer tree on cutover, burned-over, or cultivated lands and storm-damaged stands, seldom regenerates under its own canopy. Like all light-demanding species, white pine grows in even-aged stands.

Hemlock, however, a shade-tolerant conifer, germinates and endures well under the crowns of the pines as well as under its own canopy. In time, hemlock trees (or other shade-tolerant species) of all ages capture white pine sites. As the pines die out, the forest becomes essentially pure hemlock until fire, storm, or harvest begins anew the ecological cycle. Carolina hemlock, limited to mountain ranges, displays silvical characteristics similar to those of eastern hemlock.

Figure 1.22 A selection harvest of this broadleaf stand of many species in a fertile Blue Ridge Mountain cove provides good herbaceous cover for the soil until new trees invade. (authors' collection)

In the Great Smoky Mountains, 15 important vegetation types are recognized, their occurrence depending principally on elevation and moisture availability. Deciduous forests predominate below

4500 feet, while spruce, fir, and treeless balds covered with heather are the main vegetative types above that elevation. Virginia pine is the principal conifer at elevations below 2200 feet, pitch pine from there to 3200 feet, and table-mountain pine above that zone until the spruce–fir type of the ridge is reached. While soils and aspect play a role, along with climate, in delegating certain species to certain sites, the physiographic and edaphic roles are perhaps greater in the fertile coves of alluvium where American beech, yellow-poplar, Ohio buckeye, American basswood, and several birches make up much of the deciduous stand. There, eastern hemlock also encroaches to eventually claim its climax position.

Much of the existing forests of the mountainous South are at the higher elevations where stony soils formed from less-fertile sandstone and shale are of little value for farming. Here, various combinations of pines, oaks, hickories, yellow-poplar, and hemlock prevail. The absence of acid-loving mountain laurel, rhododendron, and wild azalea indicate ridges capped by dolomite, a form of limestone coated with magnesium.

Lesser Zones Of The Appalachian Highlands

Ridge and Valley Province—The Ridge and Valley province of the Appalachian region, some 50 to 75 miles wide, lies between the Blue Ridge Mountains and the Appalachian plateaus, to the east and west, respectively. There is an exception in the extreme south, where the Blue Ridge is absent, and the Ridge and Valley province lies adjacent to the Piedmont foothills.

In the Ridge and Valley province, conglomerates, shales, and sandstones predominate, although seams of softer limestone occur among the rock formations. These strata have been subjected to lateral pressures that built them into long, narrow, rather even-crested ridges which, in turn, are separated by narrow valleys. Sandstone is exposed at the ridges, while the valley rocks are limestone and shale. The ridges are more pronounced in the northern section; to the south they may be so indistinguishable as to appear as a great valley when viewed from afar.

Some physiographers refer to the low gradients and fertile soils found in a nearly connected chain from Pennsylvania to Alabama as the Great Valley or the Appalachian Valley. These are the rich lands that long ago attracted migrants and settlers for agricultural enterprises.

Most soils of the valleys, especially the Great and Appalachian valleys, being derived from limestone, are therefore alkaline in reaction. They are fertile. Intense weathering, however, may encourage acidification of the soil, even if of limestone origin. Where shale is the weathered mantle, soils are less fertile, less well-drained, and shallower. Still shallower are the soils along the ridges. Often high in stone fragments, the relative proportion of sand (in contrast to the silt and clay fractions) in these soils depends on the parent material from which they are derived.

American chestnut was likely more abundant in the Ridge and Valley Province than in any other southern zone prior to its demise as an important tree of commercial value due to the chestnut blight fungus. The rich valley soils are now mostly in agriculture. Only culled-over remnants of the valley forest remain, while vast tracts of bottomlands and their adjacent valley soils have been inundated by power- and flood-control projects.

Appalachian Plateaus—Within the Southern Appalachian Mountains are the Appalachian Plateaus, a geological uplift without the lateral pressures necessary to build strongly folded forms. Instead, the rocks are nearly horizontal. Elevations almost everywhere extend above those of the Ridge and Valley province. The region is bounded on all sides by out-facing escarpments of dissected mountain fronts. The eastern boundary, from West Virginia to Alabama, is a prominent escarpment some 500 to 1000 feet in height, while the western boundary, from the Ohio River to Alabama, is a minor tableau cut by streams into promontories and buttes.

The part of the Appalachian Plateaus extending from the Kentucky River northward bears the local name Allegheny Plateau. The easternmost escarpment is called the Allegheny Front or, where strongly dissected, the Allegheny Mountains. The southern sector is often cataloged as the Cum-

Figure 1.23 An oak–hickory forest cover type. These species serve as climax vegetation throughout much of the South. The young tree, with especially good form, is a white oak. (USDA Forest Service photo by P. Carter, 1935)

berland Plateau, the Cumberland Front having formed to the east, and the Cumberland Mountains occurring where the cutting of terrain by rivers has been most severe.

Interior Low Plateaus—The Interior Low Plateaus of Kentucky and Tennessee also lie within the Southern Appalachian Mountain chain, west of the Appalachian Plateaus. Most of the Highland Rim, one of these plateaus, is underlain by cherty limestone, which weathers into stony soil. Although chert fragments help retard erosion, soil productivity is low. The best soils of the Interior Low Plateaus are in the Nashville and Blue Grass basins where nutrient-laden parent material has weathered into deep, slightly acid, fine-textured soils.

Formed along the summit and flanks of the Cincinnati Arch, the low plateaus form a broad upwarp approximately parallel to the Appalachian Mountains. Geologists say the summits of the arch, originally domed in two places, were eaten away by erosion to produce topographic depressions like the Bluegrass Plain around Lexington, Kentucky, and the Nashville Basin.

Surrounding the Nashville Basin is an extensive plateau at elevations of 700 to 1300 feet and, until cultivated, supported prairie grasses. Around the limestone outcropping of the gently rolling Lexington Plain is a belt of steep hills formed on shales. This area, too, is now largely farmed.

The calcareous origin of the soil of the Interior Low Plateaus often excludes pine forests while encouraging the growth of calcium-loving eastern redcedar. Nearly 80% of the present forests of the region are classed as oak–hickory types, a figure obscuring the great variety of species found there. The original forests of these plateaus have been described as transitional between the mixed mesophytic of the Appalachian Plateaus and the oak–hickory types of the prairie transition zone to the west. In this situation, numerous major vegetative components formed a mosaic in response to local environmental factors. Cavernous limestone underdrainage, called *karst*, for example, favors grasses over trees, giving rise to open savannas like the so-called barrens of Kentucky, the Blue Grass Region, and the Nashville Basin. From the Nashville Basin westward, lower slopes afford sites on which more-valuable hardwood species develop into well-formed stems, while upper slopes and ridges produce stands of xeric species like post and blackjack oaks, as they did in the virgin forest.

The level and fertile land of the plateaus encouraged farmers to clear the forests for agriculture. Where not cleared of timber, valuable black walnut and eastern redcedar have been severely overcut, and these trees then replaced by scrub hardwoods. Pine forests predominate in the Highland Rim south of the Nashville Basin, in the western coal fields of the Ohio River, on abandoned farm lands, and on both reclaimed and unreclaimed banks of surface-mined soil.

The climate of the Interior Low Plateaus is not markedly different from that of the Appalachian Plateaus. Rainfall amounts to 40 to 55 inches annually, and the growing season lasts almost 200 days.

Beech Gaps and Balds—Beech gaps, small islands of gnarled, broken, deciduous trees in dense stands with sharply marked boundaries, occur above 5000 feet in the Southern Appalachians.[15] The persistence of American beech in these south-facing slopes and in slight dips in ridges that lie east-west has been attributed to the species' ability to withstand strong winds that funnel through gaps in the mountains, even when calm weather prevails elsewhere. Surrounding the beech gaps, forests of spruce and fir trees deposit deep layers of acidic foliage relatively low in nutrients. In contrast, the thin, less-acidic leaf mold under the beech trees, rich in plant nutrients, stimulates decomposition of more recently deposited foliage by micro- and macro-organisms. This decomposing activity leaves humus layers thinner than under adjacent spruce and fir forests. The soil pH, too, under the beech trees usually measures a unit above that of the conifers in these high mountain zones.

Balds high in the Appalachian Mountains occur as treeless, dome-shaped summits on well-drained sites with deep soils at elevations above 4000 feet. Why the balds remain treeless can only be conjectured: Neither fire, browsing wildlife, freezing temperatures, wind, shallowness of soil, influence of ancient burial grounds, nor postglacial climatic fluctuations seem to be the cause of the phenomenon.

On abandoned farms within the Southern Appalachian Mountains are small barren areas called *galled spots,* where old-field plant succession has failed to develop. Inadequate phosphorus could be the cause, preventing the invasion of nitrogen-fixing legumes often needed for normal plant succession.

Interior Highlands

Physiography—The Interior Highlands refers to two elevated physiographic provinces in Arkansas, Missouri, and Oklahoma. The Ozark Plateaus, to the north, formed on a broad, domed upwarp mostly of limestone and dolomite. Some chert gives the soil a rocky texture. In the southern Ozark sector, also called the Boston Mountains, sandstones and shales predominate. Elevations rise to above 2200 feet. Drainage from this range, exhibiting an east-west orientation, is radial, the south-flowing streams being the more vigorous in their dissection of the plateau. Relatively flat lands between rivers are commonly called prairies.

The Ouachita province lies south of the Ozark Plateaus, the 25- to 35-mile-wide Arkansas River trough separating the two ranges. The Ouachita region exhibits linear folds in the mantle, like the

Figure 1.24 Treeless dome-shaped summits occur above 4000 feet in the more-northern reaches of the Southern Appalachian Mountains. These "balds" support grass and an assortment of broadleaf heather-like shrubs (rhododendron and mountain laurel). Deciduous trees along with spruce and fir surround the balds.

Ridge and Valley province of the Appalachian Mountains. While most of these hills lie less than 1000 feet above sea level, they rise to 2600 feet to the west near the Oklahoma boundary. The soils, formed mainly on sandstones and shales, are classed as red-yellow podzolics. Ridge surface horizons are shallow and stony and of low fertility. Valleys have more productive, finer-textured soils.

Climate—In these provinces, precipitation ranges from 40 to 50 inches annually, with serious summer droughts taking a toll on the forest in survival and growth. Growing seasons average about 200 days. Because of the prevailing east-west orientation of these mountains, increased isolation on south-facing slopes affects more of the forested land than in other mountainous regions of North America. This, combined with erratic rainfall and high temperature effectiveness (700 units), limits much of the area to tree species adapted to drier sites.

Forests—Forests of the Interior Highlands are mostly (68%) oak–hickory. The pines, principally shortleaf and some loblolly, make up 15% of the forested area, while mixtures of pines and hardwoods compose another 7%. Greatest concentrations of shortleaf pine appear on the drier south- and west-facing slopes in the Ouachita Mountains, where both a national forest and industries maintain extensive pure stands. The virgin forest was rich in species variety. White oak, black walnut, black cherry, sugar maple, and eastern redcedar attained large diameter and excellent form. Quality hickory grew on the drier slopes. Some trees still find use by local craftsmen; riding the back roads, one may come upon a whittler, his back against a tree, carving a custom ax handle from a green hickory bough. Or, using eastern redcedar, he may shape a rolling pin so perfectly round it appears to have been turned on a cabinetmaker's lathe.

Eastern redcedar growing on the relatively chert-free limestone-derived soils seems to be maintaining its place in the biome, in spite of severe over-cutting for posts and for lumber for products requiring the aroma of the oil exuded from the wood. Yet, in spite of this demand, markets are inadequate for encouraging landowners to manage for this species. The Junipers do invade overgrazed grasslands of the glades of the zone.

As the prairie to the west is approached, the forest becomes more open, allowing bunch grasses to invade. Attempts to convert large tracts to pastureland have been only partially successful; drought-hardy deciduous scrubby trees take over the land.

A WORD ON WETLANDS

Society's concern for wetlands requires the silviculturist to manage these sites cautiously. With proper management, their functions are preserved; water remains free of sediment, wildlife habitat is enhanced, fisheries are improved, floods are controlled, biogeocycling takes place, landscapes are protected, and eutrophication avoided. Prevention of eutrophication allows for denitrification of organic matter, microbial immobilization, and retention of soluble phosphate in the silt and clay components of these soils. In addition to providing sites for growing trees for mankind's needs, wetlands enhance flyways and breeding grounds for migratory birds, provide habitat for rare and endangered plants, supply sinks for pollutants, and nourish food chains for living organisms (micro- and macrofauna). In the southern pine coastal plains, wetlands have minimal value for flood control or groundwater recharge.

Figure 1.25 Reclaimed surface-mined land is configured to new wetland. After grasses become established, hydric forbs and trees invade. (TU Services photo)

Government agencies, environmentalists, and foresters define wetlands variously. For the present purpose they are sites in which hydrophytes grow in hydric soils. Thus, plants that grow and reproduce in anaerobic soils, those soils saturated long enough during the growing season to develop anaerobic conditions in the surface horizon, indicate *bona fide* wetlands. Such sites generally include forested swamps and bogs, pocosins, mangrove swamps, shrub swamps, freshwater basins, riparian zones along streams, and flood plains. Some classifiers include pine flats and certain pine plantations on land formerly farmed. Streamside riparian zones need not be wetlands.

Forested wetlands support trees or tall shrubs; they may be drained or undrained. Vegetation includes hardwoods, as in the swamps of the coastal plains; bald- and pondcypress, as in swamps and domes; pond pine, as in the pocosins; and Atlantic white-cedar, as in peaty sites along the Atlantic coast. All of these forest types may be surrounded by southern pines or, at the fringes, intermixed with pines. During dry periods, buttressed trunks and silt marks on boles indicate wetlands.

As wetlands are lost to agriculture and economic development, new wetlands are created. This occurs in the reclamation of surface-mined sites on previously forested uplands. Natural drainages develop on the restored land, ponds fill, hydrophytes seed-in, and forest trees follow.

Of the South's 57 million acres of wetlands, 30 million are forested. Some 7% of the total is in the loblolly–shortleaf pine type; 15% in oak–pine; slash pine, 3%; and an unreported percentage in pine flatwoods of the Southeast and Gulf Coast.[16]

Wetland silviculture should follow *Best Management Practices*, sometimes controlled by federal and state regulations, the latter involving the Environmental Protection Agency and the Corps of Engineers. The procedures include delaying logging until surface soils dry sufficiently following rain to avoid *puddling* of the soil, using rubber-tired skidders cautiously to avoid soil compaction, limiting the number of skid trails, and "putting roads to bed" following harvest. Practices should be designed to (1) enhance plant and animal habitat (including establishing game food plots, (2) encourage valuable species that are tolerant of flooding, and (3) avoid sedimentation by proper treatment of forests at higher elevations. Feral hogs should be controlled by harvest; their consumption of mast of desirable species prevents tree reproduction and seedling establishment. Conversion of true wetlands to pine plantations, as in the past, will not likely be condoned. On the whole, timber harvests have minor and transient effects, scarcely impacting the forest.

Under some circumstances, silviculture may include the regulation of water levels by drainage, ditching, and controlling water flow from wetlands to lower bodies of water with outlet gates. These gates also protect forested sites from intrusion of saline tidal water.

Riparian zones that serve as buffers between agricultural or urban development and wetlands filter sediment and microbes. Periodic harvests in these zones may enhance nutrient retention, enabling young growth that is more vigorous than the older harvested stems to promptly utilize available nutrients before they are leached into water bodies at lower elevations.

Some 15 wetlands across the South are included in the Ramsas Treaty as "wetlands of international importance." Wetlands are also designated in categories for regulation under the Fish and Wildlife Coordination Act, which grants review authority to the Fish and Wildlife Service of the U.S. Department of Interior over dredge-and-fill activities permitted by the U.S. Corps of Engineers and the U.S. Environmental Protection Agency.[15]

With an understanding of the vegetation-related geography of the South, the reader now considers ecological associations—how the climate, soils, physiography, and living organisms interact to produce the forests of the region.

2 Ecology of the Forest: The Southern Pines

Those who study how trees grow and how they can be encouraged to grow better to provide for the needs of people consider the *oecological* relationships of soils, climate, physiography, and biotic entities. Since forestry became a profession, oecology, now shortened to ecology, has been a forester's word. *Silvics* joined the vocabulary to accompany ecology. Silvics deals with the sciences basic to understanding how trees grow, and ecology with the relationships of living things to each other and to their environment. In this context, involving silvics and ecology we now consider the complex interactive nature of the South's woodlands. Biotic components—notably here the trees—of any particular site interact with physiographic, climatic, and edaphic factors to establish the kinds of vegetation at any one time and place.

Most of the commercial coniferous woods in the South come from trees with similar requirements for natural reproduction. For successfully establishing a new forest, seeds must, of course, be available. Then, to regenerate the principal species, mineral soil should be scarified to serve as the seedbed. Southern pine seeds seldom germinate and become seedlings if they fall on leaves, grass, and brush. Finally, full sunlight is desirable so that the young trees can be firmly established following seed germination. For instance, loblolly and shortleaf pines may survive with 50 to 60 percent of full sunlight on better sites, but often this shade-tolerance diminishes when seedlings reach heights of 6 to 10 feet.

In nature, fires and storms scarify the soil, exposing mineral matter as they remove leaves and grass lying on the ground. Fires and hurricanes, too, may obliterate vast areas so that full sunlight reaches the forthcoming seedlings that germinate from seeds in the soil. For successful forest renewal, seeds must be available at the time the soil is freshly disturbed and the canopy of overstory vegetation opened to the sun. Natural events often provide the scenario. Therefore, in making openings in the canopy, foresters attempt to imitate nature. Clearcutting is often unsightly for a season, but the method may be necessary to perpetuate pine forests.

SPECIES OVERVIEW

Ten hard, or yellow, pines occur in the southern United States. The four species most important commercially are shortleaf, loblolly, longleaf, and slash pines. In this order, their ranges generally occur from north to south within the region. Other yellow pines of the South are Virginia, pitch, pond, sand, spruce, and table-mountain. (Eastern white pine, confined in the South mostly to the Appalachian Mountains, is a soft pine. For that and other botanical reasons it is not classified as a southern pine. It is listed with the lesser conifers in Chapter 3.)

Shortleaf pine, the most cold hardy of the four principal species, intermixes with loblolly pine throughout much of its range. As a rule, shortleaf pine predominates to the north of an imaginary line across the middle latitude of the Gulf Coastal Plain, while loblolly pine is the more abundant of the two species to the south. Throughout much of the Ouachita Mountains of Arkansas, shortleaf was the only pine until the introduction, beginning in the 1950s, of loblolly pine on industrial and government lands.

Loblolly pines, the tall trees first encountered by the early pioneers as they stepped ashore in the murky loblollies along the southern Atlantic Coast, are the most important timber-producing

Figure 2.1 Hardwood encroachment in pine stands. A mixture of perhaps 50 broadleaf species enters the stand in the absence of fire. Controlling weed trees in order to encourage growth of the more valuable pines is a continuing task for the forester. (USDA Forest Service photo).

trees of the southern forest. Often most vigorous at the edges of swamps, the species prefers wetter sites, attaining maximum growth on poorly drained clay and clay loam soils. The name derives from the early-English term for a mudhole and the color of the broth called loblolly served as rations for the sailors on the vessels that landed on Virginia's coast. However, loblolly pine also grows in pure stands on drier sites in a zone of Central Texas.

Longleaf pine, although given the Latin species name *palustris*—meaning in the ancient language "swamp"—is usually a dry-site tree.[1] Typically found in dry sands of the lower Gulf Coastal

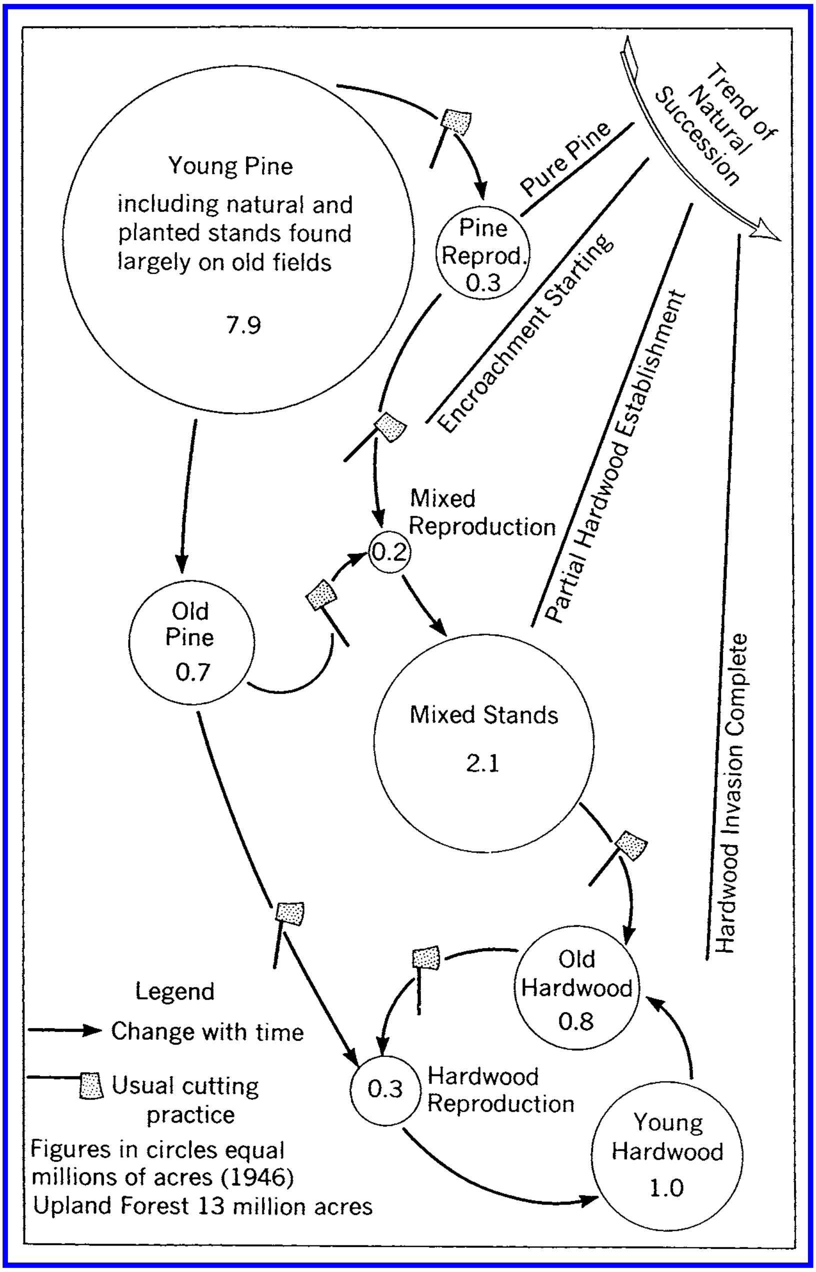

Figure 2.2 The result of natural and human influences on loblolly pine and shortleaf pine forests. Nature tends toward climax hardwood types. Pines are harvested in preference to hardwoods, and this hastens nature's swing toward broadleaf woodlands. (USDA Forest Service drawing by W. G. Wahlenberg)

Plain and the Fall Line sandhills of the Carolinas, the tree extends northward from the Gulf Coastal Plain as a finger into the shallow cherty soils in the mountains of northeastern Alabama.

Occasionally, longleaf and loblolly pines hybridize, giving rise to Sonderegger pine. This species cross appears like longleaf pine except for the lack of a grass-stage, called *nanism*, the classic dwarfing of the seedling stage.

Slash pine, often occurring in both natural and planted stands where virgin longleaf pines once covered the land, also hugs the lower Coastal Plain. Least cold hardy of the four primary southern

Figure 2.3 A 45-year-old stand of loblolly and shortleaf pines in the Atlantic Coastal Plain on Site Index 70 land. Note the encroaching broadleaf understory. Note, too, past ice-storm damage, evidenced by the crooks at about the same height in several stems, where tops had been broken or bent in a particular year sometime in the past. (authors' collection)

pines, trees are frequently broken by the heavy ice that accumulates on their branches when the species is planted north of its natural range. Until annosus root rot began to take its toll of planted trees in the 1950s, this was the most widely planted of the southern pines. Strobili phenology—the timing of pollen dissemination—usually precludes hybridization of slash pine with other pines.

Into the 1950s, slash pine, from Florida to eastern Louisiana, was cataloged as *Pinus caribeae*, along with similarly appearing trees of the Caribbean islands, the Bahamas, and Central America. Mainland North American trees were subsequently renamed *P. elliottii* to honor a botanist, leaving the original designation for the more southerly Central American (including Mexico) and island species.

Still later, dendrologists distinguished between the slash pines of northern and southern Florida. Those to the north in the peninsula and throughout the species' range to the west retained the species typical designation; those in the south of Florida became variety *densa* because of the harder wood. The needles are also longer. Another distinguishing characteristic for South Florida slash pine is the grass stage through which its seedlings often pass. Occasional harvests and conversion of forested tracts to agriculture have diminished the acreage covered by variety *densa*.

Virginia pine, pitch pine, pond pine, sand pine, spruce pine, and table-mountain pine, while not greatly significant commercially, are ecologically important species in the forests of the South. Peculiar characteristics, respectively, of the habitats of these hard southern yellow pines are dry sterile sites at sea level, moist ridge tops at 4000 feet elevation, organic swamps along the coast, inland plateaus with a distinctive fire history, and as an intermingler at the transition zone of more important timber types. When they occur in such odd locales, we call them "conifers of convenience."

Virginia pine, a scrubby tree, serves as a pioneer in ecological succession. Although not serotinous, it seeds-in abundantly from bumper seed crops following land disturbance or vegetation manipulation.[2] The species also sprouts from epicormic buds at the root collar or just below ground level on a horizontal section of the root. Its prolific production of viable seeds and its sprouting habit encourage regeneration of this short-needled, short-boled, and small-coned tree on road cuts and burned-over, cutover, storm-damaged, and agriculturally abandoned lands in the southern Piedmont province and in the Appalachian Mountains.

Pitch pine, frequently found on the scalp locks of tree vegetation in the upper reaches of the Appalachian Mountains, is a serotinous species. It occurs on those ridges, as on other sites, because of past fires that heated the cones, thereby melting the resin that sealed the scales, of parent stems. Opened cones then release their winged seeds to flutter and fly to the ground.

Figure 2.4 Blue-stain infected wood. The fungus shows in all southern pine logs not immediately salvaged or milled (unless stored in a millpond or subjected to continuous hosing with water) following death or harvest. Beetle-infested trees are especially vulnerable to the lumber defect, one that, however, does not affect strength properties. (Texas Forest Service photo by R. Billings)

Pond pine, for many years considered the same species as the mountainous pitch pine, is now classified separately. Its principal habitat is the other extreme in topography. Pond pines occur in pocosins and other swampy lands of the Carolina coasts. The species occasionally is found also in wet lands along the Gulf shore. Its serotinous nature enables its perpetuation on organic soils which, when dried to tinderlike conditions, are readily ignited. A fiery holocaust results. Shortly, after the fire has passed and the ground has cooled, the newly opened cones release seeds to restock the land with trees. Sprouts also arise from old stumps.

Sand pine is native to peninsular Florida and to a zone of the panhandle of that State and South Alabama. Only the strain that grows in the peninsula is serotinous. There, the reflected heat from the sun's rays on the white sandy soil is adequate for releasing seeds held in cones attached to logging slash that lies on the ground. The western race of sand pine is, for reasons unknown, not dependent upon heat for releasing its seed. As the seeds fall shortly after the cones mature and few seeds germinate in the unburned and therefore unprepared site, stands of trees in western Florida are less dense than those of the eastern race of the species.[3]

Spruce pine displays both bark and needles that resemble members of the *Picea* genus; yet it is a pine. The smooth gray bark and the foliage at first glance also sometimes appear like that of white pine. Locally it sometimes bears the name cedar pine. One finds spruce pine on damper soils surrounding dry islands of longleaf pine, particularly in southern Alabama, Mississippi, and Louisiana not far inland from coastal shores and just above the alluvium of river sides. A separate colony occurs in the Santee River zone of South Carolina's coast.

Table-mountain pine, found at high elevations in the Appalachian chain, is not a tree for the lumbermen. Little commercial use is made of the poorly formed, short, limby logs, although years ago it was reported to occur occasionally in pure stands suitable for timber production. The species' highest use is for watershed protection.

Flowers and Seeds

There is a chronological sequence for *strobili* (the "flowers" of conifers) production of the southern yellow pines. For the principal species, the phenological order of development coincides roughly with the natural ranges of the four principal species—from the warmer south to the cooler north within the region. In southern Mississippi, where slash, longleaf, loblolly, and shortleaf pines grow naturally in the same stand, pollen dissemination occurs, respectively, in early February, mid-February, late February to early March, and late March. Of course there is some overlap, causing natural hybridization as the sperm organs of one species fall on and fertilize receptive ovules of another. Pollen maturity may vary by as much as three weeks from one year to another and about three weeks between trees of the same species in the same stand. In Florida, for example, a spread of three weeks may occur for flowering of slash pines within a 15-mile radius and as much as two weeks for stands 3 miles apart.

Exceptionally cold weather during flowering causes female strobili to mature slowly, thus male organs may shed pollen before the females are receptive. Two crops of female conelets might develop as a result of unseasonably cold weather that kills the first strobili produced. The conelets likely will not mature if too few ovules within them are fertilized by the disseminated pollen. Sexual fertilization, the union of male and female gametes within the female cones, probably takes place when cones reach full size during the summer of the second year after flowering. Seed growth within the cone is then rapid.

Genetics probably controls the age of trees when flowers form. Trees of loblolly pine have produced seed-yielding cones at 4 years of age. That means flowering had occurred two years earlier. The yield of seed from a single cone is likely also an inherited characteristic, for yields (and seed weight) differ among the cones produced by individual parents of this species.

Hybridization—crossing between species—has created individuals of small size as well as those that exhibit the classical hybrid vigor. Hybrids may be adapted to a wider range of environ-

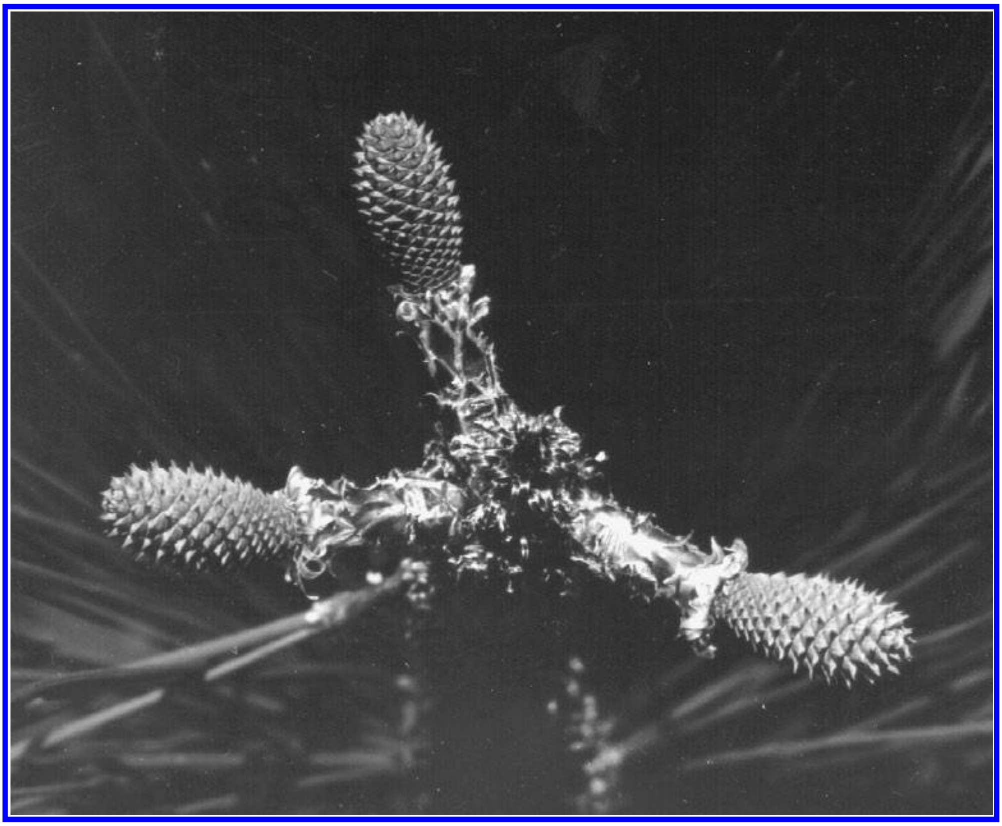

Figure 2.5 Conelets of a southern pine. Female strobili appear like these in mid-summer of the first year prior to pollination the following spring. Cones ripen in the fall, and seeds (except for longleaf pine) are released the following spring. (USDA Forest Service photo)

mental conditions than either parent. Crosses of loblolly and shortleaf pines resist fusiform rust to a greater degree than does loblolly pine alone, while longleaf pine crossed with slash pine makes height growth like that of the latter species, the seedling never passing through a grass stage. Nor does the loblolly pine and longleaf pine hybrid (*P. sondereggeri*) exhibit nanism. Pitch pine crossed with loblolly pine outgrows, and has better form than, genetically pure pitch pine. This hybrid is more cold resistant than loblolly pine, surviving harsh climate and infertile soil better than does either parent. The cross also produces a more extensive root system and has better seedling survival than either parent. Crosses of loblolly and slash pines are thought to be more drought resistant than either parent.[4]

Flowering and, therefore, pollen production of the southern pines relate to accumulated temperature. Differences in heat requirements among the species probably account for purity of race, precluding overlapping pollination periods. Thus, temperature gradients in the days or weeks before flowering, when cool weather slows and warm weather hastens development and dispersal of yellowish-orange pollen from male strobili, at least partially controls hybridization.

Peak flowering of the southern pines may extend from three to six weeks, depending on the species. The production of Sonderegger pine can be attributed to the overlapping pollen shedding by the parent species in contrast to the lack of overlap for other species.[5]

Artificial hybridization of pitch pine and pond pine in seed orchards should not be considered extraordinary, even when the several-hundred-mile distance between the usual natural ranges for the species is considered. For a long time, as noted earlier, foresters cataloged both trees as *Pinus rigida*, the name derived from the stiffness of the foliage.

The ease with which loblolly pine and pond pine can be artificially hybridized, the greater cold-hardiness of pitch pine, and the better quality of loblolly pine have suggested the development of a three-way hybrid for planting in the northern reaches of the southern forest. (Hybridization with shortleaf pine also occurs.) Such an artificially developed hybrid could be as well received for lumber and plywood manufacture as loblolly pine.

Pine strobili and cones receive a lot of natural abuse. Thrips, an insect, injures flowers, causing them to shrivel and die. The insect also damages newly formed conelets. Cones are attacked by a small beetle (*Ernobius sp*.) and several pitch moths (*Dioryctria sp*.). Upon attack, cone and seed development is arrested, cones become malformed and, in a crook in the cone, sticky frass collects.

NATURAL REGENERATION

Natural regeneration of the hard southern yellow pines requires three criteria. In addition to the availability of seeds carried with the wind by hymenous-like wings, mineral seedbeds are necessary. Where mineral soil is exposed, seeds promptly germinate and seedlings become established; where covered with grass, pine needles (called straw when accumulated on the ground) or dead leaves, germination and seedling establishment often fails. Too little starch, protein, and nutrients are stored in the tiny seeds to provide sustenance while the root grows through the dry litter toward the soil. Some seeds germinate where the ground is covered with grass or debris or the “rough” of a longleaf pine stand, those seeds falling in crevices that provide contact with mineral soil. Finally, adequate sunlight is necessary. While some seeds germinate under canopies of brush and large trees, these seedlings succumb within several years if the overtopping foliage or water-competing stems are not removed.

Hence, under normal undisturbed and natural conditions, stands of the southern pines sometimes do not naturally regenerate to the same species. Rather, under large old pines, one finds oaks and hickories or other broadleaf trees. These hardwoods compose the climax forest, that assortment of species that continues to be found on the land *ad infinitum* if nature is left alone and neither wildfire nor hurricane-strength storms occur. These broadleaf plants, in contrast to the southern pines, are shade tolerant. They endure and fare well in undisturbed forests. Eventually, as the shade-intolerant conifers die, broadleaf hardwoods capture the site.

While yellow pines in the South are unable to compete successfully for light with the oaks and hickories, they grow aggressively in other situations. Adaptability as an initial plant in ecological succession on abandoned lands relates to abundance and frequency of seed production, seed mobility, and tolerance to droughty conditions. Loblolly pine has replaced longleaf pine over much of the lower Coastal Plain because of the latter’s sensitivity to the timing of fire and to its uniquely sporadic seed production as well as the shorter rotation required by loblolly pine to reach pulpwood-size boles. Fires control a seedling needle blight attacking longleaf pine while a large number of seeds of the species fall only at 10-year average intervals. Ten-year averages may tally abundant seedfall two years in a row and then a 20-year lapse occur until the next crop of seeds matures.

Natural occurrences damage many seedlings. Evidence of injury to young seedlings by cottontail rabbits shortly after seed germination are the mammals’ droppings and the trees’ nipped stems. The harvest mouse cuts off the small tops of seedlings. Cotton rats remove the edges of seed coats before germination, and fox squirrels chew open the seed coats. Shrews and white-footed mice cut seed hulls. The short-tailed cricket joins in the raid, clipping cotyledon-stage seedlings 1/8-inch from the ground and depositing small fragments of seed leaves in their galleries in mounds nearby. Feral hogs, raccoons, opossums, skunks, pocket gophers, and town ants also hustle their share of southern pine seeds and seedlings.

Figure 2.6 Often it appears that natural regeneration of loblolly and shortleaf pines is readily obtained in dense stands or following partial harvests, like the selection and shelterwood systems. However, these 3-year old seedlings will be dead in another 2 or 3 years, their photosynthetic ability diminishing with age in the early years where a canopy provides shade.

Insect Attacks on Southern Pines

Insects harvest more southern pine timber than man and fire together. A group of bark beetles takes the blame for most of the damage. Some are primary sources of injury, destroying stems that otherwise appear healthy. Secondary insect attacks occur when fire, fungi, or vegetative competition for soil moisture, nutrients, and light weaken trees. The more common include the southern pine beetle, the *Ips* bark beetle, and the turpentine beetle. The initial attraction of insects to certain trees is thought to be due to the escape of volatile chemical aldehydes or esters, by-products of respiratory fermentation resulting from abnormal enzyme activity that occurs when trees suffer physiological stress. According to studies reported as early as 1931, the first few beetles that attack a tree introduce a yeast. This serves as a strong attractant, with beetles now moving to the area from far-distant locales. The inner bark of the pines is a favorable medium for yeast growth. More recently, *pheromones* (odor hormones), serving as sexual attractants for insects, have been isolated.

A question often asked is why the virgin forest did not suffer devastation by the chewing jaws of bark beetle larvae. Those stands were, of course, not subjected to management. Serious infestations, of which we have no accounts, probably did occur, but, for the most part, the low density

Figure 2.7 Damage to a loblolly pine stand by the southern pine beetle, *Dendroctonous frontalis* does much more damage to southern forests than does fire. (Texas Forest Service photo by Ron Billings)

of the pine component in the old-growth southern forest enabled more than an adequate amount of moisture, nutrients, and sunlight to sustain tree vigor. The trees were overmature and growth was slow, a typical stand probably numbering fewer than 10 or 20 trees per acre. The classical stands seen in historical photo collections were exceptions; it is the fact that they were exceptions when the pictures were taken that made the photographs worth saving.

Also worthy of note is the relation of southern pine beetle attacks and the occurrence of colonies of the endangered red-cockaded woodpecker. Management that maintains pines at wide spacing and that also reduces understory hardwoods produces colony stands in good health and, at the same time, trees highly resistant to beetle attack.[6]

Other insects of importance ecologically include the Nantucket pine tip moth. This moth leaves a sort of witches'-broom on most southern pine species (longleaf pine is the exception) as it bores into the terminal buds of twigs. Lateral buds then burst to extend many branches to compete for a leadership role in replacing the tree's terminal leader. (Many knots show in boards cut from such trees.) This, in turn, results in more compression wood being formed in the merchantable part of the bole. (Compression wood, exemplified by the fiber developed on the underside of a lateral branch, is inferior for all uses. Abnormal shrinkage and swelling of this denser wood causes warping and twisting of lumber cut from such trees.) Tree growth is stunted, and some stems are killed by repeated attacks.

The moth adults exhibit 1/4-inch wings showing brick-red and copper-colored patches separated by bands of gray scales. The eggs change from white to orange to gray color during incubation. They hatch to produce minute cream-colored caterpillars with black heads and hairy bodies (see Chapter 6). Some strains of southern pine species may be immune to tip moth attack. In that event, future southern forests that are artificially regenerated likely will be from genetically selected seeds carrying the immunity gene.

Notable among the insect pests of the pine forest, especially in the West Gulf South, is the Texas leaf-cutting ant, *Atta texana*. Ants in a colony may "work" 100 feet from their nests to cut needles of seedlings. Most of their effort is on sandier soils of well-drained sites with warmer western or southern exposures.

These ants march single-file along cleared trails that resemble miniature highways, carrying needle fragments over their heads to underground galleries. The intricate systems of chambers may extend more than 20 feet below the surface. The ants then carry small pieces of foliage into smaller cavities. There the fragments serve as a culture medium in "gardens" where a fungus is produced. The fungus, not the pine needles, provides food for the colony. The ants parade above ground only when the temperature is within a narrow range. Work ceases on hot, cold, cloudy, or rainy days.

Pine web worms in the larvae stage often defoliate and kill young pine plantations. The striped caterpillar lives in silken webs enclosing the main stems and tips of leaders and small branches. The web entraps the insects' excrement pellets with a frass-like material. After feeding on the foliage, the 1-inch-long larvae drop to the ground to pupate just under the surface of the soil.

Many other generally less serious insects also aid in keeping the southern forest a dynamic ecological enterprise. Some plague the woodsman and his woods for brief periods: pitch moths kill shoots, spider mites cause foliage to turn brown, and colaspis beetles make needles appear as though scorched by fire. Needle miners, pitch midges, scale insects, and aphids are other lesser pests that become serious menaces to stands of trees planted beyond their natural ranges or on sites for which they are ill-adapted.

Fungus Problems for Southern Pines

Four groups of fungi infect southern pines without a specific choice of species: needle blights, heartrots, butt rots, and pitch cankers. (Fungi, bearing scientific binomials, **cause** diseases; they **are not** diseases. Diseases have common names.) Needle blights, like those caused by *Hypoderma lethale*, attack pines from seedlings to maturity. Needles of most species are infected with spring inoculations of spores that have lain dormant since their dissemination the previous summer. *Lophodermium pinastri*, also spread by airborne spores in wet weather, forms a black elongated growth on needles. Foliage then suddenly dies, and the malady is sometimes mistaken for seasonal shedding of needles.

Heartrot fungi, represented by many species of several genera, are the cause of the greatest volume loss of all diseases to standing timber. Some produce fungi fruiting bodies on trees lying on the ground, the spores spreading to infect and introduce decay to living stems. Conks of heartrots, often appearing like shelves or dark-colored elephant ears protruding from wounds or long-since-healed-over scars, are the fruiting bodies of some species. From these conks, spores disperse to infect other trees over many years. Conks knocked off diseased trees by wind or man disseminate

Figure 2.8 Texas leaf-cutting ant colony. With backhoe excavation, the top of a cavity was located 9 feet below the surface of the ground and extended diagonally farther downward. In winter, the gardens, into which the ants carry parts of needles, are especially deep, thus providing protection from the cold of the ground surface. (Texas Forest Service photo by Ron Billings)

spores for as long as five years while the fruiting bodies lie on the ground. For the most important species, *Fomes pini*, spores are cast in spring and fall, when warm weather follows cool spells. Mycelia, the microscopic strands of the vegetative organ of the fungus, grow year round, introducing decay-causing toxic chemicals as they penetrate the interior of the tree.

Red heartrot is usually found only in southern pines over 50 years of age. Twenty-five percent of such older trees might be infected, thereby providing abundant habitat for housing the red cockaded woodpecker. As the heartwood deteriorates in circular fashion, the disease also bears the name red ring rot. Because many diseased stems do not exhibit fresh pitch flow from branch stubs and fire wounds, the lack of exuding sap may not reliably indicate the absence of the decay within the bole.

Most notable among the causal agents of butt rot fungi is *Polyporus schweinitzii*. Infection results in decay of the interior of a tree at its base, the rotting wood breaking into brown cubes. Seldom does the decay rise more than a few feet above the ground. The inconspicuous fruiting bodies may be found in the soil litter, still attached to the base of the tree.

When sap flows copiously from trees, and no insects are apparent, the cause likely is attributed to *Fusarium lateritium*, the fungus that causes pitch canker. Bark is retained, although the canker appears sunken and the wood beneath soaked with pitch. Fire danger is high in young stands in which wads of flammable gum collect on the trees.[7]

Cronartium fusiforme causes spindle-shaped cankers on branches, main stems, and the bases of needles. The alternate hosts of this fusiform rust are oak trees. Except around nurseries, elimination of oak trees is economically impractical. The disease may be spread by insects. Of particular significance in times of concern for sanitary landfills and other distressed planting sites is the effect of mycorrhizae fungi on the growth of pine seedlings. Mycorrhizae secrete a plant growth regulator—as well as enabling the transfer of nutrients from the soil to roots—which ordinarily enhances tree growth. However, the usefulness of such fungi is affected by methane gas given off by decomposing garbage in landfills. The gas may be phytotoxic, reducing root development and subsequent growth of seedlings. Inoculation with an auxin may compensate for the detrimental methane.[8]

Considerable concern has been expressed over the effect of ozone and nitrous oxide in the atmosphere upon the growth and survival of trees. Growth reduction of naturally regenerated southern pines over a 10-year period has been attributed by some observers to these industrial and vehicular contributions to the atmosphere. Reduction ranged from 10 to 31 percent for trees with initial diameters of one inch or more. Cause of diminished growth for this 1972–1982 period, however, was not totally identifiable. The period may have been normal, the previous decade's growth abnormally high. Ozone, however, is seen as responsible for some growth reduction in all major forest ecosystems, the decline continuing even if emissions into the atmosphere remain constant.[9]

High concentrations of ozone (O_3) seem to have little effect on needle production, although foliage retention is often greater, according to trials in air-filtered chambers. Southern pines are considered intermediate in terms of suspected growth losses due to air pollution, in contrast to high-elevation spruce and fir.[10]

Wildlife Relations

Foresters, game biologists, amateur wildlife enthusiasts, nonprofessional environmentalists, and others disagree on the value of southern conifer forests as habitat for game and other wildlife. Value depends on the kinds of animals and on the period in the life or rotation of a dynamic forest.

Dense virgin stands were likely poor habitat for white-tailed deer because closed canopies excluded browse shrubs and grazing broadleaf herbs, or forbs. A clear-cut harvest, in contrast, encourages doveweed, ragweed, Bermuda and carpet grasses. Soon, this ground cover is joined by trailing bean and milk peas. With ecological succession accompanying natural regeneration to another pine stand, broadleaf herbs give way to sod-forming broomsedge and other tall grasses. Woody shrubs then enter the stand, and the herbaceous forbs and grasses pass from the regenerated stand. Deer food is therefore plentiful for 6 to 10 years after clearcutting, with the population of the mammal diminishing as stands close to exclude ground vegetation and shrubs.

Optimum numbers of cottontail rabbits occur at about the same time as deer in the life of a pine forest, though some rabbits are found in all stages of second-growth woods. Cottontails feed on the *Andropogon* grasses of open fields. Jack rabbits in contrast, are most plentiful in grazed forests, seeming to appear from nowhere right after a timber harvest. They are gone from the pineries within 5 years after stand regeneration. If the cutting is in a bottomland, rabbits browse after herbaceous plants are crowded out and the underbrush has thickened. Rabbits are especially serious pests in plantations; more than 90 percent of newly planted pine seedlings may be nipped. Rabbits even prune lateral branches from older seedlings.

Red wolves long ago left most of the southern forest, though efforts to reintroduce them have been initiated. Gray foxes, in contrast, are abundant. They are most numerous 15 years after a harvest, when birds, fruits, and sheltering vegetation are abundant. Fox squirrels, which usually lose their dens in clearcutting, may be expected to re-inhabit a site in about 5 years after a stand's reestablishment.

As for birds, clearcutting dramatically alters the tally of an Audubon check-list. Quail are most numerous 4 to 10 years after cutting; they do not inhabit tall, thick, second-growth stands older than 15 years. Mourning doves frequent cutover lands 5 years after harvest. The disappearance of the red-cockaded woodpecker from the southern pine forests and its reappearance with appropriate management practices will be considered later. The ivory-billed woodpecker's demise occurred with the harvest of the old-growth pine–hardwood forests. The passenger pigeon also no longer nests in these, or any, woods. We now consider these hard, yellow pines in more detail.

Loblolly Pine

Four distinctly different climatic conditions occur within the range of loblolly pine: east coast, central Florida (though this species is not abundant there), mid-continent of Arkansas and East Texas, and the Lost Pines of the Bastrop area of central Texas. The Lost Pines have inherited characteristics of drought hardiness: the annual rainfall within their range is about one-half that of the Atlantic Coast. Regeneration is, conversely, reliably obtained in the high summer rainfall zones of the Carolina and Georgia coasts.

Figure 2.9 Four internodes of 1 year's height growth. The first internode is always the longest, the last the shortest. Six or seven flushes of growth, resulting in as many internodes, may occur in the southern extremity of the range of loblolly pine. (USDA Forest Service photo)

Of the climatic factors that determine this species range, probably the most important are the number of summer days each year with precipitation of 1/4 inch or more and the number of days each year with rain of at least 1/4 inch. Both of these relate to the replenishing of moisture lost by *evapotranspiration*—the combined losses of moisture from the soil by evaporation and from plants by the transpiration of minute droplets of water from the small stoma openings on the surfaces of foliage.

Winter temperatures affect the range of loblolly pine by controlling availability of soil water. The warmer the soil, the more readily the soil's moisture is absorbed by roots. In addition, roots may continue to grow all winter where soil temperatures are high. This, in turn, improves tree vigor and the chance for survival.

Differences between day and night temperatures affect growth of this species. For example, optimum growth occurs along the Atlantic Coast at the Virginia–North Carolina line. There, night and day temperatures differ more than elsewhere in the species' range.

High temperatures late in the summer may also reduce growth. Apparently, oxygen deficits develop in buds, resulting in anaerobic respiration. Growing-tip respiration with inadequate oxygen may cause formation of a hormonal inhibitor that induces dormancy earlier in the autumn than otherwise expected.

Photoperiod, the botanist's term for day length, is the cause of inception and termination of dormancy in trees in the fall and spring. When red light is introduced at night, for example, steady increases in height growth follow. This species grows all winter in cold climates where the day length is artificially increased by providing supplemental light. However, in the warmer climate of the southeastern coast, loblolly pine trees grow all year under irrigated and fertilized conditions.[11]

The effect of soil properties on the growth of loblolly pine has been demonstrated, most thoroughly perhaps in the Piedmont of South Carolina. There, site index decreases as much as 50 percent with sheet erosion. Where most of the surface soil has been washed away during cultivation, the index may be 50 units less than that of an adjacent virgin soil. Site index also diminishes with diminishing depth to subsoil and decreases with decreasing subsoil friability, most easily recognized by the amount of sand in the soil. Very plastic, heavy clay subsoils at least 18 inches below the surface may have a site index as low as 66. These are very friable.[12]

In the Atlantic and Gulf coastal plains, depth to subsoil (the zone that contains the greatest amount of clay and is the least permeable to water), subsoil texture, and surface drainage interact to determine site index. As surface soils in coastal flatwoods are quite shallow (usually less than 12 inches) and poorly drained, soil texture becomes the principal criterion for measuring land productivity; the more fine silt and clay in the subsoil, the better the growth of trees. Well-drained soils of the Coastal Plain usually have subsoils permeable to water and roots. However, where permeability appears poor, as evidenced by water standing on the land, root extension seems not to be greatly retarded.

The western Gulf Coastal Plain differs from that of the Atlantic, as the land surface for the former developed during periods of submergence following the Cretaceous period when material was carried down streams and rivers from the older main land to the north. These sediments were deposited as horizontal beds of sands and clays in shallow coastal waters, and later uplifted. Here, growth predictions for loblolly pine are based on texture, surface drainage, and depth to subsoil. Good surface drainage is associated with hilly and rolling uplands, while poor passage of water occurs in the flatlands. Hence, sandy soils of good drainage with less than 10 inches of surface soil are the poorest: Clay sites with poor drainage and more than 20 inches of surface soil are preferred.

Depth to subsoil is important because the thickness of the surface soil reflects the volume of soil available for root penetration without restriction. Site quality also improves as soil texture becomes finer until a certain point is reached. It then falls off due to poor aeration, with further reduction in soil particle size. Such soil relationships to loblolly pine growth have been ascertained throughout the region.

Periodic droughts are perennial obstacles to loblolly pine growth, even where annual rainfall exceeds 40 inches. The effect of drought on growth was calculated for several soil types in the lower Piedmont of Georgia where 6-week periods without rain occur in spring and summer an average of once every 25 years. Four-week droughts take place every 5 years and dry spells of at least 2 weeks virtually every year. Where severe erosion occurs, 2 weeks without rain result in drought conditions, especially in islands of shallow soil interspersed among the deeper, more fertile soil types. In one dry year, for instance, diameter growth was one-half of normal. While the width of the previous year's earlywood ring, when rainfall was normal, equaled the width of the late wood, earlywood in a droughty year was three-fourths of the total annual ring. This suggests that drought losses are largely in wood laid down during the latter part of the growing season.

Depth of soil, next to rainfall, is the most important criterion controlling mortality under drought conditions. Mortality was greatest during the worst drought on record where depth to a plastic, compact subsoil or to bedrock was less than 20 inches. Whole stands were killed where soil was less than 16 inches deep. Stand density was not a factor.

How loblolly pines adapt to excess atmospheric sulfur caused by ore smelting, coal burning, and other industrial processes, has been studied using radioactive sulfur. Translocation of the radio-labeled element throughout the tree's tissues, rather than leaching of the element from the foliage, appears to be the mechanism by which forest trees adapt physiologically to this environmental stress.[13]

Shortleaf Pine

There is no typical site for shortleaf pine. Like most forest trees, it grows best on moist but well-drained, or mesic, sites. While occurring with many other species, shortleaf pine also grows in pure stands from the West Gulf Coastal Plain to the northeastern extremity of the region.

Often, this pine is the initial tree to seed-in on old fields freshly abandoned from agriculture. Favorable weather must accompany good seed crops for this to occur. Oaks, as a rule, enter old-field stands when the pines are about 20 years old. By that time, enough litter has collected to protect the soil from desiccation and to improve the porosity of the surface horizon. The importance of soil moisture has been shown by artificially inducing drought in a 35-year-old shortleaf pine stand in a Piedmont sandy loam soil in an effort to mimic littleleaf disease. Branches died from the bottom upward, needle length was greatly reduced, needle retention time was shortened, and growth practically ceased after 5 years of such stress.[14]

Height growth of shortleaf pine following germination depends on the depth of the surface soil and consistence and texture of the subsoil. Fastest growth takes place on the deepest surface soils, the most friable subsoils, and where the subsoil has less than 20 percent clay. The degree of slope also influences rates of growth: It is best on level land.

While available water is the most important variable influencing both growth and survival, the species' drought resistance has been attributed to the capacity to absorb water when moisture is limited, to hold water in its needles during drought, and to maintain high solute concentrations in the foliage when recovering from drought. Perhaps optimal growth for shortleaf pine is in the south-central (Coastal Plain) area of Arkansas.

Littleleaf Disease—The study noted above relating to drought was installed to learn the effect xeric soils could have on a malady first reported in 1934, that by the 1950s caused appreciable reduction in growth of shortleaf pines, especially in the Piedmont of South Carolina. Why were needles abnormally short, sparse, chlorotic, and hanging as tufts at the ends of twigs? Drought alone does not cause this abnormal phenomenon called littleleaf disease. While the amount of nitrogen was normal in drought-induced needles, the nutrient was deficient in foliage characterized by the disease-shortened leaves.[15]

The malady occurs only where severely eroded or abandoned farm lands have been reforested. Originally, on such sites, a deep, friable and fertile surface soil bore hardwood climax forests. The surface zone, in which roots of trees are most abundant, was deep and well-drained. With cultivation of these rich-appearing virgin soils, however, the surface layer washed away, leaving a thin mantle that forced roots to grow into the impervious, poorly aerated subsoil which, because of erosion, now lies near, or at, the surface.[16]

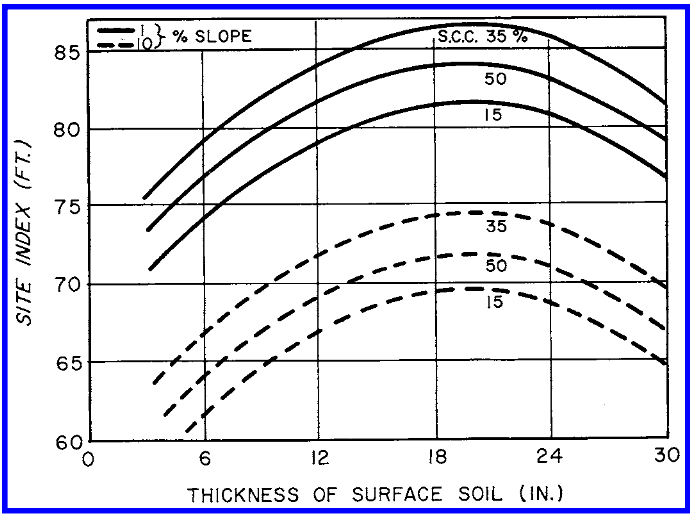

Figure 2.10 Shortleaf pine growth and soil. Site index on Coastal Plain soil in Arkansas depends on depth of surface soil, clay content of subsoil, and steepness of the slope. Steep slopes lose top soil to erosion, deep surface soils lose water to underground aquifers, while tight subsoils hold water perched over shallower surface horizons. Too much clay binds water so that it is not available for trees; too little allows water to be lost to drainage and evaporation. (after USDA Forest Service chart by R. Zahner, 1953)

On lands like this, the shortleaf pines introduced following agricultural abandonment exhibited the disease. While the deficiency turned out to be the nitrogen nutrient, the relationship is not direct. The minute nitrogen-absorbing pine roots were gradually killed by a parasitic soil fungus. *Phytophthora cinnamomi* interferes with nutrient absorption, especially that of nitrogen, by injuriously infecting the root ends. Spores of the fungi occur widely. In well-drained soils in which sufficient moisture is periodically present for swarm spore production and root infection, spores spread during rainfall to infect other sites. Later, as the soil provides optimum conditions for root growth, new roots form and effectively replace those lost by the infection. In poorly drained soils, the period of high moisture is extended, and root recovery consequently retarded. Applications of nitrogen fertilizer delay death of the trees (see Chapter 6). The disease may also be related to manganese toxicity.[17]

Why is the problem not so prevalent with loblolly pine under similar conditions? Shortleaf pine feeding roots are most abundant in the upper few inches of the soil; while loblolly pine roots, though fewer, are larger, more deeply distributed, and show greater ability to penetrate heavy soils. Loblolly pines are also more tolerant of poor soil aeration. Perhaps, too, in the Piedmont province the longer-needle species is inherently more vigorous than is shortleaf pine.

Prolific Sprouter—Shortleaf pine is one of the most prolific sprout producers among the southern pines, especially after fire. New trees emerge from damaged seedlings at a "collar" at the juncture of the hypocotyl and the primary root. This is the zone where the root meets the stem in larger trees. As sprouts are traced to the axils of primary needles at that position, new stems, therefore, do not form from adventitious buds, as often thought. Nor do shoots arise from roots.[18]

For young seedlings, the stem lies horizontally prostrate as shoot growth begins. The stem then turns upward from a point just above the cotyledons on seed leaves. These bends form the crook that typifies shortleaf pine seedlings. (Careful lifting of seedlings of any age enables observation of the crook, a sure way to distinguish between shortleaf and loblolly pines when foliage appears similar.) Then, primary needles and their auxiliary buds form a cluster just below the second bend of the crook. Further thickening engulfs the short horizontal portion. Rootlets develop from the uppermost root tissue close to the bud cluster that is often covered by soil.

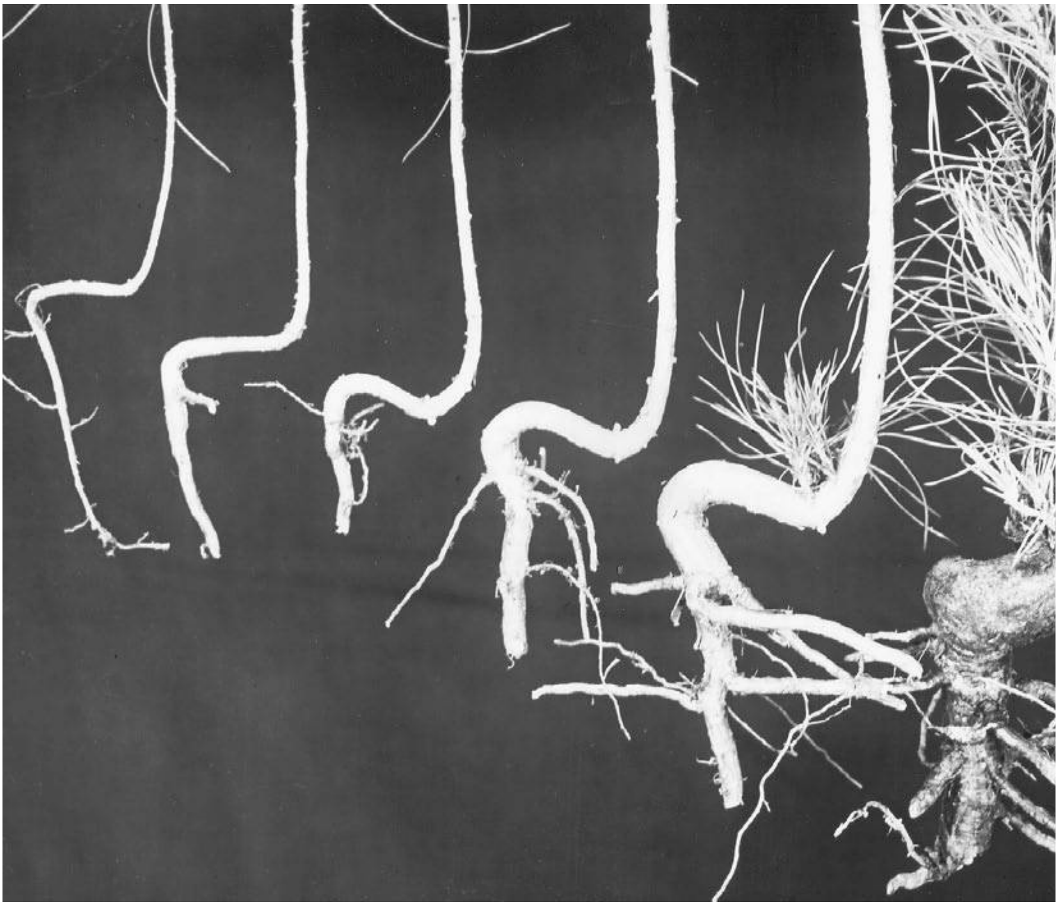

Figure 2.11 Bud steles in a shortleaf pine cross-section. A 3.5-inch diameter section basal view shows branching of the steles and the origin at the pith. (authors' collection photo by Earl Stone)

LOBLOLLY PINE—SHORTLEAF PINE

The prevalence of mixtures of these two species across much of the South suggests consideration of the forest cover type. Mixed forests of these pines occur over a major area of both the Coastal Plain and the Piedmont provinces. Oaks and hickories are generally associated with them, but some 50 broadleaf species invade and frequently take over the site. Sweetgum, blackgum, hickories, red oak, and post oak often replace the loblolly pine–shortleaf pine–hardwood subclimax types.

In the western sector of the range, hybridization and back-crossing of the two species is apparent, resulting in numerous intermediate forms that cannot be readily classified as belonging to either species. Bark, cones, seed, foliage, buds, and seedling progeny are intermediary. Foresters may find themselves in a quandary when tallying tree volumes by species in a timber cruise.

Forest geneticists suggest wide variation in inheritance as well as interbreeding as possible causes for the intermediate forms. No doubt both take place, but the latter seems more probable in spite of the time difference in pollen dissemination, usually March for loblolly pine and April for shortleaf pine. The two species have similar silvical characteristics; together they respond to the same silvicultural treatments as either of the pure types.[19]

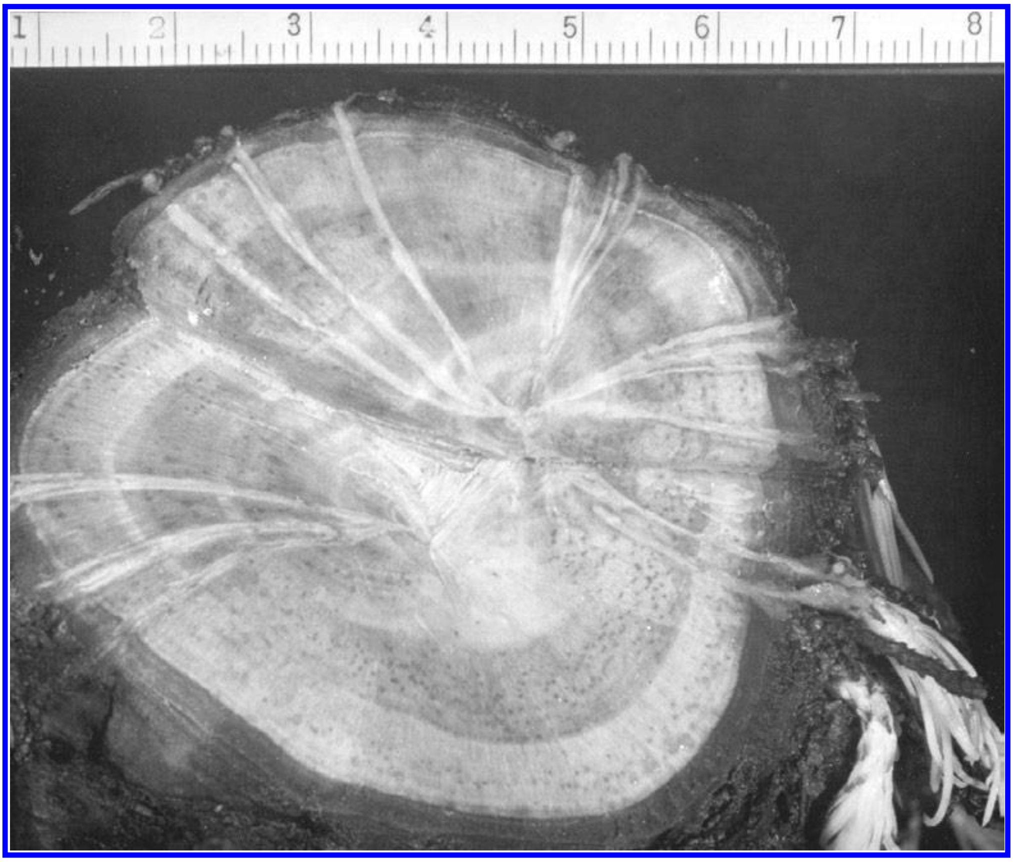

Figure 2.12 Basal ground-level crook of shortleaf pine. From the horizontal position on the stem at the root collar, buds break into sprouts when trees are injured. Except for redwood, no conifers produce sprouts from roots. (authors' collection photo by Earl Stone)

Slash Pine

As a rule, natural stands of slash pine grow only within 125 miles of the South's coasts. The species' abundant seed production, rapid growth, relative tolerance to shade (in contrast to longleaf pine), ability to withstand feral hog rooting and fire (after trees grow beyond the sapling stage), and adaptability to a wide range of sites have enlarged its habitation.

Slash pine stands often inhabit creek drainages because seed sources have been available at just the time—during severe drought—when a fire burned over these lower-elevation lands. This coincidental phenomenon occurs perhaps every few decades. For the same reason, slash pine replaces longleaf pine in poorly drained sandy flats. Both species may seed-in together, slash pines overtopping and crowding out the grass-stage longleaf pines in the lower-elevation moist sites while later fires kill young slash pines on the hills, where the longleaf pine seedlings survive, protected from fire injury in their ground-hugging grass stage. Hence, there is an abrupt transition from slash pine to longleaf pine as one traverses a slope from a creek to a knoll. (The same transitional relationship occurs where loblolly pine, rather than slash pine, competes with longleaf pine. This is especially apparent west of the Mississippi where slash pine is not native.)

Slash pine, usually a subclimax, but a climax species when periodic fires keep competitive trees from attaining dominance, allows favorable forage production for livestock and many wildlife animals. Herbaceous ground cover may exceed 1 ton per acre until stands close. The shade of the canopy then causes rapid decline of grasses and forbs.[20]

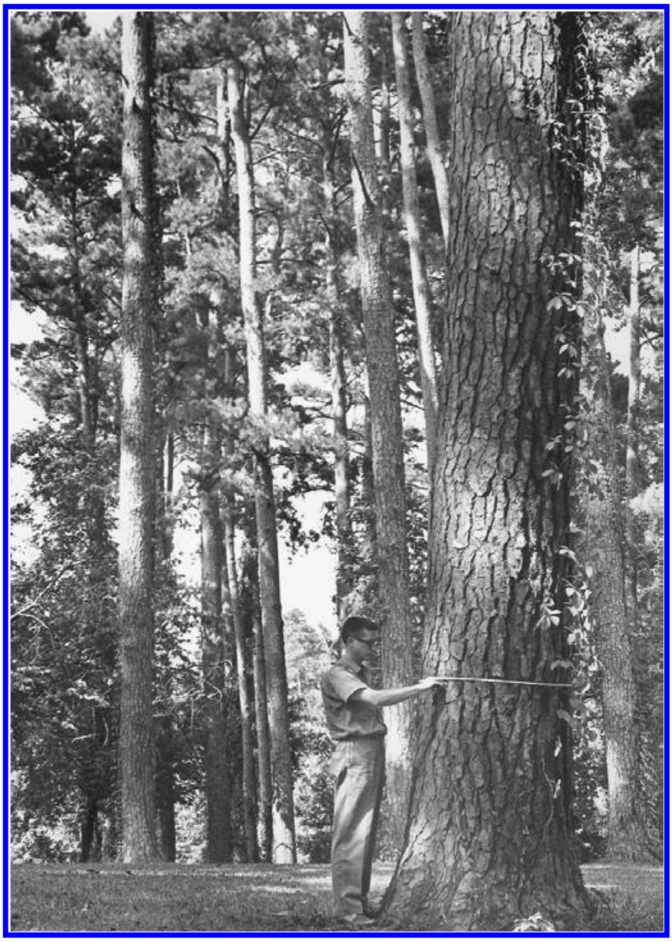

Figure 2.13 Loblolly pine–shortleaf pine forest. This 85-year-old stand in the upper Coastal Plain originated from natural seeding on cotton cropland abandoned during the agricultural depression of the 1890s.

Highly successful plantation establishment has favored the spread of the slash pine range. Indeed it was planted into Texas, well west of its natural western extremity—the Mississippi River—and north into the South Carolina Piedmont until plagued by the pathogen discussed below.

Root Rot—*Fomes annosus*, the causal agent for annosus root rot, infects slash pine more extensively and severely than any other southern tree.[21] Windthrow from even mild windstorms is attributed to the decay of tree roots by this fungus. Ironically, intensive management often increases the infection because the fungus spores—always in the atmosphere—come to rest on freshly cut, gummy, resin-soaked stumps where stands have been thinned to improve the vigor of residual stems. Mycelia grow from the germinated spores down the stumps to roots and via root grafts to nearby healthy trees. Death occurs within about two years after infection. As a rule of thumb, the infection is found in thinned stands that have been planted on abandoned farmland. The disease is not occasioned by the establishment of stands off-site, as sometimes claimed.

Certain evidence of the malady is the premature thinning of tree crowns a year before death. The stringy appearance of decayed wood, another symptom, appears where roots have been broken off from trees recently toppled by wind. The brown-topped fruiting bodies of *F. annosus* are camouflaged by needle litter at the bases of infected trees; the conks also grow on stumps or roots. The careful observer finds them any time of year. Groups of trees dying simultaneously has led to misdiagnosis, death erroneously attributed to bark beetle infestation. Beetles do enter *Fomes*-weakened stems, there to girdle the boles and to kill the trees as they feed. Other evidence suggests no carryover of root rot hazard on sites where trees had been clear-cut due to serious infection and subsequently planted with slash and other pines (see Chapter 6).

Mycorrhizae—As with all North American pines, mycorrhizal fungi are necessary for survival of slash pines. The minute hair-like growths on roots aid in exchange of cations between soil and plants. Foresters learned this in planting seeds of the species in islands of the West Indies where pines were not native. Newly germinated seedlings succumbed unless the soil was inoculated with the fungus. Transporting seedlings from nurseries in the South to the islands also provided the microbial spores and infected roots. The fungal strands, clinging to the roots, had been abundant in the nursery soils.[22,23]

Longleaf Pine[24]

Usually found on sandy lands and often accompanied by turkey oak and other scrub hardwoods, longleaf pines also seed-in on moist sites subjected to drought where the soil has been exposed. Fire exposes the mineral soil as flames consume pine straw lying on the forest floor. Pure stands give way to mixtures with loblolly, slash, and shortleaf pines in loamy flatwoods and along the streams of the lower Coastal Plain. Longleaf pines grow on clay as well as sandy lands, regardless of fertility. Along the Atlantic coast, the species' occurrence on sites where water occasionally perches over shallow surface soils atop impervious subsoils probably influenced the taxonomist Linnaeus in naming the species *palustris*, meaning swamp.

A fire-subclimax type, this species dominates the forest only if periodic fires occur. Prior to the Europeans' entry into these woods, dead snags were often struck by lightning, setting the grassy lands on fire. With fire exclusion in recent years, the acreage covered by this species has greatly diminished. New natural growth is likely to be slash pine along the eastern Gulf and Atlantic coasts and loblolly pine in the western sector of the Gulf coastal area.

Acreage decline also is attributed to the clear-felling of vast expanses without leaving a single seed-producing longleaf pine tree in the days of the cut-out-and-get-out lumbermen, to hogs' grazing on seedling roots rich in carbohydrate, and to a seedling blight. Other causes for the species' reduced range include cone- and seed-insect infestations, heavy (though winged) seeds that do not travel far with the wind, a ground cover of grass and forbs (called rough) through which the seeds do not penetrate to reach mineral soil for germination (unless fire passes through to reduce the amount of rough), and consumption of the seeds by rodents and birds. While more than 100,000 seeds per acre might fall within a stand adjacent to an opening, only 15,000 fall within 130 feet of a forest's edge, and few sail with the wind beyond that rim into a clearing. However, with especially abundant (although rare) seed crops, adequate numbers fall in clear-cut openings as far as 500 feet from walls of trees.

Longleaf pine seeds germinate shortly after seedfall in the autumn. This enables initial establishment of seedlings in the sandy, often droughty, soils. A long taproot then penetrates lower-level soil horizons, absorbing moisture and nutrients during the winter, spring, and early summer. Thus, the seedling is well established before late summer droughts occur. In contrast, all other southern pine seeds overwinter on the cold, moist ground, germinating in the spring. (Abnormally cold spells in late winter, however, can readily kill the freshly germinated longleaf pine seedlings by frost-heaving them from the ground.)

Competing vegetation underlying longleaf pine–turkey oak forests in Florida's sandhills includes explosively dispersing seed plants including bullnettle, rattlebox, and queen's delight. Ballistically, dispersed seeds are distributed from a "maternal patch" of about a meter in diameter. Harvester ants then carry the seeds as far as another 8 meters. Without the insect's aid, dispersal alone would not be adequate for moving the seeds beyond the maternal patch to establish a new colony to compete with the pines for soil moisture and nutrients.[25]

Figure 2.14 Note the flat top in this fine longleaf pine stem, evidenced by cessation of height growth and maturity for that particular site. Diameter growth continues. (USDA Forest Service photo by W. Matoon, 1930)

Nanism—Temporary nanism of longleaf pines keeps seedlings in the grass-stage. No other North American tree (except on occasion South Florida slash pine and pitch pine in the New Jersey barrens) demonstrates this dwarfing, a condition often solely and erroneously attributed to vegetative competition (including other longleaf pines) for moisture and nutrients. Nanism is at least partially an inherited seedling trait under rigid genetic control, although the length of time in the grass-stage—from 2 to more than 25 years—is strongly influenced by plant competition and the environment. The short shoot habit may be associated with the production of auxins—naturally occurring plant-growth hormones—in newly germinated seedling buds during early stages of development. The popular belief that seedlings, appearing like clumps of bunch grass, remain in the grass stage until taproots reach moisture seems unfounded. Taproots grow to depths of more than 6 inches in three months and twice that distance in the first 5 months after seed germination. Meanwhile, lateral roots develop, enabling absorption of moisture even from droughty surface soils.

As a rule of thumb, seedlings remain in the grass stage until they reach 1 inch in diameter at the root collar, then, almost invariably, emerging from the grass. In the earliest grass stage, the terminal meristem, out of which the needle fascicles arise, forms a flat surface. Then, a slight convex curvature develops in this fascicle-bearing organ, and a semblance of a bud appears. The typical silvery white pointed bud eventually develops into a main axis from which lateral fascicles arise. Once the conical bud has appeared, elongation occurs rapidly and dominance is strongly expressed. Annual height growth for the tree may then exceed several feet for a few years. The saplings appear so similar to some grasses that oldtimers from the days of the Civilian Conservation Corps, decades after their planting experiences, realized that they had planted nursery-grown stock among naturally regenerated seedlings in 1938. The trees more recently appeared random, not in rows as planted stock would be. Alas, the nursery-supplied seedlings had died.

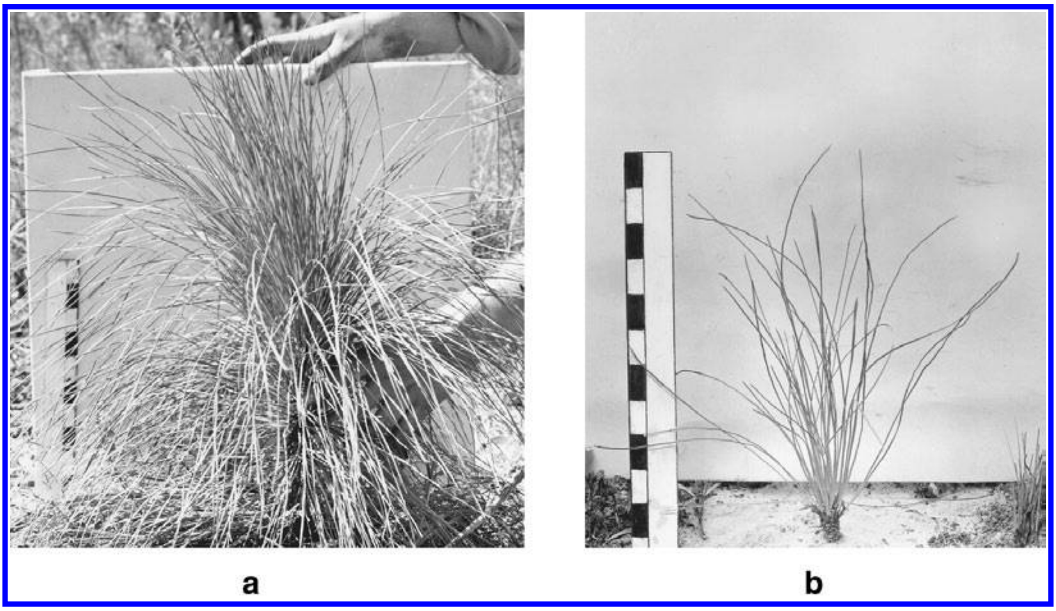

Figure 2.15 Three-year-old longleaf pine seedlings in the grass stage. The tree on the left had been released from the scrub oak competition; the one on the right had not.

Pocket gophers, soil burrowing vegetarian rodents appearing like stout mice but with strong claws for digging, play havoc with grass-stage seedling stands in sandy soils. Making extensive tunnels about four inches in diameter in their search for starch and the resinous flavor of pine roots, the mammals sever the roots below the ground. Gophers dig rapidly, their obvious entry mounds leading to tunnels. After a summer rain, they "throw out" perhaps two mounds a day. One family threw out over 300 mounds on l0 acres in a single year. Usually meadow dwellers, preferring bitter dandelion roots to those of pines, pocket gophers migrate out of young forests when tree crowns close. They not only cut roots in constructing tunnels, they also eat the roots. Perhaps apocryphal is the tale that one can witness seedlings disappearing as they are pulled by the rodents into their tunnels below the surface of the ground. Cottontail rabbits also destroy seedlings by nipping off terminal shoots for food and moisture.

Fire—Longleaf pine seedlings resist most fire injury after their first year and until height growth begins. In the grass stage, the single large bud on each seedling is shielded from the heat by a sheath of needles. Bud protection by the rosette of foliage is demonstrated by letting a fire sweep over a stand of seedlings in which buds have been wrapped with cigarette papers. Needles will burn to 1-inch stubs, with the papers left unscorched. Once the seedlings emerge from the grass to make initial height growth, trees may be injured by fire—heat from the burning rough rises to kill buds, because the thin bark on the young stems is an inadequate insulation against high temperature.

Fire has little, or no, measurable effect on the soil and the roots of trees in it. If roots are injured, new feeders develop in the top few inches of soil. Occasional fires, temporarily increasing

Figure 2.16 A longleaf pine forest floor. Burrows made in the surface soil were probably tunneled by pocket gophers, mammals of the genus *Geomys*. A note on the 1936 photo indicated the site had not been burned for at least 30 years, an unusual situation for sites supporting this species. (USDA Forest Service photo)

nitrogen and exchangeable cations, may be slightly beneficial in the typically acidic soils in which the species grows. Calcium, potassium, and other positively charged ions released in the ashes of the oxidized organic matter become available to the trees, and to other plants.

Where soil organic matter is not appreciably altered by fire, bacterial populations proliferate. These microbes, however, hasten decay of vegetative organic matter and, in the process, consume a significant amount of nitrogen. To the detriment of higher plants, some soil nitrogen may be liberated to the atmosphere by the heat of fire. Yet, at the same time, more nitrogen in the soil becomes available to plants.

Many more forms of microfauna are found in unburned ground cover of longleaf pine forests than in burned areas characterized by herbaceous cover and where fermentation and humus layers are absent. The surface 2 inches of unburned soils have many more mites, earthworms, ants, and crayfish than do burned sites. As for macrofauna, cotton rats move from burned to unburned fields while old-field mice and Florida deer mice remain to nest in areas scorched by fire.

In a longleaf pine site in which slash pines had been planted, prescribed burning at 3-year intervals, the earliest time at which fuel is sufficient, does not sustain greater yields of herbage for cattle. For herbage production, the use of fire may just as well begin when trees are 9 to 12 years old. Early burning does, however, maintain woody browse for wildlife.[26]

Virginia Pine

People in the Appalachian Mountains and Piedmont provinces are likely to know Virginia pine as scrub pine. As an initial tree species following fire and in old-field ecological succession, the seemingly ubiquitous dead twigs find use as kindling for a Boy Scout's "two-match" fire. The species, however, is not limited to the mountains and their foothills. It occurs throughout most of the Atlantic Coastal Plain, from New Jersey to Georgia, and in vast pure stands in the Cumberland Plateau of Tennessee. While the species is generally succeeded by shortleaf and loblolly pines following its pioneer appearance on deforested sites, in the 1950s a remnant virgin forest in northern Alabama included Virginia pines in mixture with shortleaf pines.[27] Indicator plants delineate site potential for this species. In the northern part of Virginia, two such vegetative covers occur. Better sites—Site Index (SI) 50 to 70—are characterized by flowering dogwood and clubmoss, while bear oak (one of the scrub oaks) and reindeer moss (less demanding of the nutrients of a site than the true mosses) indicate average and poorer land productivity—SI 30 to 50.[28]

Mycorrhizae fungi, the microscopic growths on pine tree roots, especially affect the vigor of Virginia pine. How favorable or detrimental the effect is depends on soil moisture. As root systems are small when moisture is low, the proportion of rootlets infected with the favorable fungi *Cenococcum granifome* and *Thelephora terrestris* increases. Their abundance also is greatest in dry summers, increasing as much as 10-fold with decreasing available moisture. Apparently the mycorrhizae lack competitive ability in moist soils.

Photoperiod and the kind of light available also affect the growth rate of Virginia pine. In greenhouse trials, stem elongation and the number of leaves on seedlings increased by extending day length from 8 to 16 hours. Hence, longitudinal range restriction may be related to day length.

As for all southern yellow pines, seed development for Virginia pine requires almost two years from the time of flower formation. The time varies slightly, depending on longitudinal position. In Mississippi, pollen is disseminated in mid-March; in the colder clime of North Carolina, ripening of the flower-like strobili occurs in late April.

Flowers develop almost every year, enabling frequent seed production so that hardly a season passes in which an abandoned field or burned-over forest may not be naturally regenerated. Seedfall begins in late October and continues until the following spring, though the number of seeds released from the cones drops off appreciably by late December. The trees in open stands are most prolific. Although seeds are disseminated each autumn, heavy seed crops occur with regularity every three years. Natural regeneration also comes from sprouts arising from dormant buds near the bases of charred trees.

Meadow mice nibble at Virginia pine seedlings and saplings in dense stands. This is especially so adjacent to cutover lands where grasses and forbs provide a habitat that encourages the increase of rodent populations. Small beads of resin form on the exposed wood where the mice gnaw on the bark, seldom more than 8 inches from the ground. Later, a white resinous coating appears and, still later, a black resinous rim forms around the injured area. The mice feed on trees in winter when sap is the most readily available moist substitute for creek water, which is frozen and unavailable at that time.

Pitch Pine

Like the Phoenix of Egyptian mythology, pitch pines often depend on fire for their continuation, as seedings rise from the ashes. Although killed by heat, these pines quickly seed-in following a holocaust on burned-over lands of shallow, dry, charred, and scarred soils. Competing hardwoods also succumb in the fire. That only some pitch pine trees are serotinous suggests this to be an inherited characteristic.[29]

The tree has fantastic restorative ability following fire. Even when heat kills all the foliage, crowns sprout new needles. New terminal shoots replace charred ones and sprouts at tree bases join with newly germinated seedlings to promptly replace fire-killed stems. Basal sprouting, however, depends on the existence of a basal crook where dormant buds are protected by thick bark. New stems on 90-year-old stumps rejuvenate root systems.

Pitch pine, of course, is not limited to the scalp-locks mentioned earlier. In every locale, regeneration must take place at least every 80 years, for the stands of pine mysteriously break up, apparently not for any pathogenic reason. For this rapid-growing tree, diameters of 20 inches may be exceeded in that time period, even on the relatively sterile sites of the higher elevations. In time, and in the absence of fire, more tolerant hardwoods or shortleaf pines replace the ecologically temporary pitch pine forest. Here, shortleaf pine endures, for its deeper taproot penetrates crevices of crystalline rocks that lie under shallow mountain soils. Stability against strong winds that whip across the ridges is thereby enhanced. Windthrow for pitch pines is attributed to the species' shallower roots in these soils. On the typically warmer, drier, south- or west-facing slope on which this tree grows, only low-value stems of any kind persist, and on damper lands given over to pitch pine, even trees of high-value species are likely to be poorly formed. The species' presence is an indicator of a poor site.

Figure 2.17 Fly ash as a plant-growth medium. This material from a coal-fired locomotive accumulated on the lower slope of a steep railroad grade. Pitch pine and broadleaf tree roots grow in the ash layer immediately above the original soil surface. (authors' file photo by E. Tryon)

Flowering of pitch pines in the mountain climes extends from late April to mid-May. The trees produce seeds at an early age, occasionally as young as 4 years. Dispersion of seeds, even where fire is an aid to cone opening, is usually limited to about 300 feet. This limitation continues the scalp-lock appearance of stands in hilly country.

Openings of cones of pitch pine are subject to changes in humidity as well as to changes in temperature. A crude barometer can be made from a cone by gluing a stiff wire to a cone scale and mounting the cone on a board to which has also been affixed a paper chart with lines indicating humidity. The wire moves as the cone scale responds to changes in atmospheric moisture, the wire's free end pointing to the forecast weather conditions on the chart.

Ring-counts are especially undependable in aging pitch pine trees. False rings develop from mid-seasonal growth flushes, while enduring drought prevents the formation of true rings.

Copper Basin—An unusual site for pitch pine includes the Copper Basin of southeastern Tennessee and north-central Georgia. There the species has been planted to effectively reforest the eroded hills. It is the choice tree for reclamation here because of its extensive and fast-growing lateral root system for absorbing moisture and nutrients in xeric infertile situations. The 23,000-acre "desert" was created a century past when smelter fume effluent from copper-refining stacks formed sulfuric acid as it poured from industrial flues into the atmosphere. The descent to the ground of this liquid particulate matter in the form of acid rain lowered soil pH by several units. Vegetation was destroyed, exposing the land to such severe sheet and gully erosion that one authority claimed that by 1954 the soil had been washed away in places to a depth of 16 feet. The smelter fumes are now largely controlled.

Influence of a forest upon air and ground temperature is demonstrated by the appreciably higher summer and lower winter readings in the denuded area than in the forest that surrounds the Basin. Harsh microclimate due to the absence of ground cover makes plant establishment difficult. Throughout the year, loss of water from the soil to the atmosphere is greater within the treeless zone than in the nearby forest. While seeding fume-resistant grasses offers the most promise for amelioration of the worst sites, pitch pine holds its own once grasses control erosion.[30]

The Barrens of New Jersey[31]—The Barrens of southern New Jersey, the northernmost sub-region of the southern forest, illustrate a unique situation for pitch pine. Stands there have been an ecological entity for study since at least the early days of this century. The interrelationships of the various kinds of vegetation to the nonliving components of the environment fascinate the imaginative mind. Fire has played an important role.

In the vast barrens, pitch pine occurs pure, in mixtures with scrub oaks like bear and blackjack, and commingled with other oak trees such as black, white, scarlet, and chestnut. Shortleaf pine stems are sometimes woven into the canopy. Often true podzol soils, exhibiting ash-white leached horizons, extend to depths of 14 inches. If fires could be excluded for a generation in order to accurately measure site index, the site SI might be between 50 and 65, at best an indication of low land productivity.

Within the barrens are pitch pine plains of even poorer site quality. Here the average tree height at 65 years of age tallies less than 11 feet, and normally developed trees are absent. The virgin forests probably were never lush, but acceptable stands of both pitch and shortleaf pines likely occurred. The place of these pines in ecological succession is temporary, giving way in the absence of fire to deciduous broadleaf trees.

Fires, however, periodically burn the woods, killing non-serotinous shortleaf pine and oaks (white, black, scarlet, and chestnut) in the plains. The inability of broadleaf trees to produce seeds at an early age hinders hardwood reproduction in the oft-burned areas. Even shortleaf pine and hardwood sprouts, both originating in massive clumps, cannot be maintained in such a fire situation. Forest ecologists attribute the stunted growth in the plains solely to burning, with wildfires occurring on average every 8 years—twice as frequently as in the surrounding barrens. No marked differences are apparent between soils of the plains and those immediately beyond their boundaries.

Repeated wildfires took place prior to fire protection by the state, keeping the vegetation at a low level. Shoots from the stumps of fire-killed stems quickly sprouted. Stools from which new shoots arise are 80 or more years of age, each stump producing as many as 200 sprouts. While sprouts from young, small stools exhibit good form, shoots from old or large stumps are likely to be of poor form and rot-infected within a few years of sprouting.

Roots of pitch pine, even though heavily infected with favorable nutrient- and moisture-absorbing mycorrhizae, apparently are little better adapted for the dry soils of the barrens than are

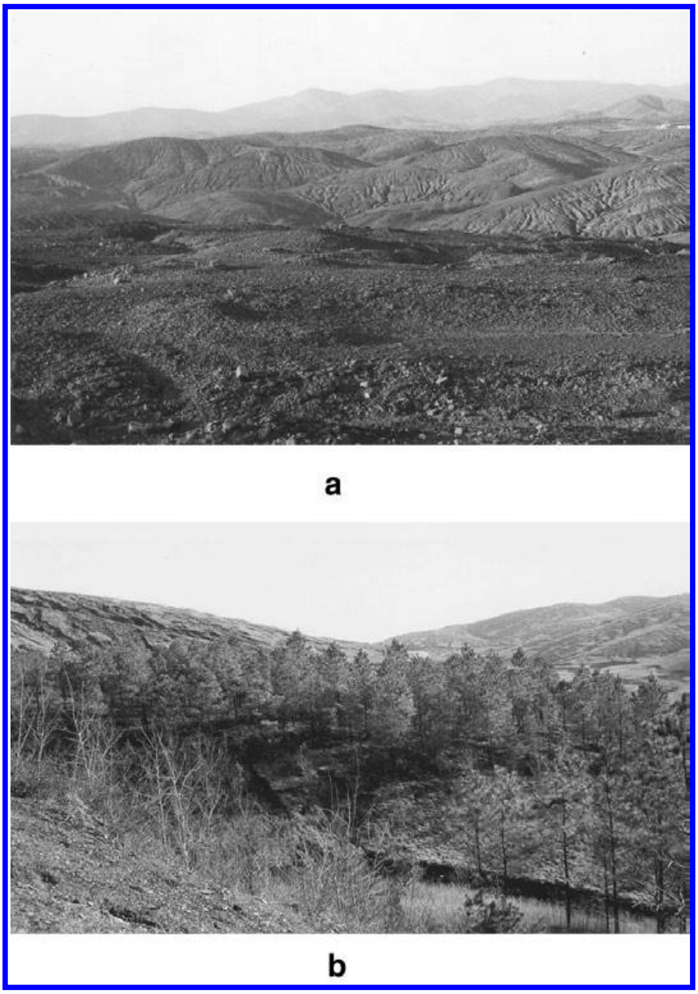

Figure 2.18 Smelter fumes from copper refining increases soil acidity to as low as pH 2, leaving a vast area in the Southern Appalachians (a) devoid of vegetation. Planting pitch pine (b) is a recommended reclamation practice.

those of more drought-hardy species. Root tips die during periods of moisture stress. Yet, roots of the predominantly taprooted seedlings of the species grow to depths of 3 to 12 inches the first year. Even for a tree's first decade in this xeric situation, taproot depth equals lateral root length—about 2 feet. Shortly thereafter, laterals take over as the most pronounced feature of the root system, eventually extending as far as 35 feet from the stems. Taproots measure as much as 9 feet deep.

Natural root grafts between trees in a stand are not uncommon. Where rock-bound, the roots join, eventually able to translocate moisture, nutrients, and carbohydrates from one stem to another. Interspecific root grafts between pitch and shortleaf pines also have been noted.[32]

Hardwood trees growing on sandy soils in other situations favorably improve the structure and nutrient levels in the soil. Apparently, this does not hold for the barrens. Even frequent fires there have little adverse effect on soil organic matter, for the warm, humid climate just as assuredly rapidly oxidizes dead tissues in the absence of fire. The dry sands are so sterile that earthworms and myriapods are scarce, due, no doubt, to the low pH of 3.4 to 5, but also to the unavailability of nutritious deciduous tree leaf tissues. However, if the site remains unburned for several years, litter accumulates in places to a depth of 4 inches; the organic matter is then attacked by fungi to bring about its decay and incorporation into the mineral soil.

In addition to fire that encourages sprouting from basal crooks of pine seedlings, burning prepares a seedbed favorable for pine seed germination. Thus seedlings begin to grow, are killed back to the ground by fire, and resprout from dormant buds; the cycle is repeated. Some trees survive each of the fires, giving the appearance of a many-aged forest. Silvical history of the oaks in the Barrens is similar. Hence, 16000 stems per acre (25 in a square yard) occur, yet fewer than a 10th of these may be larger than one-half inch in diameter at breast height when 25 years old.

When farmers abandon cultivated fields in the Barrens, pines and oaks quickly invade the land. Panicums and umbrella sedges also encroach and, within a year, over 100 species of seed-bearing plants arise on a typical acre. The relative number of tree stems on the old fields relates directly to the availability of seeds, both in time and place. Dense covers of herbs especially restrain pine reforestation. The coarseness of the soil, its consequent low colloidal content, minimal moisture-holding capacity, and the lack of organic matter contribute to poor tree growth.

Pond Pine

Pond pine is closely related botanically to pitch pine. The similarity is limited to the flower parts and arrangement, the basis for Linnaeus' original classification of the serotinous trees. Pond pine occupies unique sites along the Atlantic Coastal Plain. Areas too poorly drained even for loblolly pine, but in which this scrubby tree does well, include Carolina Bays and pocosins. The Bays, characterized by shallow elliptical depressions with well-defined sandy rims, often appear as peat swamps. Some counts tally as many as a half-million such concave features of various sizes, occurring from New Jersey to northeastern Florida. Pocosins, in contrast, found closer to the ocean shore, may each cover a few to several thousand acres. Prevailing winds probably encouraged these lower terraces to fill with soft black muck or brown fibrous peat. In these swamps-on-a-hill (slight bowl-shape rises in a nearly level terrain), loblolly pines commingle with the pond pines.

Stands of the species also occur along stream banks. In rather isolated tracts in southern Alabama, pond pines hugs the coast. There longleaf and slash pines intermingle with the serotinous species.

Pond pine forests are probably climax in bays and ponds, maintained there in pure stands in the absence of fire because of their ability to survive long seasons of flooding, and regenerated as a consequence of fire. Thus, stands sometimes are uneven-aged, the 15- to 20-year intervals in which the organic sites are swept by wildfires dividing the age classes.

Needles of pond pine are arranged on twigs in a manner that provides for mutual shading. This diminishes photosynthesis, in turn slightly increasing shade tolerance. Thus, these trees respond favorably to release from overtopping shade.

Unusual for species growing in wet organic soils, pond pines withstand high winds. The root system, penetrating to great depths through perched water tables to mineral soils, provides stability.

Drainage encourages oxidation of the peat or muck layer, sometimes completely eliminating it. Such destruction of the organic matter reduces the elevation of the land. Hence, water tables may be nearer the ground surface after drainage than they were before canal and ditch construction.[33] Pond pine, however, responds to drainage with improved growth.

Growth is slower on wet organic soils than on mineral matter. That is because inundation prevents oxygen penetration into the soil, which, in turn, retards decay of organic matter. High acidity follows, and with it reduced nitrogen fixation to a form of the element the trees can use.

When growing on mineral soils, height growth appears unaffected by soil moisture or stand density. Even where burned over, these poorly drained sites produce trees only about 30 feet tall in their first 20 years. At age 50, heights are about 50 feet, boles having no more than two merchantable logs. From then on, growth rate declines.

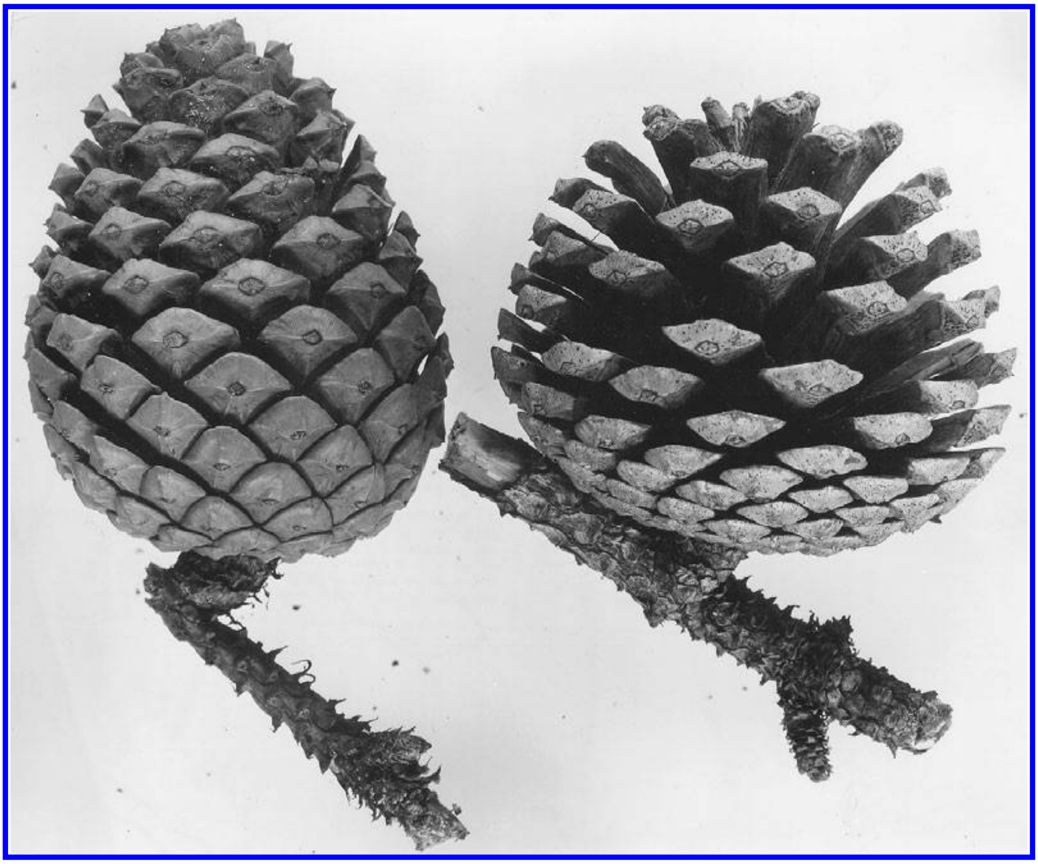

Figure 2.19 Cones of pond pine. Open cones of the serotinous species release seeds following fires that dissolve the resinous seals of the cone scales and burn the organic pocosin soils, the usual habitat of the species. (USDA Forest Service photo)

Trees bear seeds when young; cones are borne on stems only 10 years old. For these young ages, cone production and tree age are directly related and remain so until about 30 years old. By then, a single tree is expected to produce 200 cones with 75 seeds in each, half of which will be viable. Some pond pine cones open during periods of seasonally warm temperature, winter or summer.

Sprouting following fire is common, many stems arising from dormant buds formed in the axils of primary needles, which are later protected by bark. Injury triggers the mechanism that causes the buds to break dormancy.

Fire—While pond pine regenerates after fire, fire is also its chief enemy. Normally waterlogged, these forests are highly flammable when the organic matter that makes up the soil dries out. A layer of the organic surface soil as much as 18 inches thick is consumed in a single severe burn, leaving a stratum of mineral soil at the surface. This mineral zone may be a hardpan in which seeds do not readily germinate. A deficiency of nutrients then also occurs, though base elements like calcium and potassium are released from the organic matter in its oxidation by fire.

Switch cane abundance provides a clue to the fire history of a pocosin site. The reed-like grass, growing to a height of 15 feet, sprouts after burning. Where protected from fire, evergreen shrubs soon replace the switch cane.

Figure 2.20 A 160-year-old stand of pond pine in a North Carolina pocosin. Note the poor form, in part due to frequent fires running through the organic soils. (authors' collection)

Nutrients and Toxic Chemicals—As inundation prevents oxygen penetration into the soil which, in turn, retards decay of organic matter, growth is slower on organic soils than on mineral sands. The higher acidity in the swamps also results in lessening the fixation of atmospheric nitrogen to a form of the nutrient element that trees can use.

Nutritional relationships for trees in organic soils are complex, especially for nitrogen. The low level of the nitrate form of the element is due to the high water table, which prohibits oxygen from penetrating the soil. Nitrogen is thus retained in a chemically reduced state. Even when oxidized nitrate forms of commercial nitrogen fertilizer are added, seedling needles exhibit nitrogen-deficient chlorosis.

Calcium often tests surprisingly high in these acidic soils. The pH, controlling the availability of phosphorus and iron, is in turn influenced by nitrogen in the organic matter. The relative acidity or alkalinity also controls the occurrence in these soils of fungi, other flora, fauna, and bacteria.

Salt contamination in coastal soils seems to have little influence on pond pine growth. Even though storms send ocean-water salt inland with seawater and air currents, the soils analyze low in sodium salts.

Some lesser tree-form vegetation disappears as pond pines grow toward maturity; holly, waxmyrtle, and swamp ironwood diminish. Subsequent expansion of grass and sedge bogs, reducing the area covered with pond pine, is attributed to a toxic substance in the soil not unlike that in English heaths. There, gliotoxin, produced by a mycorrhizal fungus of the genus *Penicillium* growing on roots, inhibits growth of some woody species. It is a naturally selective herbicide, encouraging grasses and sedges to invade and shrubby broadleaf trees to pass from the biome. (This phenomenon closely resembles allelopathy, the exuding from certain plant roots and foliage toxic chemicals that injure plants of other species growing on the same site.)

Sand Pine

Sand pine is native to the deep, coarse-textured soils of relatively high, dry ridges in Florida and Alabama. It frequently occurs in dense, even-aged, pure stands of relatively minor importance and is associated with scrub oaks, scrub hickory, and dune holly. Past fires influence the prevalence of the species, which is rather tolerant to shade in youth, becoming less so with age. Stems express little dominance over their neighbors in the stand, whether of the same species or another.

Sand pine flowering extends from late December to late January. As for other southern pines, conelets grow little the first year, develop rapidly in the spring of the second year, and mature in late summer. The trees do not produce heavy seed crops every year. The size of the crop and the number of seeds in the cones are greater when precipitation during the period that flowers are formed than in contrast to drought years.

Cones, produced as early as age 5, may—because of the serotinous nature of the species—be held for many years before releasing their seeds. Seeds from recently matured cones are most viable between mid-September and mid-November, viability dropping rapidly over a 5-year period during which cones are retained. Following fire, most viable seeds will be released within a week. Germination occurs in winter, 2 to 3 months after seeds fall. After 3 months in the soil, many seeds are no longer viable.

Adequate moisture and warm temperature in winter result in germination in 2 weeks, making young seedlings susceptible to frost damage. Damping-off, root rot fungi, and nematodes also injure freshly germinated stock. Harvester ants consume seeds, even when no more than two nest hills occur per acre. White-footed deer mice, centipedes, mourning doves, and chewinks also eat great quantities.

Two races—Sand pine occurs as two races: Choctawhatchee and Ocala, named for distantly separated Florida national forests in which each race predominates. The former Choctawhatchee National Forest (now Eglin Air Force Base) lies in the West Florida Sandhills, while the Ocala National Forest is in the upper central zone of the peninsula.

Cones of the Choctawhatchee race release seeds every autumn, in contrast to the serotinous nature of the Ocala stock, which usually holds seeds until high temperatures are generated by fire or the sun's reflection on the light-colored sands in open stands. Seeds of the Ocala race in cones on trees along stand borders and roads often are released without subjection of the cones to heat other than that from the sun in the opening. The sporadic nature of Choctawhatchee seed release often results in sparse, uneven-aged stands. This encourages intrusion of scrub oaks.

Heat intolerance actually may be a cause of poor seedling survival. This was shown when roots were bathed with hot water at a temperature of 120°F for nematode control. The roots died. Yet, surface soil temperatures of 160°F frequently occur in sand pine sites. Soil temperatures of 116°F do not visibly injure trees.

Maximum photosynthesis takes place at about 78°F, becoming negligible at temperatures above 140°F. On the other hand, the relative efficiency of sand pine in carrying on photosynthesis at high

Figure 2.21 Longleaf pine seedlings, if not protected by hog-proof fencing, may be pulled from the ground by piney-woods rooters. A single tusked boar has been known to consume the roots of 80 trees in an hour. (USDA Forest Service photo by J. Cassady)

temperatures may account for successful plantation establishment on hot sands where other conifers fail. Temperatures are notably cooler just under bare sand within an unshaded litter layer or the upper 1/2 inch of a charred surface soil than on the surface of the ground.[34]

The Big Scrub—The Big Scrub of central peninsular Florida, in which sand pine is the dominant species, is apparently the result of the inability of coarse sands to store water for more than a few days. These unconsolidated sands were moved from the Appalachian Mountains and the Piedmont of the Carolinas and Georgia during the Pleistocene period, transported to the Florida peninsula by offshore currents, washed and sorted, and finally exposed upon the lowering of ocean waters in the Big Scrub.[35]

A relatively pure stand of sand pine of over 200,000 acres occurred before recent engineering developments in this gigantic, flattened pine-clad dune. Intermixed with sand pine to a slight degree and on adjacent hammocks or “islands” with better soils of greater moisture-holding capacity are longleaf, slash, loblolly, and pond pines. The presence of the associated species, especially longleaf pine, may relate to wildfire occurrence, burning in turn varying with the physiography of the site and with quantity and kind of fuel to feed the flames. While longleaf pine stands on the slightly elevated ridges have a ground cover of wiregrass and other flash fuels, the longleaf pine withstands fire much better than do forests of sand pine.

Species transition in the Big Scrub is so obvious that roads are laid out to conveniently separate the timber types. Deep, white, coarse sand may support sand pine on one side of a lane, while slightly more fertile yellowish, finer sand produces longleaf pine on the other.

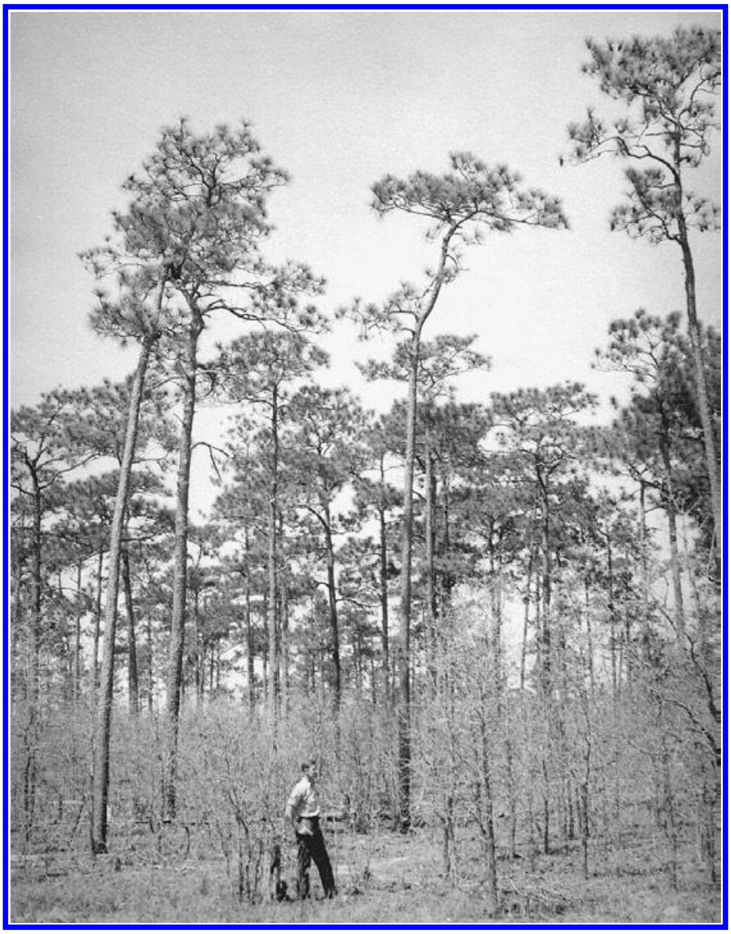

Figure 2.22 Left unchecked by fire, scrub oak vegetation captures sand pine sites. Fire, prescribed or wild, enables control of the broadleaf weed trees and the release of seeds from the cones. Sites like this in the Big Scrub have also been burned in order to establish more valuable species, like slash and longleaf pines. (USDA Forest Service photo by E. Hebb, 1957)

Where sand pines intermix with longleaf pines, cones of the former appear to open more readily, leading to the observation that the serotinous characteristic may relate to soil fertility, trees on the less fertile typical sand pine sites exhibiting the seral nature.

Evergreen scrub oaks (myrtle, Chapman, and sand live) follow sand pines in ecological succession in some sites—like hammocks—from which fire has been excluded. Species other than sand pine make satisfactory growth where moisture is adequate in this bed of silica, to which the term “soil” is but remotely applicable. Physical and chemical properties of the soil, aside from those associated with texture, are not notably better than for the more favorable peninsular sites supporting more-demanding trees. As silt plus clay content (up to 8 percent) at pond borders increases, the amounts of potassium, calcium, magnesium, and phosphorus also increase.[36]

Soil water may not be chiefly responsible for the type occurrence; distinction in vegetation may be attributed to an as yet unknown nutritional deficiency in these severely leached soils. No grass grows here: Rosemary and poor joe are the principal shrub and forb. A mat of lichens covers the ground. Even animals, micro and macro, avoid the area, for the sands reflect the glare of the burning sun to take a toll of the unfit.

Probably no ecological successional invasion of vegetation in the Big Scrub occurs from the adjacent sandhills in which wiregrass and sawpalmetto accompany longleaf pine and turkey oak. The plants of both communities seem to have remained static for millennia, seldom mixing. Where species transition gradually occurs, it is because either (1) severely washed and sorted sands were air-lifted to intersperse with less-strongly washed and sorted deposits or (2) insufficient washing and sorting took place to limit an area to the only tree species capable of withstanding extremely xeric conditions.[37] Contrarily, sand pine invades longleaf pine islands and ridges with which it borders. Sand pine even encroaches in slash pine and loblolly pine stands of the wet flatwoods.

Figure 2.23 A well protected sand pine tree of unusually good form. With heat to open its cones, the seeds from a single tree like this specimen could seed-in an acre. (USDA Forest Service photo by W.D. Brush, 1950)

Scrub plants in the sandhills may leach allelopaths. These organic chemicals could keep the soil bare of competing herbaceous plants and pines that provide fuel for surface fires that otherwise cause shrub mortality. This may account for the abrupt transition from sand pine scrub, with its dense understory of evergreen oaks and minimal ground cover, to sandhills of open woodland dominated by longleaf and slash pines and deciduous oaks. Under these latter trees, in contrast, grow mats of native grasses.[38]

Sand pine site indexes in the Big Scrub range from 50 to 70. However, as the species matures in 35 years, trees seldom reach the 50-year height by which site index is defined. Some consider the denser wood of the Choctawhatchee race ideally suited for biomass production in energy plantations.[39]

Spruce Pine and Table-Mountain Pine

Two species of lesser significance growing at opposite ends of the topographic and longitudinal spectrums of the South complete our discussion of the hard southern pines of the ecologists' forest.

Spruce pine, its weak wood similar to that of white fir and thus insignificant in the timber economy of the region, is often planted for its beauty. Naturally occurring on wet sites, usually surrounding slightly higher islands of longleaf pine, spruce pine's silvical characteristics closely resemble those for slash pine on similar hydric sites. While the fairly shade-tolerant spruce pine occurs in pure stands, it also seeds-in and successfully regenerates under the shade of hardwoods and other pines. The finely furrowed thin bark, in contrast to the thick, plated bark of other southern pines, makes the species prone to fire injury.[40]

Table mountain pine, at the other topographic extreme, grows at the summits of the southern Appalachian Mountains. Dense heather restricts regeneration. The stunted, crooked trees thrive in the cold windy climate and in the shallow rocky soils where other conifers do not survive. The trees grow alone or in small pure stands hugging the ridgetops or on eroded flat tablelands, the latter underlain by shale. Isolated stands can also be found in high mountain bogs. Sometimes table-mountain pine is called hickory pine because of the toughness of the wood of its branches, but the wood can also be weak and brittle.

Old fields and eroded lands abandoned from agriculture by mountain farmers are naturally reclaimed by table-mountain pine. The single-winged seeds, about an inch long, sail with the wind to reforest cutover lands. Regeneration also results from stump sprouting. Because of the stout, hooked spines that arm the cones, squirrels prune large cone-bearing sections of limbs in order to later wrestle seeds from the sealed burrs.[41]

Our attention is now drawn to conifers other than the 10 hard (yellow) southern pines that occur in the South.

3 Ecology of the Forest: The Lesser Conifers

EASTERN WHITE PINE

Gifford Pinchot, the father of American forestry, claimed the eastern white pine plantations on the Biltmore Estate in North Carolina to be "the first practical application of forest management in the United States." Plantings there from as early as 1890 today remain principal sources of information on the long-term management of this species in the South. While white pine has been successfully introduced in areas as remote from the species' natural range as southeast Georgia, its treatment here is limited to its geographical habitat in the Southern Appalachian Mountains.[1]

Eastern white pine, in contrast to the hard and yellow pines, is characterized by its soft wood. In contrast, too, white pines are uninodal, developing one whorl of branches each year. The cones of both groups require 2 years to mature from the time of primordia initiation.

SITE-SPECIFIC SPECIES

Natural sites for the species are at elevations between 2000 and 4000 feet on red and yellow and gray-brown podzolic soils derived from schist, gneiss, and granite rocks. On such areas, the species often replaced diseased American chestnut in openings in the forest made by the harvest of the commercially useful hardwood tree. By the mid 1930s, white pine, along with yellow-poplar, chestnut oak, and pignut hickory filled in the woodlands where chestnut trees were killed by the fungus *Endothia parasitica*.

Preferred sites for white pine are the mesic lands along rivers and streams. Dry southern and western exposures are considered least favorable; but even there white pine often does well in competition with other indigenous conifers such as pitch and Virginia pines. Some trees persist in locally dry sites where, it is believed, intraspecific grafting of roots enables movement of moisture from adjacent wetter soils into trees growing in more xeric situations.

In much of the white pine range in the South, trees grow as much as 16 inches in diameter and 70 feet tall in 35 years. Often, diameter increment exceeds 3 inches in 10 years.

SOILS AND SEEDBEDS

Among the characteristics of site that most influence white pine growth is the depth of the surface soil horizon. The deeper this zone of vigor-sustaining roots, the better the growth. Roots are most abundant in finer-textured strata, regardless of the depth to which they must grow to reach that zone. Root extension also depends on the availability of soil nitrogen, organic matter, and soil moisture. Poor root growth in mottled soils indicates poor drainage.

Good seed germination and seedling establishment occur on old fields because the soil is warm, stimulating cotyledon development and root growth. In contrast, soil under a dense forest canopy is cool, because little solar radiation reaches the floor. Low soil temperature, inhibiting white pine growth, encourages replacement with later successional species.

Soils under pure white pine forests deteriorate because decomposition of organic matter is retarded. The humus layer that develops lacks incorporation of organic matter with the mineral soil. Fungi and microfauna intrude and reproduce in this accumulated raw humus, consuming

Figure 3.1 Virgin white pine, a pioneer species in the Appalachians, is encroached upon by the more shade-tolerant eastern hemlock that eventually captures the site. (USDA Forest Service photo by E. Shipp, 1936)

available nitrogen as they do. The organic matter to nitrogen ratio then widens, providing less available nitrogen for the trees. Over several rotations this could be detrimental. However, the chances for pure stands to continue for more than a couple of rotations are so improbable, because of disturbances and natural succession, that the occurrence of a low nitrogen problem is unlikely. Species either proceed toward the ecological climax or successional degressions occur.

Root Grafts

Although natural root grafts between white pine trees stimulate growth of residual stems following thinning, the prevalence of such grafts is unknown. As roots of harvested stems continue to absorb soil moisture and nutrients and to compete with pioneer vegetation endeavoring to become established, growth improves for residual stems grafted to a harvested tree. Thus, water consumption by residual trees adjacent to openings in a canopy made by thinning keeps such clearings relatively barren of vegetation for years.

Both intraspecific grafting and unions of the roots of a single tree have been noted for both wet and dry sites and in stands ranging from 15 to 70 years of age. During periods of moisture stress, water supplied through root unions permits survival of trees some distance from streams. Apparently the phenomenon occurs mostly among stems in a cluster of trees.[2]

Flowers and Seeds

Flowering of white pine in its southern range extends from May to mid-June, when yellow staminate cone-like blossoms appear on new shoots of lower branches and small, pink ovulate flowers with purple scale margins occur on the ends of upper shoots. The green conelets, an inch long at the end of the first season, grow to maturity during the second summer. Elevational distinction within the tree precludes selfing and the consequent production of hollow seeds the staminate strobili are carried by wind from these low branches to the female flowers high among the foliage of neighboring stems. Natural crossing among trees within the species follows.

Watershed Protection

As forests of white pines in the South are generally indigenous to mountainous areas, they often clothe lands dedicated to the production of clean, clear water. Even where timber is an important commodity, white pines aid in maintaining favorable watershed conditions. The depth of litter and unincorporated humus tends to be greater for a longer period of the year than in broadleaf forests, as most of the litter layers of fallen leaves and twigs of hardwoods decompose in early summer. With litter depth constant throughout the year, white-pine forests continuously provide favorable rates of rainwater infiltration into the soil surface.

Figure 3.2 A second-growth white pine stand in the northern reaches of the Southern Appalachian Mountains. These pioneer species seed-in on abandoned agricultural land and almost always occur in even-aged stands. While the crowns at a distance give the appearance of an even-sized woodland, dominance expresses itself early; stems of many sizes are in the understory. (USDA Forest Service photo by E. Shipp, 1936)

White pines may, however, over several rotations, alter crumb-mull humus layers in once-deciduous woodlands to a less-porous mull and mor humus—the latter with minimal organic matter mixed with the mineral component of the surface horizon. Infiltration through mor humus layers is generally slower than for crumb-mull types. For example, 7 inches of rain seeps into the soil in a cove-hardwood stand within a minute, while 5 minutes are required under a 30-year-old stand of white pine. The thick mat of needles under the conifers also absorbs water from light storms, holding it like a sponge until evaporation removes it. This rainwater is neither used by plants nor percolated into streams for later consumption.[3]

Blister Rust

The infamous white pine blister rust, caused by *Cronartium ribicola* and having members of the *Ribes* genus as alternate hosts, is not as serious in the Southern Appalachians as in woodlands of the North. In the South, diseased trees are seldom found below 3500 feet, and few stands of white pine occur above that elevation. On the other hand, *Ribes* species, the gooseberries and currants, grow mostly at higher elevations, particularly in narrow belts along the main mountain ranges. In the geographic range of *Ribes*, infection of white pine is more common on moist sites and in dense, unthinned stands. Under these conditions, micro-climate is optimum for spore infection. Open, park-like stands have higher air temperatures, more air circulation, and lower relative humidity, the combination of which is not conducive to sporulation. *Ribes* seeds, remaining viable in the soil for many years until logging or fire allow germination, produce a brushy vegetative cover unless shaded by hardwood trees.

The life cycle of the rust involves the production of three kinds of spores. Spores from cankers on pines are released in early spring, traveling perhaps hundreds of miles to infect *Ribes* plants. A little later, another kind of spore is released from the infection on the currant or gooseberry foliage to spread the rust to other *Ribes* bushes. Now, a second fungal stage on the broadleaf shrub appears. From this infection, still another kind of spore spreads the disease, usually not more than a few hundred feet, back to the pines. These spores, however, may ride with the wind for a mile.

In a month or two after spore dispersal, small discolored spots appear on white pine needles. The next year, the tree's bark is yellow or orange at the base of the infected needle bundle. As the fungus grows, the bark swells, soon exuding light-brown gummy drops from the swollen site. Then, in the following spring, the orange spores in the blisters push through the bark at the site where the resin was exuded the previous summer to reinfest *Ribes* plants. Soon the bark in the blistered area becomes rough and dark, and a spindle-shaped canker develops. "Flags" of copper-colored needles in the crowns signal the presence of the disease.[4]

Emergence Tipburn

A mysterious blight of white pine, first diagnosed in 1908 and called emergence tipburn, may be due to excessive ozone in the atmosphere, by sulfur dioxide given off where coal is burned, or by chlorine released from stacks in the effluent of manufacturing processes. Terminal halves of the current-year's needles turn brown and die, usually in midsummer. The dead needle ends then break off. Chlorosis of dwarfed needles and stunted shoots, accompanied by shriveled or wrinkled bark, occur for several years thereafter. Resistance may be genetically inherited.

Chronic air pollution stress may also cause declining vigor of sensitive eastern white pines in the Southern Appalachian Mountains. Needle length and needle persistence diminish with lowered rate of respiration and changing carbohydrate translocation patterns.[5]

Lesser Pests

Of the insects, white pine weevils are the most destructive to this species in the Southern Appalachians, though these had not been recorded there prior to the mid-1950s. The sporadic appearance of the low-flying adult is usually attributed to the absence of young stands in groups sufficiently contiguous for continuous breeding of the insect.

Several polypore (*Polyporus*) fungi, a needle cast fungus, aphid-like chermids, cone beetles, and pales weevils also take their toll in these forests, as they do for many other conifers. Sunscald, while not a biological pest, damages and kills these thin-barked conifers, especially if trees on south- and west-facing exposures are released too drastically from shade-providing competition.

Some mammals and birds contribute to controlling the extent and vigor of white pine woodlands. Gray and red squirrels and white-footed mice consume an abundance of seeds, the former by day, the latter by night. Seeds are "squirreled" in caches containing green cones, the rodents apparently ignoring the disseminated seeds on the ground. Mice, in contrast, devour seeds in place and also carry away squirrel-collected seeds to store. Mice and voles together are capable of consuming nearly all naturally disseminated seeds in the forest. Where they abound, few seeds are left for the mourning doves, which then peck at fallen cones to extract seeds. White-tailed deer can severely graze white pine seedlings in openings, such as logging skid trails in a thinned stand of trees. On the other hand, they do minimal damage to seedlings overtopped by brush.

SPRUCE AND FIR FORESTS

Only at the upper reaches of the Appalachian Mountains are the fragrant and verdant forests of red spruce and Fraser fir found. In an earlier time, these trees were important locally for pioneer use, but the inaccessibility of these sites, the problem of transport to the large centralized mills of today, and the importance of maintaining these stands for their aesthetic quality now essentially excludes them from the logger's saw.

Red spruce enters the forest at altitudes as low as 4500 feet. From that elevation to about 5000 feet, it is found mixed with eastern hemlock and a variety of broadleaf trees. Above that, Fraser fir joins with the spruce to almost exclude the hardwoods and to form the dark, but not foreboding, spruce. Above 6200 feet in the Great Smoky Mountains, the fir often occurs in pure stands. In the moist gaps in the mountains where soil is deep, other shade-tolerant species such as yellow birch and American beech may replace these conifers. Mountain ash is another important deciduous tree in this otherwise coniferous forest.

Toward the north, as in the mountains of Virginia, forests of spruce and fir occur at elevations as low as 3200 feet. There, the fir is considered a southern race of balsam fir, a species distinguished from Fraser fir only by its cone, for balsam fir, the bracts (undeveloped leaf-like organs attached to cone scales) are shorter than the cone scales. The opposite is true for Fraser fir.[6]

Neither of these conifers grows to large size, though the wood of red spruce remains a favorite for string instruments. Those trees having a greater breast-height diameter (dbh) than 10 inches are likely to be red spruce, such stems possibly 300 years old. The smaller-size fir trees, in contrast, seldom exceed 150 years in age. One likely finds the fir trees in rocky, non-arable lands where organic soils tend toward the ash-white podzolization brought about by the leaching of iron and aluminum from the surface horizon.

Fire, Wind, Insect, Fungus, and other Maladies

The principal enemies of spruce and fir trees in the South are fire, wind, the woolly aphid, and rot-causing fungi. Apart from the cool, moist climate in which these species occur, natural fire protection is lacking, and once the woods are ignited, dense interwoven crowns that hug the ground, resinous foliage and wood, and thin bark are the ingredients for a holocaust. On the ridges, severe soil surface destruction by fire removes as much as two feet of surface moss and peat. Fire exposes entire root systems, which are then unable to maintain soil stability. With the destruction of the organic component go the seeds, stored in the humus for a future forest. Rapid drying of the soil follows. Trees such as fire cherry, sweet birch, and pin cherry; shrubs such as blackberry bushes; and ferns quickly capture the site.

Complete rehabilitation of these forests may require hundreds of years if seed-bearing trees have been destroyed. Twenty years after a fire, few conifers likely have seeded-in, as ecological succession proceeds from pioneer brush to these climax conifers.[7]

Wind topples Fraser fir at high elevations where soils are shallow. Extensive tracts have been felled in a single storm. Virtually impermeable layers of subsoil 12 to 18 inches below the surface,

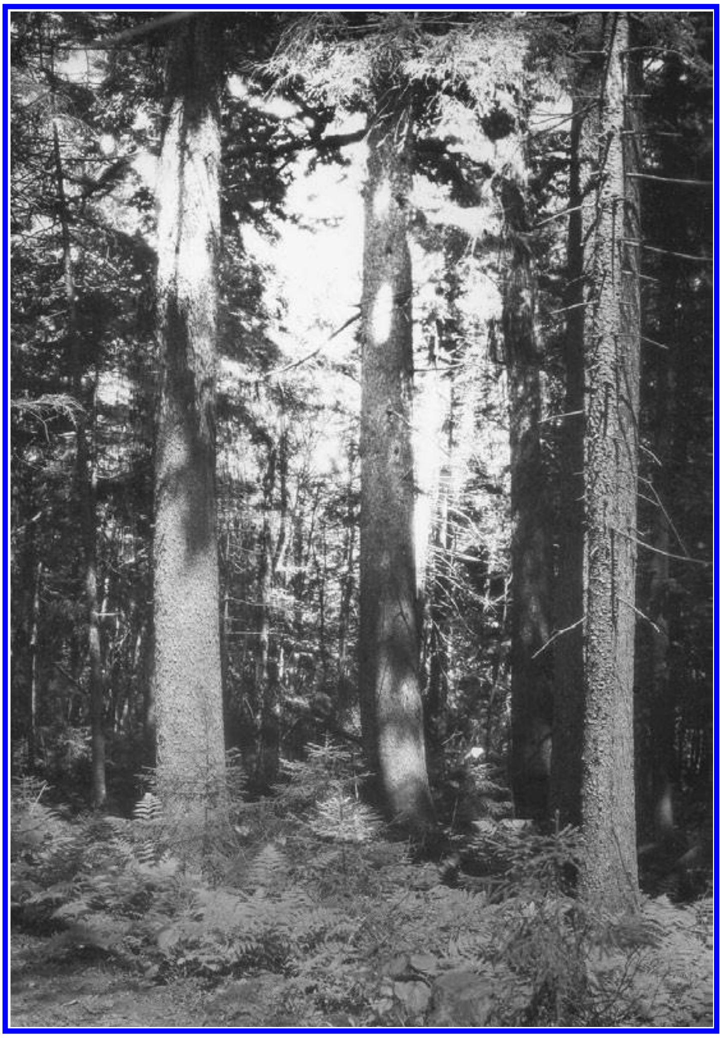

Figure 3.3 A dense stand of old-growth (likely virgin) red spruce in the Blue Ridge Mountains. Note trees of this climax species of many ages in the understory, along with ferns and rhododendron. (authors' collection)

into which tree roots cannot penetrate to gain a firm grip, encourage windthrow. The shade-tolerant characteristic of the species and the uneven-aged character of these stands, however, encourage reproduction establishment. Young trees then have an advantage over shrubs that otherwise invade freshly opened sites, and can develop rapidly into even-aged sapling and pole stands.

Periodically, the balsam woolly aphid kills Fraser fir at an accelerated rate compared with mortality caused by endemic populations of the insect. Attacks made on living tissue beneath the surface of the bark on terminal and lateral branches below 15 feet are most damaging to trees on low-lying waterlogged soils. Aphid attacks are readily identified by the white wax "wool" on twigs. Other evidence is the compression-like wood of the growth rings, greatly narrower on one side than on the other of the cross-section of the tree. Predators introduced from Germany and Australia to biologically combat the menace did not provide adequate control.

The misnamed spruce budworm, destructively feeding mostly on fir trees, generally confines its activity to the northeastern and western United States and hence is no problem in the South. However, three fungi-caused rots—top, brown, and white-string—do decay much of the wood in standing trees.

In these woodlands deer browse both species, though preferring the fir. Black bear also consume the trees, reducing vigor and limiting height growth. Browsing is not sufficiently severe to obliterate trees of all ages.[8] It is in these high-elevation forests that deposition of sulfuric and nitric acids are expected to be most injurious, in contrast to woodlands of southern pines and hardwoods. Ozone also takes its toll in reducing growth. Even if emissions from factories and vehicular exhausts should remain constant, growth rates will likely decline.[9]

The Balds

Mountain knobs protrude above the cool, damp forests of red spruce and Fraser fir in the Southern Appalachians. Alder bushes are the most tree-like species that naturally encroach on these sites. The occurrence of the balds has been attributed to Indian ceremonial burial grounds—which, over long periods of time, would have altered the vegetation. In this cold clime and high altitude, plant life recovers slowly (see Chapter 1).

Ecologists, however, variously believe this phenomenon to be due to overbrowsing by wildlife or livestock, to intense fire at the summit, to ice storms, to exposure to high winds, to a toxic substance in the soil, and to inadequate nutritional elements for sustaining tree growth. To some, post-glacial climatic fluctuations are convincing as a cause. The occurrence of the balds is not a matter of a high-altitude temperature-dependent tree line, as in the West or Far North, for no such demarcation occurs in the Appalachian Mountains. A neophyte observer may suggest shallow soils at the tops of these geologically old and eroded hills, only to learn with the aid of a spade that the mantle covering the rock is often more than 5 feet deep. In spite of this favorable soil depth, the treeless, well-drained sites probably never supported stands of trees.

EASTERN HEMLOCK

Eastern hemlock, not to be confused with the poisonous carrot herb of Socrates' fame, is a shade-tolerant member of the pine family. *Tsuga*, the genus to which it is assigned, means "hemlock" in the Japanese tongue. In the cool coves of the Appalachian Mountains, hemlock is found in uneven-aged stands, both pure and mixed with white pine and hardwoods. There it inhabits all but the upper slopes, where it is replaced by Carolina hemlock, a handsome specimen with needles described by the Latin species name *taxus*, meaning the foliage extends as spokes on a wheel from all sides of the twigs. Ranges of the two species overlap.

Hemlock often occurs in groves, these groups expanding concentrically from where initial seed trees were earlier established. Other times, isolated stands are found, as on the Warrior Plateau of Alabama. While localized high humidity is attributed to these woodlands, hemlock trees may actually contribute moisture to the air, for evaporation anometers placed in these shady conifer forests in summer have shown water lost from the forested atmosphere to be only one-half of that lost in adjacent oak and pine stands.[10]

Although eastern hemlock trees may survive when stands are regenerated in full sunlight, optimum conditions require partial shade. For this species, either selection harvests—producing uneven-aged stands or shelterwood cuttings—providing for a single-aged forest are suggested. In any event, the canopy shade should not be reduced below 50%. An even-aged hemlock stand, however, appears uneven-aged because of the wide array of size classes present in these woods.

After establishment, this conifer grows more slowly than its competing broadleaf trees, making cleanings (silvicultural cuttings) of the latter necessary as often as several times during a rotation. Hemlocks respond well to release, probably partly because of the availability of additional soil moisture for the residual stems. Openings, by cleaning or thinning, must not be so severe that sunscald results, care needing to be exercised especially on south-facing slopes. The malady is serious on advanced reproduction where forests are suddenly and drastically opened.

Fire must be kept out of these woodlands. The thin bark makes even the mildest prescribed fire an unsound silvicultural practice.

A disjunct stand (now inundated by Lake Lanier) in the Georgia Piedmont grew 20 miles south of the nearest hemlock trees and the furthest south the species occurred naturally. The stand developed because of subsurface seepage in the biotite schist and gneiss rocks found beneath the soil. This took place on a north-facing slope, where heating and drying effects are minimized. Flooding of the site by the seepage removed litter, bared the seedbed, and deposited a thin layer of sand. As the high water receded, the soil remained moist and, with seeds periodically available, gave rise in time to a three-age forest.[11]

Flowering

Hemlock trees begin to bear strobili when about 20 years of age. The staminate buds are readily distinguished from leaf buds because of the former's much larger size. (Shoots arising from leaf buds are short, rarely exceeding an inch.) Pistillate strobili are visible by midsummer, maturing in the fall. The ripened cones release their winged seeds gradually over several months, the bracts opening and closing with changes in atmospheric humidity. Winds that vary in the direction of their origin during the course of the season, along with the frequent opening and closing of cone scales, encourage widespread dissemination of seeds.

Minor Pests

Only the eastern hemlock borer, a flathead insect, is an important pest for this species. Its presence is evidenced by the mining of the bark of trees, both living and dead. Loopers, the little larvae that make haste slowly by forming their bodies in a three-quarter-inch contortion as they inch their way up a twig, commonly feed on the foliage. Some call the larvae inchworms.

The rots caused by several species of wood-attacking fungi are also found in these trees. Seldom do they pose a serious menace to the forest.

Virgin or Not: a Study in Ecology

When eastern hemlock occurs with white pine, the two species compose a type occupying many old-field sites in the Southern Appalachians. As the less-tolerant white pine is not perpetuated without fire, harvest, or tree-topping storms, the species passes from the stand, leaving a pure hemlock forest. Encroachment by shade-tolerant hardwoods, principally oaks and hickories, may preclude establishment of a pure stand. In old fields, hemlock often seeds-in after white pine is well established.

In appraising a situation in North Georgia, an understanding of this relationship was essential to defuse a politically critical matter. A government agency was being accused by a big-city newspaper of destroying a virgin forest by marking the stand for a selection harvest. Paint appeared on the chosen trees and the sale was ready to be bid. The trees in the aesthetically beautiful cove were indeed large, many exceeding three feet in diameter.

With a spade, one could readily locate the old plow sole about 12 inches below the present level of the soil in the cove. Ordinarily the plow sole, a distinctive line separating the plow layer from the horizon beneath, is but 6 or 7 inches below the surface. (Occurrence of a plow sole is attributed to the frequent turning of the soil by a farmer's tilling many times a year for many years. Oxidation of the minerals in the soil by exposure to the air causes a change in color and an alteration in the density of the soil at that stratum.)

Above the plowed zone was an overburden of topsoil that, during cultivation and since the time of land abandonment, had washed down the slope from the surrounding hillsides and into the cove. This intruded material accounted for the greater than usual depth to the plow sole.

Further research at the county courthouse revealed when this land had been purchased by the government. It also showed when an agricultural depression had occurred that forced farmers from their small patches of arable lands in the mountain coves. Soil washed down on that freshly abandoned land. And on this deep and exposed mineral soil, free from organic duff or perennial plants, winged white pine seeds borne by the wind had come to rest. Here they germinated to form a dense stand of white pine, the high quality of the site encouraging tree growth that exceeded 2 or 3 feet in height each year and annual radial growth greater than one-half inch.

Shortly, the shade-tolerant eastern hemlock trees, their winged seeds also blown by the wind, seeded in under these pines. Seeds of hemlock need not have mineral soil for germination, but may sprout on moist organic matter, the fine roots then working their way through the pine needle duff to adequate sources of water and nutrients for sustained growth. The germinated hemlock seedlings extended shallow, wide-spreading root systems in the fertile soil of the alluvial overburden.

These intruding hemlocks, like the pines, grew well. As some pines died, hemlocks took their places in the canopy of the forest. In time, many of the hemlocks were the largest trees in the woods. Together with the pines, these conifers made a dense dark stand of large boles whose crowns were intermingled in the canopy.

It was reasonable for newsmen and lawyers to consider this a virgin forest, a remnant of the past, and too beautiful to harvest. Indeed it was too beautiful to harvest, but not because of its supposed virgin condition. Rather, the excellent tree growth on the site—caused by the farmers' earlier control of competing vegetation with cultivation of the land and the fertile loam that had washed in following abandonment—presented the appearance of a primeval forest, a woodland in which man had never raised an ax. But, it was the relative tolerance of the two species that gave the matter away; the pines had to precede the hemlock in ecological succession.

The shade-intolerant white pines produce even-aged stands. A crop of their own seeds is not likely to germinate under the canopy of trees established even a few years earlier. Thus, increment core borings of small pine stems recorded the ages, by growth-ring counting, of neighboring stems too large for the use of the increment borer, for all stems of this species in the stand began life together. Not so with hemlock, for the continual, perhaps annual, introduction of new seedlings within the forest and under the canopy of older ones makes increment boring useful only for the particular tree bored. Trees too large in radius for the borer tool's length leave their dates of birth unknown. The ecological relationship of the two species, however, required the largest of the hemlocks to be younger than the smallest of the pines: shade-tolerant hemlocks had to follow in ecological succession the establishment of the pines in the mixed stand.

ATLANTIC WHITE-CEDAR

Atlantic white-cedar, hyphenated because it is not a true cedar, forms a pioneer community on peaty soil. It is likely the first tree to reinvade such sites following fire, hurricanes, or clearcutting. Always within 100 miles or so of the eastern coast and within 100 feet of sea level, the stands of dense slender stems with interlocking crowns lend an eerie stillness to the dark, dank swamps. The trees, seldom in mixtures with other species, mature at about 80 years of age. Doubted claims have been made that they reach 1000 years of age.

The durability of the heartwood is illustrated by the examples of trees windblown in the last century that were more recently "mined" from under the many years' accumulation of the peat that buried them.[13] Under pond pine stands, too, white-cedar logs may be found in the debris, illustrating both the once-greater extent of white-cedar forests and ecological succession from this pioneer species to the serotinous pine.

White-cedar swamps, locally called glades (although Webster says glades are "open spaces surrounded by woods"), are generally acidic, often having a sour smell. A pH of 3.5 is not unusual.

Sometimes water stands above the ground in these peaty soils due to saturation of the sandy subsoils, the white-cedars enduring the chemically reduced soil conditions to the exclusion of the pines. In otherwise similar sites, but where the amount of finer soil particles—silts and clays—increases, white-cedar is replaced by many hardwood species and baldcypress. Stagnant water swamps are more likely to be covered with hardwoods, the white-cedar maintaining itself in oxygen-adequate freshwater.

Good moisture relations may require drainage. But drainage ditches should have control devices that enable the maintenance of proper water levels in the soil. Uncontrolled drainage in peat soils, where good regeneration usually occurs, for example, may lower water to critical levels. Mortality of the white-cedar seedlings is often high because of flooding and because of air pockets around roots when water subsides. On hummocks of drained peat, trees die during droughts of short duration.

Seeds

The value of white-cedar wood is beginning to be realized and initial efforts are being made to regenerate these forests along the Atlantic seacoast. Nature will provide some able assistance. For instance, more than 2 million dormant seeds per acre may be found stored in the upper few inches of the organic mantle on the forest floor. Some seeds lose their germinative capacity, but not many, because delayed germination is common. Half of the crop of seeds may remain dormant the first year after the other half has germinated. On occasion, viability might be as low as 10%; equally often as many as 90% of the seeds in a crop might be healthy. So many seeds are stored in the organic duff that clumps of it can be removed and "planted" elsewhere to start a new stand of this species.

Once the seeds are sown, by nature or by man, successful establishment requires adequate moisture within reach of the short taproots arising from the small seeds. As such minute seeds have little stored starch for seedling food in the cotyledonous stage, favorable light and moisture are essential for successful stand establishment.

Fire in the Swamp

Mineral soil in white-cedar sites can be covered by some 20 feet of debris collected over many decades in the absence of drought-induced fire. Then fire can play havoc with Atlantic white-cedar, readily destroying forests of all ages. When fires occur, they may crown, moving rapidly in the tops of trees to kill stems some distance away in isolated ponds. Ground fires might occur simultaneously, once the peat is ignited. These fires burn the fibrous, well-oxygenated organic matter under the surface of the land, even during the snows of winter, until the soil is again saturated by rainwater.

A second fire following close after a first, before there is time for a new stand to replenish the supply of seed stored in the duff, eliminates this forest cover type. If the fire consumes other woody growth along with the swamp-loving conifer, ecological retrogression to a quaking bog, or even to open water, could occur.

If protected from fire to an old age, the bog climax forest that follows will likely be an assortment of wet-site deciduous species. The amount of charred peat on the surface of the ground and the quantity of charcoal in the upper layers of peat suggest how long a time has elapsed since a site last burned.

Ecological Succession

Viable seeds are safely stored throughout the soil profile of peat or sphagnum moss. Seeds delay germination until flooding subsides, fires pass over the land, or a forest is cut over. While seeds germinate in mineral soil if moisture is adequate, they also germinate in the crevices of old logs once buried in the litter and now exposed to the air. Pine needles and autumn's fallen broadleaf foliage are improbable germination beds.

Silvically, a temporary or early pioneer species in ecological succession precludes expansion of the acreage of white-cedar stands. More shade-tolerant species growing more rapidly take over the land, in spite of the vast acreages of peaty and other satisfactory seedbeds within the species' range.

While white-cedar competes reasonably well with broadleaf encroachers like gray birch, species of greater shade tolerance, such as blackgum and sweetbay, form the climax forest on swampy sites. Hardwood trees that get an early start in white-cedar bogs increase in vigor with time. As the health of the white-cedars declines and the canopy thins because of this competition (at about age 60), species composition abruptly changes. Dense shrub growth sometimes overtops the young conifers; in that event, the white-cedar stems may be nearly as slender as pencils.

White-cedar trees do not readily self-prune. While lower branches die early, they persist—especially in closed stands—for many years. The rot-resistance of the durable wood likely contributes to this characteristic.

As many as 1700 stems per acre occur in stands 60 years old. Volumes before maturity of 30,000 board feet per acre have been reported. This is a high-volume stand for almost any site east of the northern Rocky Mountains.

Height growth remains steady until mid-age, then gradually declines until cessation at maturity. Trees mature on better sites at 80 years of age. At that time, long, straight boles with little taper provide quality lumber. Diameter growth continues well beyond the culmination of height growth.

Species' Antagonists

White-cedar stands near the coast are killed by salt water blown in by storm tides. On the other hand, nearby stands of other species, especially hardwoods killed by salt spray, may be replaced by white-cedar. When that occurs, the water-loving conifer should be free of competition until past middle age. Then, broadleaf species like bay magnolia and holly intrude.

Black bears roaming these remote and inaccessible (to man) woods and birds flying over them affect growth of young and mid-aged white-cedar trees. Both beasts and birds carry seeds of the greenbriar, *Smilax*, in their bellies. Passed in droppings, the germinating seeds produce clumps of vines in initial encroachment. Great masses of the thorny vine weigh down tree tops and break trunks, deforming the boles. Browsing by white-tailed deer in winter, seedling nibbling by cottontail rabbits, and seedling girdling by meadow mice also tell of the abundance of wildlife.

Not only is white-cedar wood durable due to its natural impregnation with pesticidal chemicals, living trees are notably free of fungi and insect attacks. One pathogen, *Gymnosporangium ellisii*, causes a spherical swelling of the bole or of a branch. A growth of foliage, called a witches' broom, then arises from dormant buds beneath the bark and close by the canker.

BALDCYPRESS

Baldcypress[14] was recognized by early observers with fascination. Lyell, the pioneering botanical explorer, said the species "gave a somber tone to scenery when hung with moss."[15] Its ghost-like appearance in winter, without foliage (thus bald), conjures a foretaste of gloom.

Unique among the South's needleleaf trees because of its deciduous nature, baldcypress grows in luxurious stands along the "red" rivers that originate in the Piedmont and mountains and, from those regions, carry silt and clay to the sea. The species does equally well in black backwaters of the Coastal Plain, which carry little mineral sediment but much suspended organic lignin, the slowly decaying component of the wood that lies rotting in the region's woodlands and subsequently leaches to streams. Stands are also common in muck swamps and sloughs that border the hardwood "ridges" of deep alluvial soil. Although the species grows best in mesic sites characterized by deep, moist, fine sandy loam, severe competition by other vegetation discourages survival on such sites.

Figure 3.4 Mature baldcypress trees in a deep-water lake. The site had drained naturally sometime in the past at the time of seedfall, thus allowing for seed germination and seedling survival. Sometime after the seedlings were well established, the water level rose to depths even greater than that shown here.

Baldcypress is thus confined to the wetter areas where few other trees are able to compete to survive. Seedlings grow well even under partial shade.

Interwoven with pure stands of baldcypress are those of pondcypress, a botanical variety of the former about which there is much confusion. The smaller pondcypress of a lesser range and with ascending branchlets, occurs in denser stands that give it a slender erect appearance. This characteristic and the tree's sometimes sky-reaching branching habit perhaps influenced the assignment of its scientific name: *var. ascendens*.[16]

Pondcypress occurs on sand-bottom sites and in highly acid "pine barren" ponds in company with both pond and spruce pines. In contrast, marl-underlain soil along some rivers is not conducive to pondcypress growth, but does support baldcypress. On the other hand, the presence of the typical variety, rather than *ascendens*, could be attributed to the availability of seeds and an appropriate water level at the time of seed germination, rather than to a preference for a particular site.

Ecological pioneers, these trees become established when water is low in one or more extremely dry seasons following periods of sufficient moisture for soaking the soil for one to three months. A saturated, but not inundated, seedbed is essential for seed germination. Natural reproduction may come in after drainage of open cypress stands. Both bald- and pondcypress varieties occur in pure even-aged stands or in mixtures with many broadleaf trees.

The swamps in which these trees occur are especially important for groundwater recharge and wildlife habitat. Riverine swamps cause floodwaters to spread out, slow down, infiltrate the surface soil, and percolate through the soil profile, thereby reducing flood damage.

Stands generally recover to their original composition following clearcutting. Vegetative reproduction in the form of sprouts accompanies the natural seedlings. The sprouts themselves produce cones in two years. In Florida, where cypress swamps compose more than 25% of the commercial forest, biomass returned to merchantable levels within about 50 years following logging during the first half of the 20th century. [17]

Micro-sites for regeneration are the tree bases and residual knees of old trees on which typical bay shrubs and trees encroach to form “islands.” These small areas of slightly elevated land supporting shrubby vegetation unite to form a solid organic surface covering ponded areas. Vast root systems of bay shrubs along the edge of the pond aid in the development of the islands, which also may be portions of original shorelines that have not been destroyed by erosion.

Water Level Influences

Poor regeneration of baldcypress forests is associated with the submergence of land and seeds, failure to retain seed trees when stands are harvested, and fire. The species, however, is rather resistant to fire injury due to the insulating capacity of its bark. Consequently, even when swamps dry out and fires occur, damage to trees of this species may not be serious. When water drains from some sloughs, the extensive vertical secondary root system, like large drooping tentacles circling the periphery of the buttressed bases of trees, can be observed.

Flood waters that overtop seedlings during their first year for more than three weeks, except in winter, kill them. While it is detrimental for seedlings to be submerged after trees are in leaf, death does not necessarily result. Sometimes stems releaf in late summer after being inundated during the growing season. Warm water and deep deposits of silt and clay sediments, along with oxygen deficiency, cause poor survival of submerged seedlings because transpiration, involved in mineral translocation, does not readily take place.

Baldcypress trees are intolerant of long periods of shade from overtopping canopies. Such stands succeed to hardwood species. Broadleaf trees also take over baldcypress sites following storms or heavy cutting. New stands of sweetgum, Nuttall oak, willow oak, red maple, and water tupelo promptly invade. Where a pine or oak seed source is present, these trees take over openings and, if drainage is adequate, replace baldcypress.

Baldcypress trees produce large seeds with small wings about every third year; as the seeds are sticky, not many eaten by birds and rodents. Ripened by October or November, seeds are rarely scattered by wind and never by animals. Water alone provides the means of transportation. Seeds often wash from the site of initial deposition or sink to the bottom of a pond. Germination, in the spring, is usually poor except in seedbeds of sphagnum moss and soft wet muck. Moisture in such a seedbed softens the seed coat, preparing the seed for germination. In spite of frequent good seed crops, obtained with four to eight seed-producing trees per acre, soil moisture conditions often prevent successful regeneration more than once every three decades.

Stunted baldcypress trees occur in South Florida. The condition has been attributed to rock formations near the surface of the ground, to nutrient deficiency, to water that stands on the surface of the ground for long periods, to lengthy droughts, and to high soil-surface temperatures. Inheritance is also likely involved in the slow-growth characteristic.

Forest Relics

Forests of mature baldcypress trees are still found in the Mississippi River bottoms as far north as Illinois and in the vast freshwater Okefenokee Swamp of the Southeast. Old stands of this species also occur in the Bay Lake area of North Carolina. In the 1900s, one stand was reported to be 650 years old. Within that stand some stems were believed to be over 1000 years old. Trees there tallied as tall as 130 feet and 10 feet in diameter.[18]

Another virgin stand, this of pondcypress, was once claimed to be more than 250 years old. But that was before we learned the risk for this species in determining age by ring counts. Aging by this method is unreliable. False rings, due to periodic growth fluctuation in turn caused by

Figure 3.5 Estuaries that periodically flood. Note the high-water marks on the baldcypress trees in this 1920 photograph of a southern Louisiana scene. (USDA Forest Service photo)

variations in soil moisture and aeration, are common. False rings occur with rising water following periods of drought, when the tree behaves as though winter dormancy had ended, and springwood again forms. Increment cores extracted from opposite sides of a tree, varying by as much as 10%, indicate the presence of false rings. Cores taken above the butt swell, sliced down the middle, and examined under 20-power magnification are apt to tell a reasonably accurate story. The true summerwood appears as a narrow band of small, thick-walled cells; false rings disappear, being especially indistinct when the cross-section is magnified.

In contrast to the ancient relict noted above, a North Mississippi forest may be typical, although second-growth baldcypress forests vary greatly in stand density and volume. At age 85 years, trees averaged 18 inches dbh and 112 feet tall. The stand had grown about 0.6 cord per acre per year.[19]

The Cathedral

Graceful gothic arches form from the interlacing of the branches of baldcypress trees that tower above algae-green bayous. Rising from the mixture of silt and peat that carpets forest floors are groups of cypress knees, standing erect and resembling monks in a monastery. A grove of cypresses becomes a woodland cathedral. The song of the wood thrush contributes the solo, while a choir of prothonotary warblers and American redstarts keeps cadence with the wind. The tones might rise to a crescendo a half-hour after daylight, gradually dying to a hush as though all the creatures of the wild were at rest. Through the crowns of delicate hues of green and gold, like stained-glass windows, beams the morning sun. With the movement of the sphere comes change in the texture of the light as it radiates and reflects from leaf to leaf and to the ground as though beamed through a prism, dividing into rays of various hues. This woodland cathedral occurs as a small isolated mesophytic jungle astride the Sabine River in Texas.[20]

In this cathedral ecotype, a baldcypress tree measures 38 inches in diameter above the butt swell. The height of the "column" in the cathedral exceeds 120 feet. Among the cypress trees are thousands of overcup oak seedlings coming to life from seed that fell in the dried-up swamp. This is the sort of combination of events—proper seedbed, dried-up swamp and seed abundance—that occurs rarely. Should these seedlings endure high water, certain to follow, they will be a significant component of the forest. Here, oaks form the climax forest; baldcypress is a pioneer.

The river in times past carved out the vale, later filling it with silt and clay to form an alluvial plain. Natural levees and oxbows formed from the cutting and mounding of old meanders that bear

Figure 3.6 Immature baldcypress in an inland lake. The usual difficulty in aging trees of this species is frustrated by the rising and lowering of the water, whether under natural weather conditions or flood-control operations. Extreme draw-down during the growing season puts the trees in a semi-dormant condition; with rising water, new (false) growth rings form.

no relation to the present river's course. Some natural levees of recent origin are deep sands deposited at the river's edge. This "new land," washing down from banks cut away upstream, provides an ideal seedbed for willow and cottonwood trees. In time, and with ecological succession, sweetgum and blackgum trees intrude. Later still, oaks and hickories, more tolerant of shade, become established under the crowns of the more light-demanding trees. A few loblolly pines on higher, drier ground might enter the site where openings in canopies and exposure of the mineral soil have provided the necessary conditions for seed germination and survival.

Blue Elbow

Near the mouth of the Sabine River lies a micro-wilderness called Blue Elbow Swamp. This primeval jungle of modest proportions—four square miles—lies at the edge of industrialization. Had John Bunyan journeyed here, the sight could have inspired his description of the Slough of Despond, the almost impenetrable terrain through which his pilgrim had to travel en route to the Celestial City. Here a stand of baldcypress and a mixture of deciduous broadleaf trees, once of commercial value, occur.

One observer described the locale this way: "Tie up to a cypress root and walk a hundred yards inland (from the river) along a piney ridge, and the human signs are gone. Deeper still, except for an occasional fisherman along the lush canals (cut and dug by early day loggers), the swamp seems as elemental as it must have been when the first logger set his saw against his chosen tree.''[21]

The words ring true, but there is more. Here is a place where sea water intrudes into the fresh, where salt spray during Gulf coastal storms alters vegetation composition, and where new land forms at the urging of the river. Here, too, although the odors of the manufacturing of paper, petroleum products, and cement may permeate the air, one witnesses primitive wilderness. Man intrudes, but, with few exceptions, only to the swamp's edge.

Blue Elbow, the wet morass, may have gotten its name by fishermen and loggers in the area 100 years past, the color alluding to the black water, laden with lignin from decaying forest vegetation, that accumulates in the pond as overflow from the usually quiet river near where it empties into the Gulf of Mexico. The elbow, the sharp bend in the river, reminds one of the crook in an arm.

Soils of the Blue Elbow were delivered in water suspensions of the sluggish river, coming from faraway fertile calcareous blacklands and picking up silt and clay particles along the way. The fibrous organic soils in the swamp smell sour, indicative of high acidity and low pH. Spanish moss, the epiphytic member of the pineapple family, drapes gracefully from the arching branches of the cypress trees, especially those standing in deep water. The deciduous conifers, on which the weeping tufts of grayish-green strands root and from which they gain nutrients and water, grow well.[22]

Cypress Domes

In the flatwoods and savannas of peninsular Florida, "domes" of baldcypress and pondcypress are formed by confluent tops of crowded trees which, beginning with short ones at the outer edge, grow progressively taller toward the center of the stand. Pronounced domes occur up to 25 miles inland and only at elevations no more than 100 feet above sea level. They may be from 1 to 100 acres in size. In this area, baldcypress appears to be limited to the domes, other species being prevalent beyond the peripheries of the structures. Pondcypress domes are encountered in depressions or sluggish creeks of the flatwoods and in ponds intermingled with the higher-elevation sandy soils of Florida.

Perhaps trees at edges are dwarfed by unknown soil conditions that become so toxic as to finally exclude baldcypress beyond the dome. Perhaps seedlings invade as the site becomes more favorable for bald- and pondcypress inward from the edge. This could be due to fire prevention and cattle exclusion or to gradual deepening of water in the basin. Or, perhaps, outer trees are younger than inner ones, a situation attributed to earlier mortality of edge stems caused by fire, grazing, or drainage. New shoots or seedlings replacing dead trees are evidence that mortality increases as stand edges are approached. Damage to existing trees attributed to natural causes is greatest at a dome's edge.

When surface fires in a dome damage trees at their bases, the trees sprout, but the sprouts are often killed by the next fire. Again sprouts develop. Crown fires, conversely, kill terminal shoots, allowing low lateral branches to become dominant. As fire crosses the grass prairies surrounding the wetter domes, trees at the periphery, where water is shallowest, are more susceptible to injury than stems further inward, or may reflect fire influence on baldcypress height growth.

There is also the possibility that cattle brushing flies by rubbing against trees, or deer rubbing their antlers, damage stems at the edge of a forest, thereby reducing the vigor and rate of growth of trees near dome edges. None of this fully explains the gradual nature of the decline in the height of trees outward from the center of the dome.

Engineers have used cypress domes for tertiary treatment of sewage effluent. However, surface water quality degrades, as evidenced by low levels of dissolved oxygen and high nutrient levels. Underlying organic soil and strata of sandy clay impede percolation of chemical elements to the shallow aquifer below. The quality of standing water within the domes does not return to its uncontaminated purity for almost two years after effluent dispersal ceases.[23]

Knees and Buttresses

Trunk buttresses and cypress knees are an enigma, their role and cause of origin a matter for speculation. Buttresses, extreme taper at tree bases, extend below the surface of the ground. In deep-water swamps, buttresses terminate at a level below which water seldom recedes. From the water surface downward to the soil surface, trunks are narrow, possibly because the section of the trunk under water is saturated, but without adequate air. If that is the case, the buttress is a response to the aeration of tissues associated with rising and lowering water levels. The boles of unbuttressed trunks contain no excess water; they do hold an abundance of air. Only slight swelling occurs in swamps not subject to high floodwaters. The fluted bases of pondcypress trees are rounded in contrast to the sharp ridges of baldcypress.

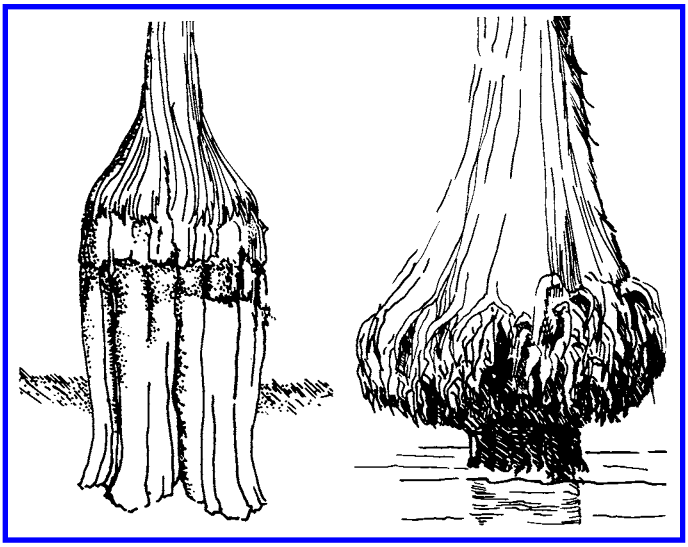

Figure 3.7 Baldcypress buttresses sometimes terminate below the usual water level, possibly because the section of the trunk under water is saturated but without adequate air for buttressing growth.[24]

Knees, peculiar conical structures, arise from shallow widespread root systems. As little gas exchange occurs between roots and knees, the latter seem not to be essential for root aeration. Respiring knees have been shown to reduce oxygen content in closed air-tight containers surrounding the protuberances, but most of the oxygen absorbed is used by the large amount of cambial tissue in these organs. This is particularly evident since knee growth is more rapid than root growth and, therefore, more demanding of oxygen. Furthermore, trees grow well in deep water in the absence of knees; and their removal seems to have no effect on bole growth and survival.

Knees may be important for basal support in organic soils described as "trembling earth." That such support is necessary is indicated by the inability of a 10-foot engineers' pole to remain erect for long on typical baldcypress sites.

Worth noting:

- The general absence of knees in swamp soils superficially dry during most of the year
- The presence of these protuberances where surface water is excessive for long periods
- The rise of knees to the approximate height of the average flood-stage level
- The interwoven network of, and the anchorage afforded by, a deep root mass beneath the knees
- Fewer knees for pondcypress than baldcypress

The Tree's Pests

Baldcypress and pondcypress are notably free of insect problems. The most serious pest is a leaf-chewing beetle, *Systena marginalis*, which discolors foliage in midsummer. Damage is done by small, flattened, dull yellowish-tan adults. Insects leave trees within three days. They do not consume the foliage, but the leaves turn red within a few days of the attack. Heavy feeding is evidenced by linear-shaped gouging that seldom pierces both leaf surfaces. After foliage turns red, leaves shrink so much that feeding holes are difficult to see unless leaves are soaked overnight in water. Defoliation reduces growth and vigor, enabling secondary pests to further weaken and kill trees.

Cypress stands are also relatively free of rots and other fungi infections. Pecky cypress results from infection by *Fomes geotropus*—the scientific species name derived from the downward curvature of the dried fungal bracts. These fruiting organs are rarely found on infected trees. Spores of the fungus probably enter through basal fire wounds. Damage, characterized by cavities that eventually occur throughout the heartwood of a tree, is especially serious on overmature stems. These pockets of a pecky nature, generally several inches long, fill with brown powder that might be antiseptic and, thereby, arrest further disease activity. Decades could be required for old trees to die; growth of this *Fomes* fungus ceases when they do.[25]

Swamp rabbits are a nuisance in young baldcypress forests. They clip seedlings just above the ground, making a smooth-angle cut. Clipped stems generally resprout, but inundation kills short shoots. Beavers, too, destroy seedlings as they forage, especially if the young trees are nursery-grown and, thus, nutritionally rich.

Nutria, the aquatic rodent introduced from South America in the 1930s to control lake vegetation (and possibly for its pelts), uproot seedlings, eat bark from tap roots, and, in some cases, consume whole roots. Damage occurs in the spring, on flooded sites first and then on adjacent non-flooded areas, for a distance of 15 to 20 feet from the water's edge. Easily distinguished from swamp-rabbit injury, the cut is rough and at an angle of about 40 degrees. As seedlings are carried back to the water to be eaten, the nutria leave sections of debarked roots and seedling tops strewn upon the surface of the pond. Ninety percent survival of 3-month-old seedlings occurs where nutria are absent; in the presence of the rodent, total destruction results.[26]

Baldcypress trees are intolerant of salt intrusions, which sometimes occur with flooding. These trees are also known for the aesthetically pleasing Spanish moss that drapes from their branches. In this fibrous material, the yellow-throated warbler forages.

EASTERN REDCEDAR

Eastern redcedar, not a true cedar but a juniper, predominates in part of the Ozark Highlands of Arkansas and the glades of the Nashville Basin in central Tennessee. The Cedar Brakes of central Texas consist of closely related species, Ashe and Pinchot junipers. These *Juniperus* species are among the most alkali-tolerant of drought-hardy trees.[27]

Eastern redcedar is of course not limited to these calcareous outcrop areas. It occurs in the dominant canopy and in the understory of almost every southern forest-cover type. Remnant stems in old stands may reach 16 inches dbh and a height of 70 feet in the span of a century. Horticultural forms, in contrast, grow faster. From some of these 30 or so landscape varieties, escapes appear in the woods. Much diversity among trees of this species occurs in form, foliage color, foliage character, and cones.

Every First Class Boy Scout knows that redcedar bark is flammable and easily ignited, serving as excellent tinder for starting fires with flint and steel. Even "cool" prescribed fire cooks the cambium under the thin shredding bark. Ready ignition of the bark and the tree's resinous foliage effectively enable fire to negatively govern distribution of the species. On rough, stony land, these evergreens escape serious fire injury, which often occurs in pure stands because ground vegetation is too scarce to supply adequate fuel. Litter under crowns is not highly flammable because it readily decomposes as it quickly absorbs ground moisture.

Ecological Succession

Seedlings appear as advance reproduction, especially in forests with partial openings. Where seed-tree cutting, clearcutting, or forest-destructive catastrophes have occurred, even-aged stands result.

However, seeds must be available at the time the site is ready to receive them. Abundant seed crops develop every two or three years.

Cedar glades in the Nashville Basin and its highland rims now are of negligible value for production of the aromatic chest and closet wood that once made the tree economically important. In the Basin, new seedlings arise in the cracks and sink holes of soft limestone rocks, such depressions and vertical fissures affording subterranean drainage that provides water and nutrients for the roots. As these crevices widen and fill with soil to give the appearance of alternating strips of rock and earth, other species like elm and hackberry enter the plant community. Limestone soils on which pure stands of redcedars occur are generally shallow, while deeper soils—even when formed from the same material—are more intensely leached of calcium and thus more acidic. Other species usually prevail in the deeper soils.

On better-quality sites, fire exclusion is essential if reproduction of eastern redcedar is to be established and the stands grow to maturity. Inherent characteristics of the species enable its continuation on dry lands, frequently where other trees do not survive. A fibrous and shallow root system absorbs sufficient moisture and nutrients for sustenance. Often considered drought-resistant, growth appears best on well-drained alluvial soils and in uplands with soil at least two feet deep.

Figure 3.8 A young stand of eastern redcedar. These open-grown stems when 14 inches dbh will yield marketable cedar oil, used in insecticides and microbial disinfectants. However, the volume—because it comes from sapwood—will be but 1/10 that of forest-grown stems of the same size. Oil from the latter will be from older stems, and, therefore, from heartwood. Value will be about three times that of the sapwood of open-grown trees.

A near pioneer in ecological succession, especially in the calcareous Cumberland Plateau of Tennessee, redcedar seedlings' establishment is preceded by only a few herbaceous plants like broomsedge. Bird droppings are a principal dispenser of redcedar seeds.

Eastern redcedar, a heliophyte, requires full sunlight, particularly in its early years. Thick foliage on the periphery of the exposed crown and the absence of foliage beneath the tree's own canopy or where it is shaded from the sun attest to this. Yet, young trees often appear more shade-tolerant than older ones. In glade communities, formerly suppressed redcedar trees rebound to some degree of vigor as broadleaf stems pass from the overstory. Nonflowering bryophytes (mosses) and woody shrubs accompany these junipers in their early life.

Colonization of southern pastures with eastern redcedar peaks about 10 years after range managers and farmers remove cattle from the field. Several factors, including the greater abundance of avian perching sites and seed sources, encourage seed germination and seedling establishment.[28]

Ecological succession on calcareous sites generally occurs like this:

- Timber harvest or agricultural lands are abandoned.
- Herbaceous plants (grasses and forbs) appear.
- Redcedar and woody shrubs invade.
- Broadleaf trees capture the site.
- The stand opens as many deciduous trees pass from the scene.
- Herbaceous cover returns where adequate sunlight reaches the ground.
- Oak and hickory trees compose the climax forest type.
- The climax forest is removed by harvest, storm, or fire.
- Birds plant a new stand of redcedar.

Avian Relationship—One notes the activity of birds in relation to this species by the straight rows of redcedar trees beneath utility lines and wire fences. The berry-like seeds (botanically speaking, the trees produce cones) are ingested by birds. Within the gizzard, seed coats are scratched; within the stomach they are softened by digestive acids. Upon being disgorged by the birds, the naturally processed seeds, high in crude fat and fiber, germinate and seedlings promptly arise.

Robins and waxwings are especially fond of redcedar seeds. A Bohemian waxwing was noted to have consumed and discharged 900 berries in 5 hours. In one Tennessee glade, robins have a winter haven. There, birds may get drunk from eating the fermented fruit of the trees. Stands of redcedars provide favorite habitat for mourning doves.[29]

Not only birds among the animal kingdom are responsible for preparing seeds for germination. A herd of cattle on a drive from the Texas Cedar Brakes of the Hill Country into Kansas stockyards gave rise, through manure droppings, to a small stand of junipers in a treeless prairie. Seeds, their coats scarified and softened, germinated the spring following their dropping to the ground. Other seeds remained stored in the duff on the soil surface, awaiting the second spring to germinate.

Calciphyllous Plant?

Eastern redcedars are often considered calciphyllous, or lime-loving, because of their appearance as virgin stands in the limestone-derived soils of the cedar glades of Tennessee and the limestone outcrops of the Arkansas Ozarks. Other junipers, as those in the calcareous soils of the Cedar Brakes of the Texas Hill Country, also suggest this ecological relationship.

While calcareous, or high pH, soils influence the occurrence of redcedar, the species also influences the pH of the soil. The tree does not necessarily prefer limestone-derived soils, even though there is a direct relationship between the occurrence of the species and such sites. Often redcedar is the earliest invader in acidic old fields where soils are so devoid of alkaline minerals that the pH is as low as 4.7. In those soils the trees grow well. Grasses may provide the ground cover where limestone underlies a thin soil mantle. Surrounding these grassy openings, and on less-calcareous soils, redcedars occur.

Figure 3.9 Ashe juniper in the Texas Hill Country at the western edge of the southern forest (some may chart the zone as the eastern periphery of the western forest). Older stands (left) in the high-pH soil provided fence posts, charcoal, and cabinet lumber for pioneer settlers. Naturally regenerated "brakes" (right) followed post-World War II exploitation of vast areas for fencing material exported beyond the region. Larger stems are exploited for the fragrant oil that is marketed for perfume in France.

Presence of the juniper raises the pH by as much as one unit, due to the leaching of calcium oxide from the fallen and decaying redcedar foliage. Assuming complete decomposition of litter, the acid-neutralizing power of redcedar foliage is twice that of a legume cover and five times that of loblolly pine. Throughout the South, sampled soils under redcedar crowns and just beyond the crowns note this difference in soil pH.

Theorizing the pH was not dissimilar prior to the germination of the conifer seeds, the roots of the redcedar "forage" for calcium at considerable depths and well beyond a tree's crown. The roots absorb calcium, the tree concentrates it in the foliage and, upon needle fall and decay, includes the element in the inventory of cations in the soil. Continual adsorption and recycling further concentrate the element and raise the pH of the soil's surface horizon higher.

The species also favorably affects soil physical properties, probably because of the attraction of earthworms and other macro- and microfauna to the nutrient-rich soil. Activity by these animals alters soil structure. This enhances water infiltration and percolation by increasing soil pore volume (air and water space) about threefold and permeability 20 times that of pine sites adjacent to redcedar stands. Organic matter in the soil doubles, amounting to a difference of three tons of litter per acre. Thus, this species influences the site by increasing available calcium in the soil for the use of plants, as well as by raising the pH.

The presence of junipers also increases soil porosity, thereby improving aeration and water retention in the ground. Infiltration of rainfall improves as soil volume-weight diminishes. (Volume-weight is the weight of the mineral and organic matter in a specific volume of soil.[30])

The lower weight for a given volume of soil occurs because the ground contains a greater amount of organic matter. Aeration consequently improves and cation-exchange capacity increases. This suggests that the greatest use of forests of redcedar may be to protect watersheds. The land's capacity to store rainwater or snowmelt and, thus, reduce runoff and soil loss is enhanced.[31]

The ability of redcedar to survive and grow under droughty conditions involves a relationship between root development and transpiration—transpiration, and hence water consumption, increases as the ratio of root surface to leaf surface increases. Consequently, greater root growth compared with foliage growth causes sites to seem more xeric than they actually are. Tree mortality overcomes this situation, enabling increasing amounts of moisture to accommodate transpiration demands for the lesser amount of foliage. Gradual mortality maintains this shade-intolerant species in pure stands on most sites.

While these conifers may exist in pure stands, they often mix with broadleaf species, and sometimes the hardwoods capture the site to the exclusion in the biome of the coniferous species. Thus, we now consider these competing deciduous trees.

4 Ecology of the Forest: The Broadleaf Trees

UPLAND HARDWOODS

OAKS, HICKORIES, AND THEIR DECIDUOUS KIN

Upland hardwood types of the southern United States often intermingle with conifers to form mixed stands of broadleaf and needleleaf trees. Depending on soil, physiography, fire history, and past land use, pure deciduous forests occur over acreages of various sizes. Numerous oak species, several hickories, yellow-poplar, maples, sweetgum, American beech, sycamore, and several birches predominate. Found with these trees are about 100 other hardwood species, many of minor commercial value for particular uses.

Figure 4.1 Open-grown white oak. This large specimen in South Carolina, with a crown spread of 132 feet, provided shade for homes and seeds for animals to carry as they initiated new forests. (USDA Forest Service photo)

Figure 4.2 Osage-orange, the *bois d'arc* tree. Squirrels, deer, and birds eat the seeds after the compound fruit has fallen to the ground and the hard coat softened by fermentation. Natural stands arise from these seeds. As recently as World War II, a dye was extracted from the wood for khaki uniforms. "Apples" (inset) provided ballast on return trips for boats plying the Red River. Later these "apples" were replaced with goods for shipment, the unloaded fruit providing seeds for living fences far distant from the original narrow range of the species in north-central Texas. The very hard and durable wood, from trees bearing thorns so tough that they puncture truck tires, is harvested throughout the East for specialty products. (USDA Forest Service photo)

Figure 4.3 Ozark Mountain forest of the white oak–black oak–hickory cover type, as climax species, capture many sites. Lands abandoned from agriculture and planted to pines will, before the first rotation is over, begin to appear like these woodlands. (USDA Forest Service photo)

In mountainous regions, hardwood forests cover vast areas to the relative exclusion of both southern and white pines, eastern redcedar, eastern hemlock, red spruce, and Fraser fir. This is true for the Ozark and Ouachita mountains as well as for the Southern Appalachian chain, the Mississippi Bluff Hills of loess soils, and the Post Oak and Cross Timbers of Texas.

Semantics complicates descriptions of upland hardwood forests. Technically, hardwoods are broadleaf trees. Most of them are deciduous, the hollies and magnolias being notable exceptions. Some broadleaf trees have relatively soft wood—yellow-poplar and basswood, for example. Most deciduous trees display broad leaves and produce hard wood.

Much of the southern upland hardwood forests consists of uneven-aged coppice-generated stands of shade-tolerant oaks and hickories arising from roots and stump sprouts. Many of these stems eventually form the climax cover type. That is, climax species cover the land *ad infinitum* if the forest is left alone, fire is prevented, tree-topping windstorms do not occur, and stands are not harvested.

As a rule, acorns carried by rodents germinate under pines that have taken over abandoned agricultural land after about 10 years. In another few years, hickories seed-in. Where broadleaf trees occur in the harvested forest, reproduction from sprouting begins promptly. Shade-intolerant conifer seedlings eventually give way to deciduous species.

TREE GROWTH

Generally, radial growth of hardwoods begins each year after leaves are fully grown. Growth is completed by late August. The length of this “grand period,” shorter than for conifers, seems to be influenced by late winter temperatures. As height growth depends on the amount of carbohydrate produced the previous year, rather than on the current-year’s photosynthesis, terminal elongation takes place in early spring before leaf buds develop into foliage. Trees cease height growth in

Figure 4.4 Old-growth hardwoods in the Georgia Piedmont. These oaks doubtless seeded-in under pioneer species like the southern pines that, in turn, arose following fire. Eventually, these broadleaf trees captured the site.

summer, their leaves continuing to produce carbohydrate through photosynthesis for storage. Some species with long seasonal growth periods, flowering dogwood for instance, probably use the current year's carbohydrate production for additional increment. When conditions are favorable, hardwoods produce multiple shoot growth flushes, each flush followed by a rest period during which root elongation takes place.[1]

Rainfall distribution during the year may influence radial growth. Species within a genus, like oaks among the *Quercus*, vary in their responses to such patterns. Some tissues for some species withstand considerable desiccation, yet regain turgidity when adequate moisture is restored. Drought resistance of post and blackjack oaks, for example, is *primary active*. Such plants withstand dehydration, rather than being able to prevent dehydration (*secondary active*, like cacti), or to enter a resting stage (*passive*, like ferns, mosses, and lichens). Shoot to root ratios, as they affect transpiration rates and the area of moisture-absorbing root surfaces, could influence drought resistance, but the ratio of the weight of above-ground to below-ground parts of a tree is more closely tied to taxonomic than to ecological relationships.[2]

In stands of pines mixed with a variety of broadleaf species, the effect of drought is first noticed among the upland oaks. Foliage of these hardwoods may be shed by midsummer, while pines are retarded in exhibiting the effect—seedlings may not appear to be dying until autumn. Radial growth measurements that depend on ring-width tallies may mislead, because false rings also develop. There may be no way to differentiate between false and true rings. For example, frost that follows spring cambial activity causes such false rings. They are exhibited especially in cross-sections of southern magnolia growing in moist soils near streams. Provenance seems not to play a significant role in the rate of growth of broadleaf trees, as studies with sugar maple indicate.[3]

Lesser plants play a role in nurturing deciduous forest trees. Lichens contribute ammonia nitrogen, especially in beech forests. In addition to adding nitrogen to the soil in forms available to plants, legumes improve tree growth in young stands because these bean-producing stems grow during the cool season without smothering seedlings. Inoculating the soils with mycorrhizae in which maple and black cherry grow increases seedling growth.[4]

Site Quality

Several characteristics determine the rate of growth of hardwood species. These include various measures of moisture relations such as imbibitional water and available soil water. Soil humus, thickness of the surface soil layer, friability of the subsurface soil, and position of trees on slopes are others. For instance, 96% of the variation in site index (SI) for black oak can be attributed to three variables. Expressed algebraically,

$$SI = 38.7690 + 8.8057(A) + (-0.0477)(P) + (-0.4620)S$$

where SI = average height of the dominant and codominant trees at age 50 years,
A = depth of the Al (surface) soil horizon,
P = slope position, in percent of distance from the bottom, and
S = percent of sand in the Al horizon.

To determine the SI for yellow-poplar, foresters simply add 10 to 15 points to that obtained in the equation above for black oak.[5]

Tree Occurrence

The occurrence of hardwood types often relates to the direction of the slope (aspect) as well as to the elevation of the site. In the Piedmont, for instance, the post oaks or on sites characterized by impervious and plastic clay within a few inches of the surface of the land. Seldom are northern red, black, scarlet, and white oaks found in such locales. The more moisture-demanding white and red oaks occur on cooler, wetter, usually elevationally higher north-facing slopes.[6]

Shade intolerance excludes many xeric species from sunless northern slopes, while insufficient drought resistance prevents mesic species from dominating dryer south-facing sites. Although neither soil fertility nor pH seem influential in species location, microclimate plays a role. The climate near the ground affects overwintering seed, availability of light for photosynthesis, the occurrence of competing plants, and—by affecting soil moisture—resistance of the soil to root penetration.

Fire induces changes in the spatial pattern of broadleaf trees. This is especially apparent for turkey oak in longleaf pine stands in the Florida sandhills. There, fires reduce clumping by species, creating a more random pattern that thus increases segregation of the oak and pines. Repeated burning diminishes the number of clumps, while the patchiness of the oaks may be directly attributed to fire intensity.[7]

Seeds and Seedbeds

Birds and rodents distribute seeds that establish oak and hickory forests. Blue jays notably disperse black oak acorns over wide areas. While seed germination may not be improved by digestion in mammals, many seeds passing through alimentary canals do remain germinable. Birds, however, hasten the breaking of dormancy as the thickness of seed coats is reduced by abrasion within the gizzard. Acidic fluids and bacteria aid the process; seed coats then are more permeable and better able to absorb water and oxygen when later deposited on the soil. Birds distribute seeds with fleshy fruit, like those of cherry and persimmon trees, often getting drunk and falling from tree limbs as they consume fermenting fruit. Some birds are selective; robins improve the germinative capacity of black cherry, grouse carry poison ivy seeds, and pheasants and bobwhite quail enhance germination of the black locust, dogwood, and choke cherry seeds on which they feed. (Seed treatments in nurseries often mimic these natural processes. Turning seeds in sandpaper-lined portable cement mixers scarifies the seed coats and soaking the seeds in dilute solutions of hydrochloric acid softens their coats.)

Figure 4.5 Acorn viability can be ascertained to some degree by observation. The two Shumard oak acorns on the right with the light cup scar are sound; the dull coloration, as shown in the two on the left, indicates weevil or fungus intrusion. (USDA Forest Service photo)

Acorn production varies little from mountain to mountain, though rainfall between the summits might differ by 20 inches. Year-to-year trends in acorn production follow a common pattern for all species; white oak mast is abundant in the same years that black oak fruit are plentiful. This is especially interesting because species of the white oak *Quercus* subgenus *leucobalanus* mature mast in one year while those of the red oak subgenus *erythrobalanus* require two years.

When seeds fall in the autumn, 20 to 60% are sound. Birds and squirrels destroy one-fourth of the acorns on a tree, while insects take another 30%. A typical oak tree might disperse 1300 sound seeds, only 100 of which will germinate.[8] Acorns and hickory nuts, being relatively large seeds, germinate to produce large seed leaves (cotyledons) that are able to withstand much damage and still provide adequate initial nutrient and carbohydrate supplies for seedlings. Once on the ground, nut weevils, moth larvae, and gall-forming cynipids feed during the insects' larval stage on oak and hickory mast.

Deer consume entire acorn crops, although sometimes vainly trying to fend off piney-woods' rooters for this food. Wildlife seem to prefer acorns of the white oak subgenus over those of the red oak group, perhaps, as wildlife specialists speculate, because the latter are cathartic.

Oak seeds germinate readily in a litter layer about one inch thick. With deeper layers of undecomposed organic matter, hickory species win out. Under droughty conditions, thick mats of fibrous material conserve moisture for use by tender seedlings. When conditions are right, as many as 900,000 seedlings per acre arise from oak acorns.[9] After germination, long-tailed wood mice sever seedling roots in their search for food, while soil-burrowing rodents cut roots as they tunnel the ground.

Isolated Situations

The loessial soils immediately east of the Mississippi River in western Tennessee and Mississippi, which produce high quality deciduous trees, deserve special attention. Severe erosion, aggravated by intensive cotton cultivation, encouraged the U.S. Congress in the 1940s to establish a reforestation program to reclaim these lands. The U.S. Forest Service's budget constraints in the early 1980s resulted in dismantling the program to reclaim these highly erosive lands and to manage them for wood production.

Figure 4.6 Kudzu, native to the Orient. Along with Japanese honeysuckle, also an exotic, this vine was introduced to check erosion. Here, a canyon-size gully was planted to the leguminous climber. Unfortunately, when these vines cover the land, as in this photo, they do not control erosion; they only hide it. Grazing cattle and browsing deer have also broken legs when falling into stump holes or washouts hidden by the vegetation. The practice has been largely eliminated, but escapes of the vines continue as a serious nuisance invader.

Once the soils are stabilized, cherrybark red oak, Shumard oak, black walnut, white ash, eastern cottonwood, and yellow-poplar grow so rapidly that radial increment often exceeds one-half inch per year. Here, too, sassafras grows sawlog-size stems 30 inches in diameter that produce three commercial 16-foot sawlogs. Cottonwood boles in the coves exceed 30 inches dbh and five merchantable logs in 30 years.

Figure 4.7 Southern red oaks in a relatively pure stand in the Southern Appalachians. A high-quality tree for furniture and paneling manufacture, it maintains itself as a permanent component of the climax forest. (USDA Forest Service photo by P. Carter, 1935)

Where the mantle thins to less than two feet, loblolly or shortleaf pines may occur naturally in mixture with hardwoods of poorer form. Also, large areas of abandoned cropland have been planted to loblolly pine.

While kudzu and to a lesser extent honeysuckle intrude into forest land throughout the South, the problem is most serious in these bluffs. Once looked upon as miracle plants that promised to revolutionize farm practices, the propensity of these vines, introduced from the Orient, for taking over land concerns forest managers. The kudzu weed, once thought to be especially useful for cattle forage and for erosion control, climbs fences, crosses ditches, and even engulfs houses and barns.

Parts of central Kentucky and Tennessee are characterized by soil of calcareous origin that excludes pine types. Oaks and hickories compose most of the natural broadleaf forest there, with other species occurring because of the effects of local topography. These woodlands serve as transitional vegetation between the mixed mesophytic forest of the Southern Appalachian Mountains to the east and the drier prairies to the west. Eastern redcedar, as a pioneer species in ecological succession, often precedes the appearance of deciduous trees in these areas.

The Post Oak belt and the East and West Cross Timber regions of Texas offer similar transitional situations, in these cases bridging the pine and hardwood forests growing on the red clay hills and brown sandy loams of East Texas and the fingers of low-pH soils that break up zones of the rich, black, calcareous high-pH clays to the west. (These blacklands, never covered with forest and now too valuable agriculturally to be retained in grass, usually produce soy beans and cotton.) Blackjack oak joins post oak in the cross-timbers, continuing to cover the xeric sandy land as coppice-reproduced woodlands. Mesquite, the cattle-carried invader from the Rio Grande to the south, competes with the scrubby trees and herbaceous plants that occur naturally on this land.[10]

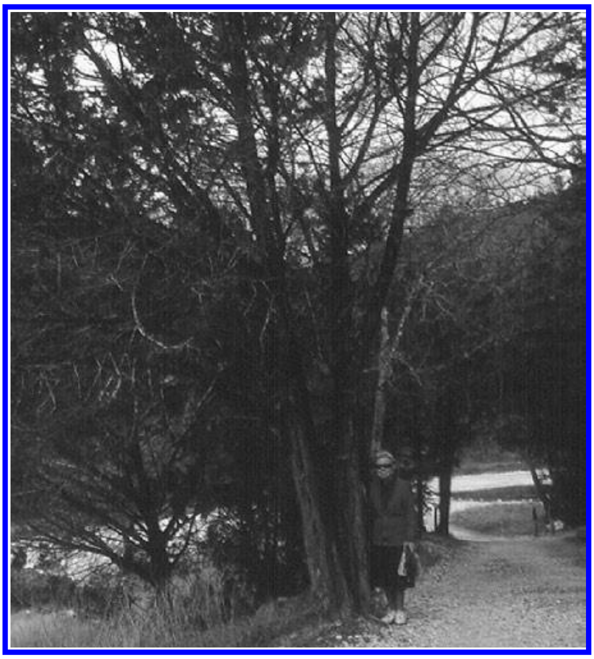

Figure 4.8 Live oak accompanies post oak and junipers in the Texas "tension zone." Ball moss (insert), a parasite of the pineapple family (some may call it a saprophyte) grows on branches of oaks and other broadleaf species.

Fire and Storm

Fires may seriously wound tree bases in upland hardwood stands, weakening and killing them. However, it has been shown in the uplands of Virginia and the Carolinas that repeated fires favor oaks over other species. The relationship may occur in other broadleaf forests with a significant oak component. The condition of the forest also often relates directly to its fire history.[11] Repeated burning sometimes encourages replacement of woody plants with an abundance of legumes, nutritious food for quail and deer.

Ice storms glaze over the foliage and branches of upland hardwoods, especially in stands above 3000-feet elevation in the Southern Appalachian Mountains. Along with glaze, late freezes damage trees. With abnormal cold and sudden drops in temperature in spring, buds and new foliage quickly freeze and die. Loss of leaf buds prevents regrowth of leaves that year. Freeze damage usually occurs in valleys and hollows, probably because buds and leaves in these ordinarily warmer sites

Figure 4.9 Heavily overcut second-growth mountain mixed-hardwood stand. Wildfires and light prescribed fires reduce sprout growth, allowing the more vigorous stems eventually to reach maturity. (Georgia Forestry Commission photo)

expand earlier in the spring than do buds and leaves on trees higher up the slopes. In the coves, wind may be insufficient to move cold air out of the hollows and over the mountains.

Disease-causing Agents

A disease called nectria canker, caused by *Nectria cinnabarina,* attacks most severely in forests of soft maple, black birch, and weed cherry species at high elevations. High-value trees, possibly because of their vigor, fortunately are often spared.

Dutch elm disease, introduced from abroad, spares no elms. The causal fungus, *Ceratostomella ulmi*, carried on the bodies of European elm bark beetles, entered North America simultaneously with the beetle. Otherwise, the disease would not have attained its foothold. The insect adults carry the sticky spores from egg galleries under the bark of diseased trees to the crotches of young twigs or leaf axils of nearby healthy stems, there to chew through the bark and introduce the fungus. The elm, America's favorite shade tree, its crown shaped like a huge vase of flower stems, disappeared from town streets and campus lanes as well as from the Southern Appalachian woodlands. The malady's spread seems unimpeded. Phloem necrosis, an infection with similar symptoms to those of Dutch elm disease, also attacks species of the genus *Ulmus*.[12]

Oak wilt presents another type of infection. The disease, entering the South from the Lake States, was first detected in the Southern Appalachian Mountains in 1951. Little infection occurs on high-quality soils of alluvial or limestone origin. Fungus mats, root grafts, and bleeding wounds

Figure 4.10 Oak wilt fungus, carried by *Chalara quercina*, found its way by the 1980s to the Post Oak Belt of Texas. Forest trees as well as landscape stems are killed. (Texas Forest Service photo by R. Billings)

provide entry points for the fungus *Ceratocystis fagacearum* into trees of the genus *Quercus*. Ax cuts, insect holes, and branch stubs that hold water serve as favorable environments for the fungus' growth. Sap-feeding beetles also carry the spores from scattered mycelia mats to fresh wounds on healthy trees. Ironically, foresters' increment hammers and borers spread the disease as they sample radial growth patterns. The holes made by the instruments, like any cavity that holds water, become receptacles for the culture medium and innoculum. Dipping increment cores in a fungicide and replacing the cores in the holes from whence they were extracted provides protection. If cores must be retained for study, a cork dipped in a fungicide and inserted into the hole serves similarly.[13]

Insect Infestation

Elm spanworms, the adults *Ennomos subsignarius* known as snow-white linden moths, adversely affect elm trees by repeated defoliation. Spanworms, called loopers, march along a branch to feed on new succulent foliage. The loop made by the larvae resembles the Greek letter omega. Long-distance migration by adults accounts for the spanworm's rapid spread.[14] The insects do not attack yellow-poplar almost alone among non-susceptible species. (See Chapter 6.)

Closely related to the elm spanworm in damage done is the gypsy moth (*Lymantria dispar*), so named because it extends its range as a hitch-hiker. Camping gear and motor vehicles carry the insect throughout the hardwood forests of the Appalachian region. Females, unable to fly, sail with the wind to infest nearby woodlands. They prefer various species of oak, birch, willow, and cottonwood.

Entrepreneurs imported gypsy moths into this country via Europe from the Orient for silk production. The industrialists intended to use the larvae to produce silk for the North American textile industry, as the silkworm serves in China. Importation from France occurred in 1869; serious damage was observed as early as 1889 near Boston.

Hickory twig girdlers and hickory spiral borers attack the terminal shoots of young trees, often killing them. If the seedlings live, trees become misshapen as their lateral branches bend upward, exhibiting phototropism, to assume dominance. Numerous parasites keep these insects in check.

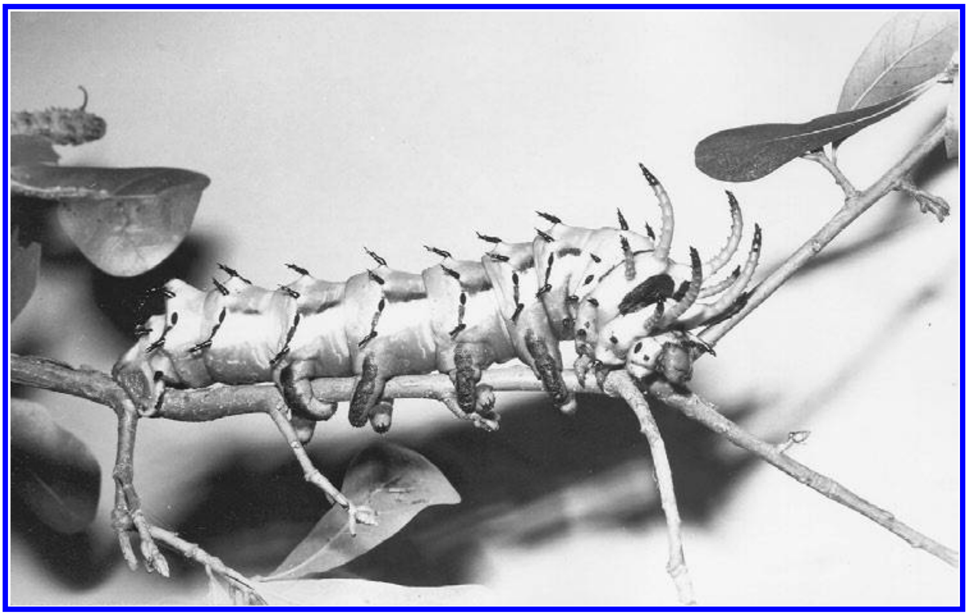

Figure 4.11 The hickory horned devil. Larvae, up to 5 inches long and as stout as a thumb, feed on deciduous trees. Ferociously appearing because of the hornlike appendages in this stage, they are harmless to people. The larvae feed on many deciduous trees, especially *Fraxinus* and *Juglans* species, throughout the South. The adult is called the regal moth. (Texas Forest Service photo by R. Billings)

YELLOW-POPLAR

The lumbermen's yellow-poplar is not a true poplar, and therefore, the name is hyphenated. Purists prefer to call it tuliptree. Its Latin binomial, *Liriodendron tulipifera*, means tulip-bearing lily tree, hardly appropriate for a species related to neither tulips nor lilies. Only in China is there one other species of the genus *Liriodendron*.

Yellow-poplar requires full sunlight and an adequate seed source for its regeneration. The species does not enter ecological succession in the shade of an overstory, including its own. One of the most economically valuable trees within its range, it grows tall, straight, and fast in dense, even-aged stands that exhibit colorful foliage in the autumn. With selection harvests, slower growing and shade-tolerant uneven-aged oak and hickory stands likely follow.

Yellow-poplar attains the greatest height, and possibly the largest diameter, of any American hardwood tree except live oak. Found in the Piedmont province and as an important component in the Appalachian Mountain forests, it demands deep, fertile, well-drained but moist loamy soils. Established stands play out early in lighter sandy or heavier clay soils, especially on drier south-westerly slopes. The tree grows especially well when planted in the Cumberland Plateau and in East Texas where a forester a generation past planted a seedling in the yard of every home in a neighborhood. After 20 years many of those stems exceeded 24 inches in diameter and had a merchantable height of three 16-foot logs.

On favorable mesic sites, trees often exceed 10 feet in height in 2 years. A 22-year-old stand originating from seed in Georgia had produced 4000 board feet, the stems averaging over 10 inches dbh and containing twice the volume of a loblolly pine stand on a similar site. One-half-inch annual diameter growth and 2 feet per year height growth are typical for the species for its first 50 years on good sites.[15]

Early succession in the Southern Appalachians depends upon size of openings in a yellow-poplar forest. Openings greater than several acres have a rich species mix in contrast to smaller patches. Often, the nitrogen-fixing legume, black locust, becomes a significant component in the larger openings. There, because of the greater amount of sunlight reaching the forest floor, biomass production is severalfold greater in stands of yellow-poplar.[16]

Moisture Effects

Growth of yellow-poplar is sensitive to spring rainfall on most sites. Other than in the moist coves, where soil moisture is seldom limiting, growth depends on precipitation at the onset of earlywood growth and when buds break dormancy. Abundant soil moisture at the time cells divide in both the cambium layer beneath the bark and in the terminal buds encourages greater growth. Growth, however, seems unrelated to the previous growing season's temperature and precipitation. While not atypical for hardwoods, this contrasts to the response expected for conifers: for needleleaf trees, the previous year's rainfall often controls growth in the present year.

Old stands of mixed hardwoods nearby yellow-poplar forests exhibit lower ambient temperatures during the growing season than do the yellow-poplar woodlands. Lower evaporation and transpiration losses reflect this modifying influence of yellow-poplar upon microclimate. The effect extends beyond the edge of the mixed hardwood stand, those trees utilizing available soil moisture from under the adjacent pure yellow-poplar stand. Hence, water in the upper six inches of soil under the mixed hardwoods stands containing the moisture-absorbing lateral yellow-poplar roots, is higher than would be the case if the yellow-poplar trees were not present.[17]

The soil landscape often appears as a mosaic of profiles reflecting occurrence and chemical characteristics of the ground cover vegetation and of individuals of the various tree species present. Thus, under individual crowns of yellow-poplar, in contrast to eastern hemlock, the soil has a higher pH, and more calcium, magnesium, and potassium than in the open. Mineralizable nitrogen also scales higher. Where certain other plants, such as rhododendron, occur in the understory, the differences in soil characteristics fade.[18]

That a tree so demanding of moist sites should also be killed by flooding indicates its sensitivity to a narrow range of moisture conditions. Short-term dormant-season inundation apparently does no damage, but a single overflow of a river bottom during the growing season virtually eliminates a stand.

The heartwood of most species is the darker, richer wood used for furniture and paneling. For yellow-poplar, the color and the amount of heartwood are controlled by soil moisture. The famous early-day forester W. W. Ashe noted that stems of this species found in fertile coves have a large core of heartwood. For those growing in rich limestone soils, the heart is dark brown, while trees on dry sites have a smaller zone of a lighter-colored interior core. As heartwood is desirable, and the darker the better for furniture and paneling, moist coves provide the best habitat for this tree. (Manufacturers now stain sapwood to appear as heartwood: some, however, prefer to retain the sapwood appearance for the variation in color of the surface of a furniture face[19]).

Evidences of Vigor

Vigor of yellow-poplar trees is exhibited by the bark. High-vigor stems—those growing on high quality sites—have diamond-shaped, corky, and shallow-fissured, light-colored ash-gray bark with light-colored inner bark. As vigor diminishes, the bark becomes thicker and the ridges more pronounced. Some inner bark remains visible in the fissures. Then with further loss in vigor, the thickening bark turns darker and the deep fissures more pronounced, but the inner-bark is not visible.[20] Rather demanding of the site, the species exhibits foliar symptoms of nitrogen, phosphorus, and potassium deficiencies.[21]

Vigor is also evidenced by crown form. High-vigor stems have many small ascending leaders, a sharp-pointed crown, and abundant lustrous foliage. With loss of vigor, the tree becomes more

Figure 4.12 Yellow-poplar in a Blue Ridge Mountain cove. Seeded-in in dense stands, the botanist's "tuliptree" exhibits many of the silvical characteristics of the principal southern pines. Browse plants able to endure the shade and the competition of the trees, cover the ground. (USDA Forest Service photo)

thinly foliated, branches spread horizontally rather than ascend vertically, and the point of the crown appears blunter.

Seeds and Seedlings

Although yellow-poplar seed crops are produced annually, the heavy layer of litter that forms a matted humus discourages seed germination. If germination occurs, dense canopies impede seedling establishment. Low light intensity in crowded stands prevents seedlings from growing beyond the succulent tissue stage.

Good seed germination on bare mineral soil—encountered following fire and clearcutting—may be associated with chilling, a condition necessary for seeds of many species to break dormancy. While abundant organic matter in the soil of undisturbed sites serves to reduce the maximum and raise the minimum temperatures of the soil, such changes in surface soil temperature under these conditions are not sufficiently great for effectively serving as a pre-germination seed treatment.

Yearly production of seeds frequently exceeds more than 5 million per acre. Distribution in the autumn peaks during periods of high temperature and low rainfall. Strong winds dislodge them from the cup-shaped ring of basal scales, sending the terminally winged seeds a distance of four to five times the height at which the fruit clings to the tree. Some seeds drift from the "cones" of fruit clusters, each cone holding about 80 seeds, in the spring of the year following seed maturity. Some seeds lie viable in the soil a year before natural stratification (an essential pre-germination treatment) enables cotyledon leaves to break through the coat. Young seedlings freeze in the cold of winter or smother in the shade of heavy leaf fall in autumn.

The only shade under which the intolerant species survives is that of grass and the low bushes of old fields. Sumac, sassafras, and black locust trees form stands with canopies too dense for yellow-poplar seedlings to penetrate, even if seed germination is adequate.

A tree that occurs naturally through a thousand miles of mountains and plains may be expected to vary by provenance. However, the geographically racial distinctions of yellow-poplar are nearly imperceptible apart from the earlier height-growth initiation for seedlings in warmer areas. Survival of seeds depends on seed source, but not on the latitude of that source. Seeds from southerly climes when planted farther north break dormancy earlier in the spring, late frosts then taking their toll. Any growth advantage of a warm-climate seed source is canceled out by the early inception of tree dormancy in the colder northern zone. As the beginning of dormancy is also correlated with the date of the first killing frost at the point of parental origin, planting northern provenance stock to the south appears to have no value.

Yellow-poplar is sensitive to the length of daylight. Trees of this species grow well in a greenhouse under long-day conditions. Growth ceases and seedlings become dormant when day-length is shortened. Interrupting darkness with brief periods of artificial light increases height growth.

Damaging Weather and Other Agents

Glaze destroys many stems of this deciduous tree throughout its range. Ice forms as cold rain falls on branches when temperatures drops below freezing. Strong winds further lower the chill factor. The ice weighs down branches and boles on the windward side. When frozen, the brittle branches easily crack. Broken tops cause permanent crooks as lateral branches assume phototropic dominance. Injuries also expose wood and inner bark to attack by insects and fungi. Branches stripped of leaf-bearing twigs by ice reduce growth for several years. Thus, dense stands in areas where glaze frequently occurs are less subject to injury than are open, or thinned, woodlands. The weight of snow also breaks tops from low-vigor yellow-poplar trees, enabling introduction of rot-causing fungi, greatest decay occurring where heartwood is exposed.

The sun's rays on southerly facing sides of trees growing on slopes of that aspect penetrate the thin bark to kill new cambial cells and to raise blisters on the boles. Sunscald is then apparent. At the other weather extreme, frosts cause similar injury, again the cold penetrating the thin bark with poor insulating quality.

Birds of many kinds in their search for food peck on the surface of yellow-poplar boles, leaving hundreds of black spots in tangential lines when viewed from the end of a felled and bucked log. Some stems appear to be immune; others repeatedly attacked. The holes made by the birds' beaks in time fill with callus tissue formed with the bark.

Microorganisms, including fungi and nematodes, are consistently more abundant in soils supporting yellow-poplar than in those supporting pines. The heartwood-rotting fungus most destructive of this species is a *Collybia velutipes* infecting 25% of the trees in a stand. The organism's mycelia grows as much as a foot a year, upward or downward, from the point of entry into the tree. Pocket rot, caused by the shoestring-forming fungus *Armillaria mellea,* appears to dissolve wood in the region of the medulary rays, those ribbon-shaped strands of tissue extending radially from the pith across the grain. Irregular cavities then develop. Sometimes roots are infected.

Fungi that cause other heartrots, honeycomb pocket rots, butt rots, and cankers also attack yellow-poplar. Boles with a target-like growth on the trunk, by which the Nectria canker disease is readily identified, seem not to be greatly damaged as long as annual diameter growth is at least one-tenth inch. Growth then is sufficiently rapid to heal the canker wounds.

Of great current concern is a dieback caused by either a fungus (*Myxosporium*) or a bacterium (*Xanthomonos*). Symptoms are chlorotic atrophy of foliage, a sparse crown, and dying twigs. As epicormic branches die, lateral cracks are left in the bark, giving the appearance of frost-shake. Death of stems occurs within a few years.

Fire wounds on the thin-barked tree are entry points for fungi, the spores coming to rest on exposed wood. Almost all yellow-poplar trees with wood exposed from fire injuries contain decay, the infection growing beneath the bark of healed-over scars. While the thicker, more fire-resistant bark of larger, older trees provides some insulation, the heat of hot fires penetrates it.

Figure 4.13 Clumps of mesquite tree, the legume originating from seed in cattle pats in Texas and Oklahoma. Larger stems provide charcoal material and, because of the rich reddish color of the wood, are milled into ornamental pieces, furniture and gunstocks. Attempts by ranchers to eradicate the tropical tree are futile. Also known as the screwbean, as the thick, linear pod twists 12 to 20 turns into a narrow, straight spiral.

Insects also take their toll of yellow-poplar trees in the southern forest. An ambrosia beetle, called the Colombian timber beetle, is probably the most injurious. The tuliptree softscale, found in great clusters on branch bark, kills only limbs. Leaf-feeding aphids, maggots, and the caterpillar of a moth also feed on these trees, but do little damage.

MESQUITE

At the western edge of the southern forest, multi-stemmed mesquite trees accompany scrub oaks and several species of "cedars" of the genus *Juniperus*. Mesquite, with wood characteristic of tropical hardwoods, has ecological significance. Known as the "forgiving wood," it is praised by cabinetmakers for its stability and gluing ease: where other hardwoods change shape with changing humidity and therefore may be disagreeable to work with, this beautifully grained wood of Texas and Oklahoma serves well. Cattle, on the great drives to Kansas City and other stockyard markets a century ago, carried seeds of the leguminous trees on the long march northward. Before the drives, mesquite was principally confined to the Rio Grande country hugging the Mexican border or as scattered trees where fire reduced the number of stems. At least its range was much less extensive than at present. Once on the drive, the bovine consumed the highly nutritious bean pods, dropping them in their pats along the trail some days later. Soon the beans in the manure piles germinated, grew to seed-producing trees, and provided browse for other cattle a few years later. Softened by acids in animal stomachs, the seeds were naturally stratified for ready germination. Now, mesquite trees occur in dense nuisance stands nearby pine and hardwood forests.

A tropical hardwood species, the wood contains quartz minerals. A hand lens enables one to see crystals of silica dioxide ingrained in the wood. How particles of the fourth-hardest mineral get into the wood remains a mystery. Although silica is not an essential element for plant growth, and although it is highly insoluble (else the sands of the seashores would not persist), the mineral moves from the soil through roots to the xylem of the tree, there to precipitate as crystals among the fibers of cellulose and lignin in the wood.[24] The crystals dull the cabinetmakers' tools.

AMERICAN CHESTNUT

The fungus historically most destructive to the upland hardwood forest is *Endothia parasitica*, the agent that causes the chestnut blight. Before the lethal fungus' entry into the Port of New York in 1904 and its discovery in Virginia in 1907, one-fourth of the trees in much of the Southern Appalachian Mountains were probably American chestnut. Tolerant of most sites within its range from the infertile mountain ridges to the rich fertile valleys; the tree was of especially high value.

Even until the 1930s, chestnut was a predominant species throughout much of the Appalachian chain. The most versatile tree species of the region, its health was not much affected by insects or diseases (except a singular case subsequently noted). Its attractive wood, ideal for furniture and interior trim, did not warp or twist. Its toughness made it useful structural timber. Its durability when in contact with the soil or exposed to the elements made the wood useful for split-rail fencing, posts, and pilings, as well as for shakes and shingles for roofs and siding. The high tannin content supported a tannic acid extract industry that, in turn, provided the chemical required for treating leather. Chestnut's edible fruit pleased both man and wildlife; its aesthetically pleasing form was valued for landscaping (as in William Wadsworth Longfellow's "Under the spreading chestnut tree, the village (black) smithy stands …"); it regenerated rapidly from both seeds and sprouts; and, as noted earlier, it grew on sites ranging from fertile coves to relatively unproductive ridges.

INFECTION SPREADS

New infections of American chestnut in the South occurred faster than government programs were able to eradicate infected stems. A legislative appropriation in North Carolina provided funds to cut a swath across the mountains to stop the spread. Before the cutting was well underway, E. parasitica infected chestnut trees throughout the species' range in the south.

Within 40 years, the disease had spread by wind, birds, and insects to all American chestnut-growing zones. There was one exception. In the late 1950s, a stand of a few healthy stems at elevations above 4500 feet in the southernmost Blue Ridge Mountains still persisted, perhaps separated for awhile by distance from forests of diseased trees.

The feet of a single downy woodpecker carried over 7,000 *E. parasitica* spores. When these minute unicellular reproductive organs land on the bark of trees, they produce spore horns that exude from bark pustules. Dissolved by rainwater, the small particles wash into bark wounds. Other

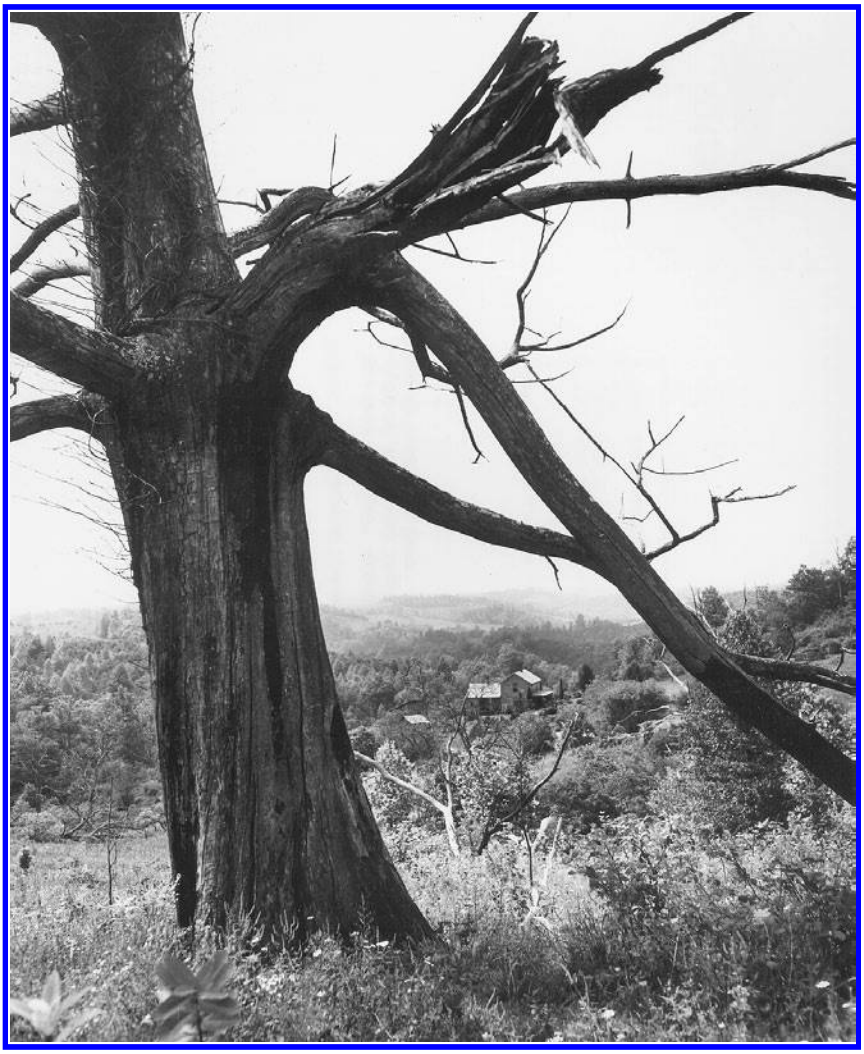

Figure 4.14 The "Dead Sentinel," a large chestnut tree in a Blue Ridge Mountain plateau, established progeny that continued to survive into the sapling stage before succumbing to the chestnut blight. (USDA Forest Service photo by B. Muir, 1946)

spores are "shot" from pustules into the air and carried on wind currents for great distances. Infected trees die as the fungal mycelia strands spread within the inner bark and sapwood.[25]

Replacement species

Sites left vacant by the death of chestnut trees have been captured by several other understory hardwoods, the crowns filling small openings. On mesic sites in the Great Smoky Mountains, eastern hemlock, yellow-poplar, basswood, sugar maple, hickories, and chestnut oak take over the land. Pure, vigorous yellow-poplar stands, mostly limited to the coves and lower slopes, make rapid growth. Above the coves on dry slopes and ridges, species more drought-hardy than chestnut now dominate. These include chestnut oak, scarlet oak, sourwood, and pitch pine. All oaks together compose about 40% of the replacement species in the Smoky Mountains. Composition of the post-chestnut forest is similar for both the Blue Ridge Mountains and the Cumberland Plateau of the Appalachian chain.[26]

A prolific sprouter, coppice shoots of American chestnut stems often arise following death of above-ground stems. Thus, the species is not in danger of becoming extinct. Sprouts from roots of disease-killed stems escape the blight long enough to bear fruit. Seeds from the fruit germinate and young trees survive, in turn to produce nuts, before succumbing to the fungus. There appears little promise for blight-resistant trees to appear among the survivors of the species. Neither does the extensive research in hybridizing with resistant Chinese chestnut species from the mountains of the Peoples' Republic of China encourage optimism for the return to commercial status of this valuable broadleaf tree. American chestnut has responded to virus-induced hypovirulence, but only when hybridized with certain oriental chestnut species. The compatible hypovirulent isolates of *E. parasitica* applied to blight cankers reduces the dieback. Similar healing remains to be demonstrated for non-hybridized American chestnut trees.[27]

Even before the appearance of the chestnut blight, disease was an important factor in the evolution of upland forest composition. The ink rootrot, caused by the common *Phytophthora cinnamomi,* eliminated many chestnut stands between 1825 and 1875, according to dendrochronological studies. A black liquid dye extracted from the wood by pioneers suggested P. cinnamomi as the causal agent of a tree's death.[28]

ALLELOPATHY

Allelopathy in the southern woodlands appears to be more prevalent than previously thought. Black walnut was once considered the principal antagonist, exuding *juglone* from its roots, leaching the natural herbicide from its foliage, and washing it from the green shucks of walnuts in late summer and winter rains. Even black walnut seedlings growing beneath parent trees succumb to the effect of the chemical. Sugar maple also releases a chemical that inhibits growth of yellow birch when the two species are growing together, providing an advantage for the former species (even though the two often occur together in northern hardwood forests). Unknown is whether southern sugar maple behaves similarly when found with river birch along southern streams. Black cherry also may be allelopathic, its foliage upon wilting releasing cyanide from the bound form, cyanide glycoside. This exudate is toxic to cattle; deer eat only wilted foliage. Several other chemicals, including citrol and a form of camphor, released by sassafras, seem to enable that species to maintain itself in pure stands in old fields. (An extract from roots provides an ingredient for perfume.)

Allelopathy occurs in the Louisiana Delta country when broomsedge grass grows among red oak, cherrybark, and sweetgum trees. There, foliar and root extracts of the low-quality grass detrimentally affect some species. Sweetgum appears to be excluded from these sites because of salicylic acid leached from cherrybark oak crowns by rain. This chemical is tied so loosely in foliage that it can be leached with cold water. Toxic products are also released by the action of microflora in the decay of their own roots.

THE BOTTOMLAND HARDWOODS

Flood plains of major rivers, swamps, and creek bottoms interspersed among upland sites produce much of the commercially valuable hardwood timber of the southern United States. Even in these moist sites, fire periodically alters the stands of broadleaf trees: setting them back in ecological succession, changing species composition, or simply causing the replacement of an old stand to a young one of the same species through coppice regeneration. Severe fire often prevents restocking of commercially valuable stems by destroying the humus layer: soils become puddled and then dry to rock-like hardness.

New forests may not readily appear following fire where coarse, loose, sandy soils deposited by recent overflows are at the surface or just below a thin veneer of fine silty material. Frequently

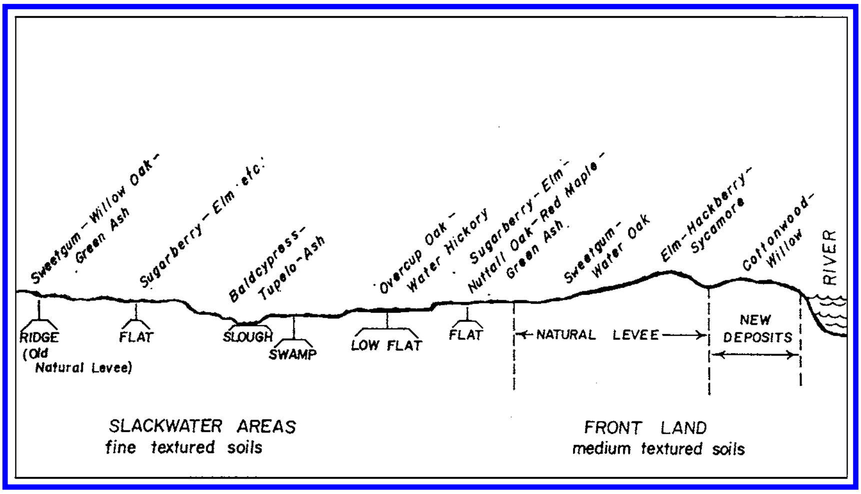

Figure 4.15 Idealized section of a Mississippi alluvial plain. The vertical scale is exaggerated in showing the relationship between topographic position, soil, and tree cover.

these situations involve *batture* lands, those tracts between either natural or man-made levees and water courses, where water tables in summer may be too deep in the ground to enable capillary delivery of moisture through the sand. Other difficult sites for natural regeneration are those where plastic clay covers the surface of the soil. One finds such in low-lying flats underlain by hardpans and in silty-clay basins below terraces that border rivers. Under all of these conditions, either soil moisture or aeration periodically may be too limited to sustain stands of many species. Poor aeration under these conditions takes place where soil moisture is overly abundant.

Edaphic and Physiographic Characteristics

Many soils of the South's bottomlands exhibit azonal features. Such soils are too immature to display well-defined horizons within or between the surface- and subsoils. First bottoms, the major sites of relatively recent origin, compose the present main flood plain. Waters often overflow them. Impervious waxy clays, silts, and fine sandy loams prevail in these lands immediately adjacent to rivers. Second bottoms, lands which at an earlier time were the first bottoms of the same rivers, appear now as terraces slightly above a river's elevation. Second bottoms flood only occasionally. On them, acidic silt loam and silty clay loam are major textural classes

Other edaphic and physiographic zones of river bottoms include sloughs, swamps, ridges, flats, and fronts. Sloughs, sluggish side channels or rivulets from a river, may also appear as mudholes or marshy backwaters.[29] Swamps are other secondary sites in both first and second bottoms. Swamps, except during extreme droughts, are inundated for the greater part of every growing season. Alluvial swamps along flowing rivers differ from tidewater and peat swamps of the Coastal Plain estuaries: the former have fairly firm clay bottoms which occasionally dry out, while water stands permanently in swamps composed of organic soils.

Ridges, the banks of former stream courses, stand 2 to 15 feet above surrounding flats. Although rarely flooded, seasonal overflows do deposit coarser soil materials on them, thereby providing better surface drainage than for most other topographic classes of bottomlands. Flats, lying between the ridges, have poor surface drainage because of the high proportion of clay in them. The perennial deposits of alluvium also discourage favorable internal (subsurface) drainage. In low flats, free water may take several weeks to subside after streams return to their banks; in high flats, a few days. Ridges and flats in the second bottoms become obscure as sheet erosion lessens their evidence. Battures, land between a river's bank and a levee, unless protected by engineered dikes, frequently flood.

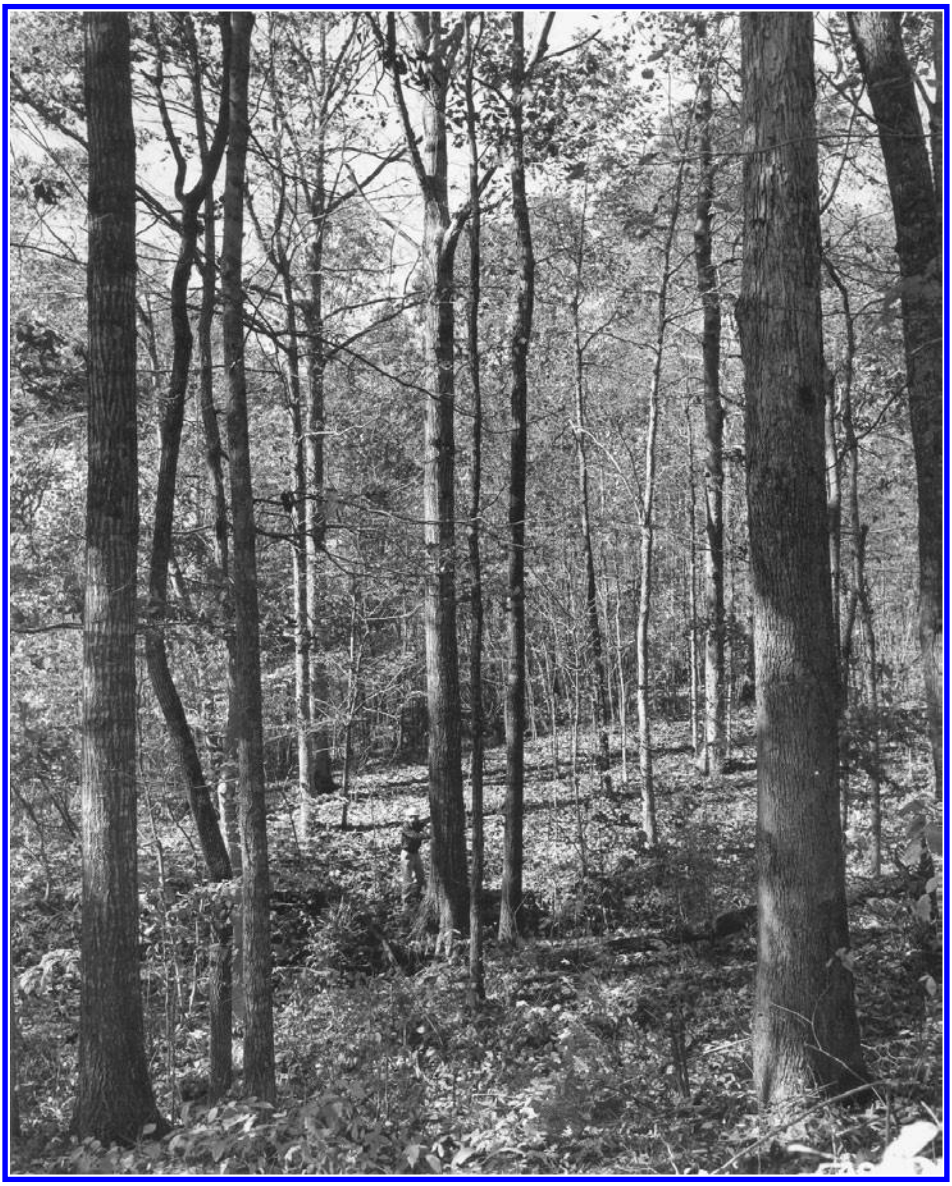

Figure 4.16 Mixed hardwood stand in a southern river second-bottom. More than 25 valuable species for various uses grow in these sites where soil moisture is always adequate, but the land never flooded for more than a few days at a time. (USDA Forest Service photo)

In all bottomland sites, nutrient drain likely exceeds nutrient gain where forests are managed on short rotations. The element-demanding broadleaf trees, in contrast to coniferous species, utilize nutrients more rapidly than soil genesis permits their restoration. This is largely because leaching to streams of elements temporarily stored in living foliage begins shortly after leaf fall in the autumn of the year. Lightning strikes that release nitrogen from the atmosphere and accompanying rainfall that washes it to the ground cannot maintain the level of this essential nutrient for maximizing growth of these trees on these sites. Erosion, and with it the transfer of nutrients, plays a major role in maintaining nutrient levels adequate for broadleaf trees in bottomland biomes.

Figure 4.17 Overcup oaks seeded-in on the banks of this small oxbow lake prior to the river changing its course and thus creating the lake. Great numbers of seedlings appeared under these parent trees following a bumper seed crop and a spring and summer without rain. The following winter, after a month of high water on the site, all the seedlings had died.

Species and Physiographic Relationships

Forest vegetation types relate directly to physiographic conditions. Sweetgum and water oak trees capture many first bottoms. White and red oaks prevail on first bottom ridges and on terraces, while the hackberry–elm–ash type occurs on low ridges, flats, and sloughs in the first bottoms. Overcup oak and bitter pecan often seed-in together on poorly drained flats typically characterized by tightly compacted clay soils.

On new land formed by sand deposits at a river's edge, called fronts, the pioneer eastern cottonwood makes phenomenal growth. Sometimes this prolific seeder captures old fields recently abandoned from agriculture where the land is a well-drained ridge in a first bottom. Black willow, another pioneer species, also seeds-in to form dense stands in fronts. Cottonwood and willow together, fairly shade-tolerant trees, occasionally take over shallow swamps and deep sloughs in the first bottoms.

Tupelo gum trees grow among the baldcypress stems in the lowest, poorly drained flats. This combination, widely distributed throughout the region occurs both in small blocks and in extensive areas in the lower reaches of the estuaries of major streams.[30]

Animal Problems

Nutria, the large rodent introduced from South America in the 1930s to control water plants in the region' lakes, has become a nuisance. The animal pulls seedlings out of the ground to eat roots. Greatest damage occurs near flooded sites, for nutria prefer to carry their food to feed in the relative safety of the water.

Piney-woods' rooters, progeny of once-domestic pigs, consume the mast of several species of trees growing in the bottoms. Lean and long-snouted razorback hogs, sows, and pigs leave the wetlands to visit drier-site conifer stands to feast on seedling roots only after acorns and hickory nuts are gone from the lowlands. The mean (foresters are sometimes treed by them) hogs also dig up young, nutritionally fertilized cottonwood seedlings, perhaps for the more succulent and nutri-

Figure 4.18 New land forms along river banks throughout the South, forming sites for establishing willow and cottonwood trees. The latter species had seeded-in earlier on the left bank.

tious roots or perhaps for the salty savor of the chemical. Fried down, these razorback boars hardly yield a pound of lard, as some suggest. The meat tastes of the diet; turpentine if of pine roots and more hickory-flavored otherwise.

Cattle escape to river bottoms, there to trample some reproduction, browse advanced regeneration, and cause streambank erosion. On the other hand, the small indentations in the ground made by cattle hooves provide favorable microsites for seed germination and early seedling vigor. Moisture necessary for seeds to sprout collects in the footprints, while the weight and movement of the animals shred competing ground cover. Sometimes cattle get trapped in the soft soil—especially so in border areas of reed swamps where man and beast quickly sink to the knees in soft, loose organic matter or clayey mineral soil. Quick sands, occurring here and there in the South, support no trees; these grassy marshes holding in their grasp animal intruders.

Beaver damage in bottoms is an increasing source of butt log decay, as well as contributing to changing land hydrology. Partial girdling results in a wound subject to attack by decay-causing fungi. Such decay may be as deep as 2 inches after 6 years. The damage is most severe in ash and sweetgum. Heavy beaver activity may significantly alter land hydrology over significant acreages.

Other Problems

The more serious insects affecting bottomland trees are forest tent caterpillars. These defoliate tupelo, blackgum, sweetgum, willow oak, overcup oak, and river birch. Larvae spin cocoons in early May; moths are in flight two weeks later; defoliated trees may put out new, but smaller and lesser, foliage by June. An unknown fungus, a virus, or fly parasites may stop the outbreaks.[31]

Fire running through bottomlands may promote the spread of buckvine and honeysuckle. The problem becomes severe where stands are sufficiently sparse to permit light to penetrate the canopy.

The increase in soil moisture that follows harvests or natural death of stands of trees increases the danger of windthrow. The rise in ground water levels coverts flats and sloughs to brushy swamps. Inundation also affect to some degree water absorption and nutrient adsorption, transpiration, water movement within the trees and soil, the amount and kind of chemicals and organic matter in the water, microbes, algae, and chemical and physical properties of the soil. These, in turn, influence the tolerance of trees to submergence. And this, in its turn, influences the amount of free oxygen available to plants. It is this oxygen deficiency or its corresponding carbon dioxide toxicity which detrimentally influences seed germination, seedling survival, and tree growth.[3]

Figure 4.19 Cottonwood trees on new land. As new land formed in this river bottom, cottonwood and willow trees promptly seeded-in, holding the sandy soil in place. In time, other more-demanding species encroach as the short-lived pioneer vegetation passes from the site.

Free oxygen is considered the limiting factor in the germination of bottomland hardwood seeds in flooded sites. Except for siltation, which covers seeds too deeply, flooded bottomlands for up to one month do not appear to reduce germinative capacity.[32] Even if bottomland tree seeds germinate while immersed in water, establishment of seedlings is unlikely unless the immersing water recedes before the seedlings perished from other causes.

The amount of light reaching the forest floor also influences germination. It is more favorable for river birch, sycamore, and American elm under conditions of full sunlight than under crown canopies. In contrast, red maple, winged elm, and alder germinate best in deep litter and under low light intensity, accounting for these less-desirable species outnumbering favorable ones where litter is deep and ground vegetation dense. New land that is regenerated with cottonwoods and subsequently invaded by weed trees is an exception to this generality.

In ponded areas exposed to sunlight after a rain, the rising temperature increases respiration and the activity of microorganisms, resulting in oxygen deficiency and carbon dioxide toxicity. Root-growth ceases when oxygen levels diminish to 0.5% in the gas around roots, but top growth then continues, possibly accompanied by toxic accumulations of iron. Flooding might also cause cessation of downward movement of carbohydrates and auxins. The accumulation of carbohydrates and hormones at the water line possibly accounting for adventitious rooting of flooded trees. Sprouting from root collars indicates that death of roots has not preceded top death and, therefore, root-kill by flooding was not responsible for tree necrosis. [33]

In the bottomlands of Louisiana and Texas, Chinese tallowtree has become a heavy invader, especially following stand-destroying storms. Infusion of this exotic (imported as a potential source of paint dryer) has dramatically reduced species diversity.

Figure 4.20 Pure black willow grove of older trees on new land formed when sand washed from one point-bar to another. The site had been foraged by cattle and browsed by deer, keeping the undergrowth checked. (USDA Forest Service photo)

EASTERN COTTONWOOD

As the meandering of a river cuts its bank, depositing new land on a point-bar downstream, cottonwood readily seeds in to produce dense stands. Flood waters deposit additional coarse sediments near the river's bank, building high, well-drained ridges or natural levees. Inundation then covers the cottonwood seedlings with water or, at least, covers the soil. Roots die when soil is soaked for over a month, but extensive adventitious roots quickly develop from dormant buds on the main stem. Terminal and diameter growth resume after flooding water subsides. Trees have survived when as much as 3 feet of silt has been deposited, a new root system developing just under the new surface of the ground.[34]Growth of cottonwood trees depends upon the texture of the soil and its internal drainage. These true poplars grow best where internal drainage is rapid, the soils inherently moist, and the soil texture fine silt or clay. Growth is least on dry sands and on soils with poor internal drainage.[35]

.

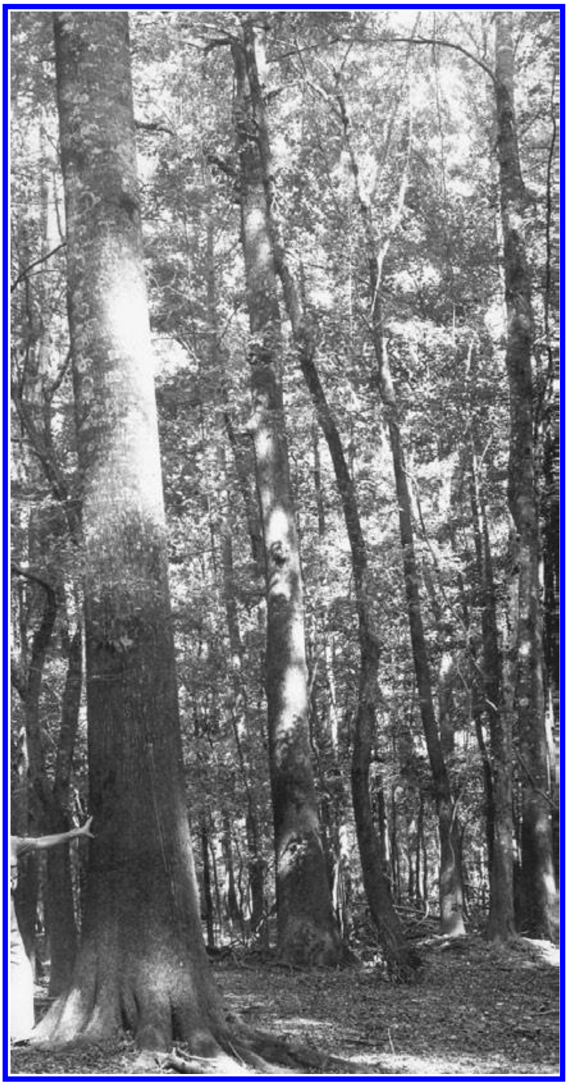

Figure 4.21 Major wet-site forest cover types of the South are flood plains of major rivers, swamps, and creek and stream bottoms, the latter interspersed with upland pine–hardwood sites. Here, cherrybark oaks grow on a flood plain.

The life cycle of the cottonwood tree begins in the spring when male and female flowers appear on separate trees as young as 10 years of age. This dioecious (from the Greek, meaning two houses) flower arrangement encourages cross-pollination, in contrast to the monoecious (one house) physiology of many tree species. Swiftly the seeds mature, most of them falling between April and July. Apart from an occasional freeze, following the breaking of dormancy of flower buds, that destroy the crop, abundant seed crops occur every year. Wind and water carry the seeds. Short periods of flooding seem beneficial to germination: annual floods deposit a fresh layer of silt on which the white masses of the cottony seeds settle out to germinate. Favorable soil moisture must prevail, for seeds remain viable under dry conditions for but a few days. Many seeds will not be viable, after even a few hours, if dry. These trees are relatively drought-resistant once the seedlings are established. Many thousands of seedlings per acre will appear. Hard, blowing rain takes its toll of many; as does the hot sun. Few other trees or shrubs will encroach on new land to compete with the cottonwoods. The exception is black willow, but even that hydric tree is crowded out by the

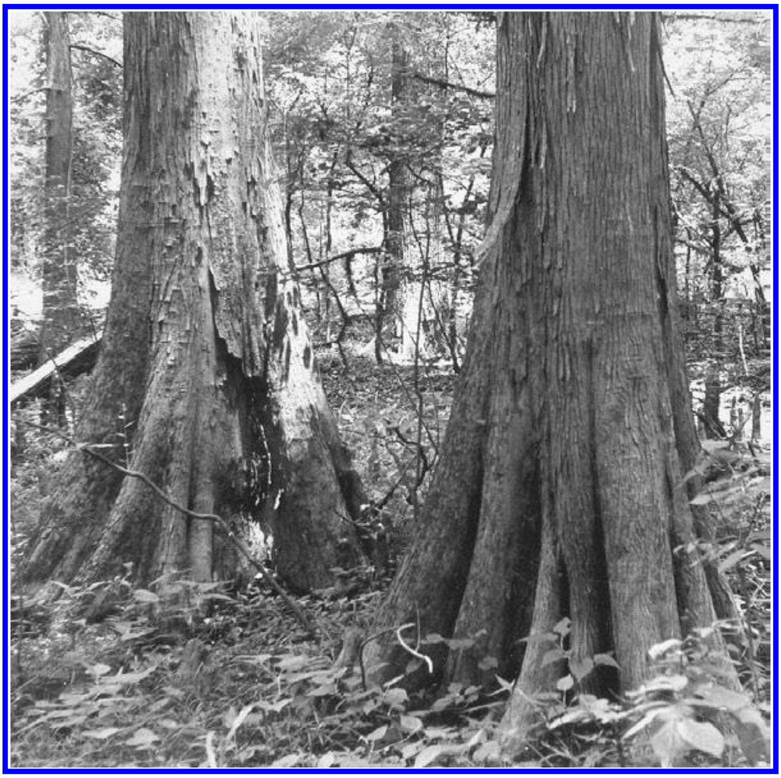

Figure 4.22 Swamp white oaks display buttressed trunks in river bottoms. Intermittent high water causes this fluting, providing support in times of high winds for stems growing in saturated soils. (authors' collection)

cottonwoods. Both are highly intolerant of shade, seldom persisting under even sparse stands of trees.

OAKS

Water oak generally occurs in dense patches in temporary shallow pools beneath closed canopies. In such situations, natural regeneration occurs. Standing and moving water prevent reproduction establishment whenever seedlings are inundated for more than several weeks during the growing season. If submergence takes place prior to the growing season, seedlings remain dormant longer than usual in the spring and do not begin to make height growth until after water recedes. Regeneration usually fails if floods during the growing season occur too frequently for seedlings to have a chance between periods of high water to grow above the average depth of flooding.

Mesic oak seedlings rarely survive the low soil aeration conditions of inundation. Leaves of cherrybark oak and pin oak seedlings become chlorotic and roots die when the soil is saturated for several weeks. In this situation roots are not replaced through adventitious buds, and those that do form after excess water drains are weekly developed. One seldom finds white, cherrybark, and pin oaks on sites frequently flooded.[36]

In the upper reaches of the Delta, pin oak reproduction increases as overstories become heavier until basal areas reach 100 sq. ft. per acre. Thus harvest and mortality openings retard regeneration of that species while encouraging the entrance of more desirable broadleaf trees.

Fire wounds are the most important cause of decay in bottomland oaks. Among the infecting fungi are species of *Polyporus, Corticium, Stereum, Poria,* and *Fomes*. Rots not infrequently extend

Figure 4.23 Vigor of bottomland hardwoods relates to site quality. Nuttall oak vigor in the Mississippi Delta can be ascertained by observing the bark. The stem on the left shows poor vigor; on the right, high vigor. (USDA Forest Service photo)

2 feet above the top of a hollow made by fire or the bulge in the trunk. Heart rot, caused by *Poria spiculosa*, is extensive in these forests, probably infecting more than 1% of the oaks and hickories. Small, roughly circular cankers on boles with traces of a branch stub remaining in the usually depressed center indicate the presence of the brown decay. Fruiting bodies seem to occur only on dead wood in contact with the ground. Well established infections exhibit brown fungus matter readily available when the suspected tree branch is cut. Length of rot increases about 10 inches a year. Age of the infection can be readily determined by counting rings on the callus tissue formed around the infected branch trace.

Polyporus hispidus results in elongated swollen areas surrounding dead depressions or cankers which, upon recurrent killing of bark and cambium and renewed callus folds, give spindle-shaped swellings. Yellowish-brown to rusty-red conks 2 inches or more in width, spongy, hairy, and without a stalk, occur on surfaces of well-developed cankers in fall or winter. Drying to a rigid mass, the conks fall to the ground by spring. In summary, the many canker-forming fungi attacking hardwoods

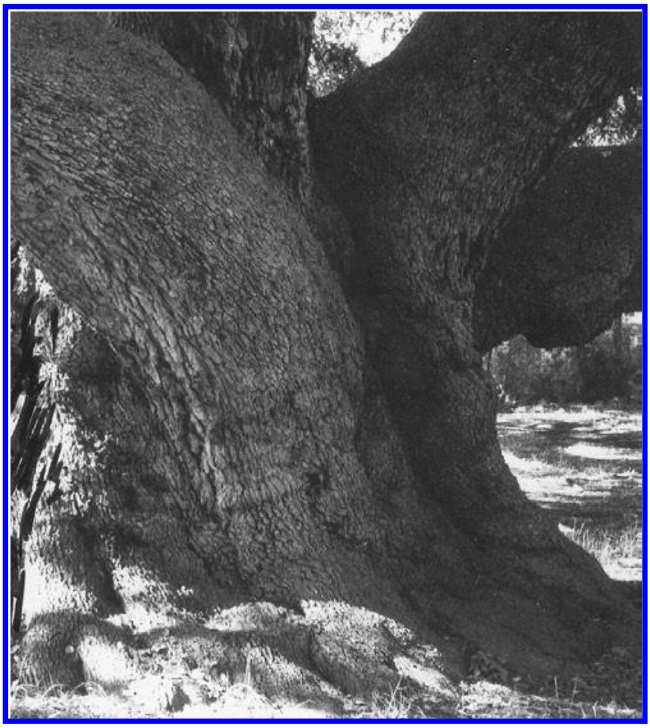

Figure 4.24 Live oak growing in a second bottom. The species appears in many forms throughout the South. This specimen is typical of those used by ship-builders for knees in the days of the tall-masted ships. Scouts sent by the yards in the Northeast searched the river bottoms for stems that fit the naval architect's drawings, cut and hewed the timbers, and skidded them to a river's edge for shipment north. (Texas Forest Service photo)

enter through stubs of dead branches, work down the heartwood, and spread from the point of entry to kill the cambium.

SWEETGUM

Second-growth sweetgum in alluvial soils of the South usually occurs in fully stocked, relatively pure, even-aged stands. If seeds are available, stands develop within 10 years of clearcutting. Trees of this species exhibit vigor: those of high vigor exceed 3 inches dbh growth in 10 years, those of medium vigor between 2 and 3 inches, while low vigor stems have less than a 2-inch increment during the period. These vigor classes, however, apply only to trees 16 inches dbh or greater. Vigor can also be ascertained by bark color and fissures and by crown form.

The sweetgum blight of unknown origin was first noted in 1950, a drought year. The first visible indication appears in late summer when leaves on some branches prematurely develop fall coloration. Crowns then thin gradually from the top down. Some buds do not open; others produce small chlorotic foliage, the tree dying a year or more after symptoms first appear. Sometimes the dieback is arrested, and trees appear healthy except for the dead top. As much as 90% of the fine feeder roots in the surface layer of the soil die on blighted trees, while larger roots remain healthy in appearance. Cutting into the wood of diseased branches reveals irregular tan or dark brown streaks in the white sapwood. The blight is more severe on slack-water soils and less on natural levees.[37] Loose soils which drain readily and retain less water seem most susceptible to the blight.

Sweetgum is also subject to another malady of unknown origin and as yet without a name. Although trees are not killed, lumber is degraded as the bark becomes encased within the stems, and bumps and ridges of callus tissue form over the lesions. Young stands seem most vulnerable.[38]

Figure 4.25 Sweetgum blight, a dieback of unknown cause in southern river bottoms. Both crowns and roots appear to be infected. An environmental insult, rather than a fungus, is suspected. (authors' collection)

The cambium of sweetgum can be heated to a lethal temperature of 140˚F, much more rapidly than for the southern pines and baldcypress. This points up the necessity for fire exclusion in stands of this species.

WATER TUPELO

Water tupelo, or tupelo gum, survives on swampy and poorly drained land, provided water recedes by the time the growing season begins and first-year height growth is above the growing season water level of the succeeding year. Under continuous inundation from winter on, seedlings and young saplings maintain dormancy into July and then proceed to grow normally. Because of butt swell, dbh measurements are meaningless: a stand of 200 $ft.^2$ per acre above the butt swell would exceed 1000 $ft.^2$ if measured at breast height. Butt swell "bottlenecks" increase with wetness of the site, tree size, and tree age.

Associated with water tupelo are baldcypress and swamp tupelo trees. In deeper swamps, swamp tupelo is absent, indicating that depth of water is a limiting factor in the distribution of the species. Swamp tupelo, but not water tupelo, occurs in the Okefenokee Swamp and in deep bogs of the Louisiana and Tennessee Delta. Species occurrence reflects the secondary distinctions within the Coastal Plain: muck swamps, small estuaries, and piney-woods tributary stream bottoms. In those locales, water tupelo, if present, inhabits the fresh, moving water sites along drainage courses and alluvial swamps. The two species meet along the margins of moving water swamps, in some minor stream bottoms on their respected preferred sites, and in the smallest estuaries. Standing water in water tupelo swamps is generally deeper, though of shorter duration, than in the swamp tupelo sites.

Figure 4.26 Quality hardwoods in a southern swamp. These tupelo gum trees, like many other broadleaf species growing in wet sites, developed buttressed bases. The site was free of standing water when the seeds fell and germinated and continued to be so until the seedlings were established, probably several years. (USDA Forest Service photo)

Seeds of water tupelo retain viability for up to 14 months of submergence. This is significant, for southern swamps supporting this species are typically flooded throughout the winter and spring months, occasionally remaining under water for an entire year. Thus, water tupelo seeds are able to germinate when the flood waters have drained, while the seeds of competing species, especially baldcypress, have succumbed.

AMERICAN SYCAMORE

Early height growth of American sycamore is very rapid, tapering off at about age 30. Soils on which the trees grow naturally range from loamy sand to heavy clay loam. Surface drainage varies from poor to very good. Thus, once established, trees of this species endure. Typical cottonwood sites and some friable and loose soils too dry for cottonwood are also locales in which one finds this species. Practically any condition of temperature and light intensity of seedbeds under stands of sycamore trees is expected to favor germination of American elm to the exclusion of the sycamore. However, sycamore seedlings may be as tolerant as elm; in that case, the ecological transition to

Figure 4.27 Virgin forests are often not pristine wilderness. This southern bottomland site has never been harvested. Two companies claimed ownership; to avoid the consequences of litigation, the site was essentially abandoned.

elms must be due to another factor. Temperature of the exposed soil at the time of seed germination may encourage elm over sycamore.[39] After establishment, invaders include boxelder, winged elm, hackberry, and sweet pecan. Later, epicormic branches develop, the number depending on light intensity which, in turn, depends on stand density.

We now consider the management of the southern forest. This involves *silviculture*, "The art of growing trees in managed stands." This art is based on *silvic*s, the sciences basic to the practice of the art.

5 Establishing the Forest*

Our concern in this chapter is reforestation, the establishment of forest trees on lands that earlier had supported stands of arboreal vegetation. Afforestation, the conversion to woodlands of sites that never produced trees, is also considered. In the South, however, afforestation would be limited to the dunes along shore lines and the calcareous black belts of Alabama and Texas, but the latter locales are too valuable for agriculture to warrant the effort. Sand dunes do receive some afforestation. Some may suggest that the reclamation of surface-mined lands, severely eroded sites, and the acid-drenched Copper Basin of southeastern Tennessee and northern Georgia calls for afforestation, but these are tracts that once supported fine stands of timber.

Figure 5.1 Essentially, afforestation was required following the 1880–1930s cut-and-get-out harvesting practices across the South from Virginia to Texas. Vast acreages without a seed source were subsequently covered by weedy vegetation, while artificial regeneration was necessary on millions of acres. Restocking of many sites such as this awaited the coming of foresters to manage the reclamation of these lands to highly productive forests.

Site Indexing

The relative value of land for reforestation depends on its site index (SI), a measure of the average total height of the dominant and codominant trees in a stand at 50 years of age. While this definition holds true for southern forest stands, several additional considerations are implied—original SI curves were determined from measurements in pure, even-aged, and unmanaged second-growth stands. A hypsometer to measure height and an increment borer for determining age by counting the annual growth rings provide the necessary field tools. Then, for trees of any age, SI can be read from curves (Figure 5.2). If an age other than 50 years is employed in calculating the shape of the curves, the designated age must be noted; e.g., SI(30) for the average total height at 30 years

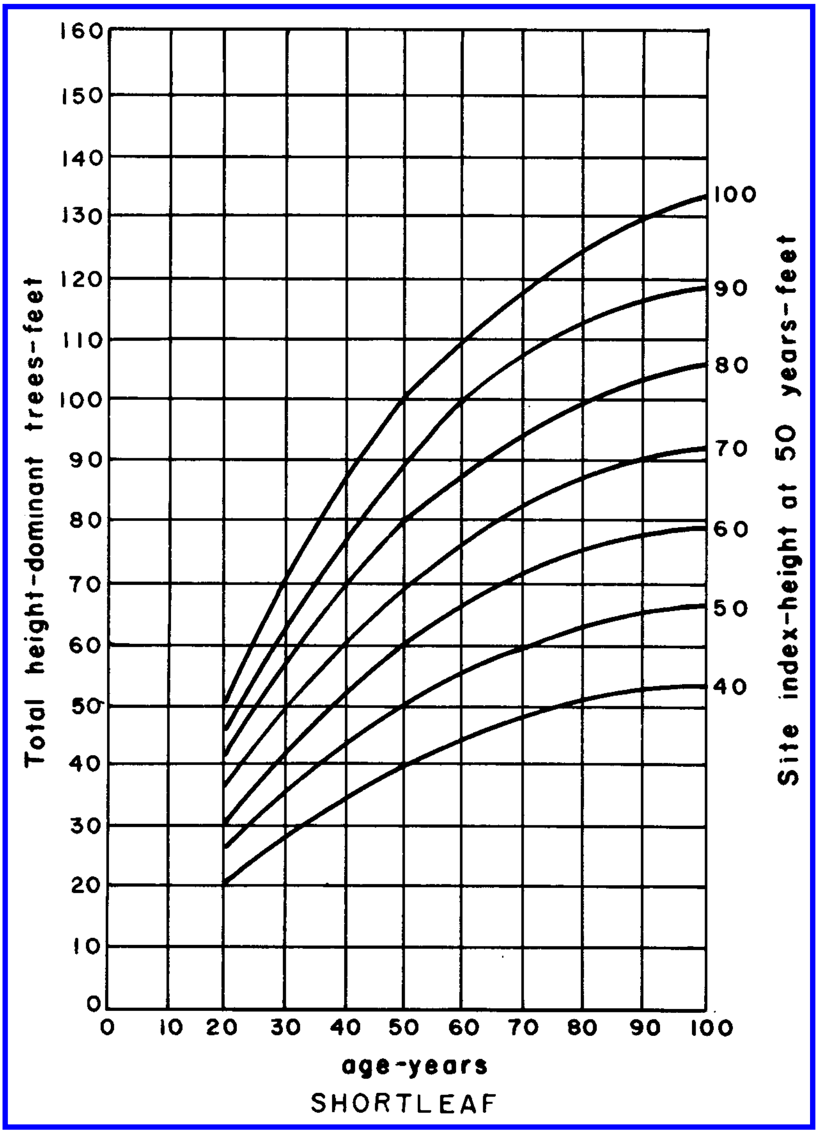

Figure 5.2 Site index curves for shortleaf pine. Most species of economic value now have site index curves that enable the determination of land capability for that species. In this example, a 60-year-old stand in which the dominant and codominant trees are 75 feet tall is on land having a site index of 69. Better sites, such as those in coves, may tally over 90; poor, denuded and eroded lands less than 50.

of age for the dominant and codominant trees in a stand. Site Quality can be used for plantations where all of the trees are averaged at a certain height.

Where trees sufficiently large are not available for determining the site index, which requires the counting of annual growth rings, another method is needed for determining the capacity of land to produce commercial forests. To establish these curves, graduate students of T.S. Coile, a Duke University professor, fanned out across the South to sample the soils in many kinds of forests, relate edaphic qualities to land productivity, and arrive at appropriate equations. For instance, for longleaf pine in the western portion of its range, the significant criteria appeared to be soil depth to the least permeable horizon (D) and the average rainfall (R) of the area for January through June. Thus, the regression equation: Log SI = 1.8697 + 0.0002636(R) – 0.006734(D). First published in 1953, before foresters had ready access to computers.) The equation was then converted to a simple table such as the following:

TABLE 5.1
Site Index of Longleaf Pine (Interpolated intermediate depths and rainfalls).

	Rainfall, January through June		
Depth to least permeable horizon (inches)	24-26	28-30	32-34
		Site Index	
0-5	74	74	75
11-15	73	76	78
21-25	73	77	82
31-35	72	79	85

Source: After McClurkin, 1953.

The least permeable layer may be hardpan or simply a silty layer underlying a loamy surface soil.[1]

For the Atlantic coastal plain from North Carolina to North Florida, SI for longleaf pine

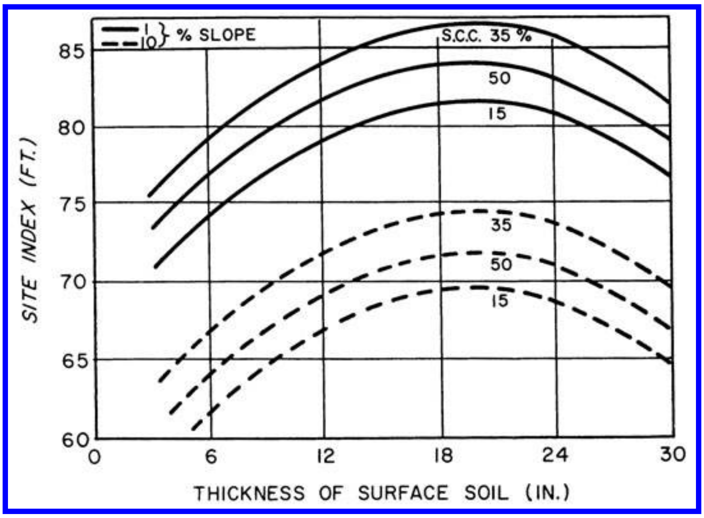

Figure 5.3 Shortleaf pine site index for treeless soils. Where no trees exist for which to measure height and age, curves showing variation in subsoil clay content, steepness of slope, and surface soil depth provide approximations.

depended mostly on the subsoil, with the SI increasing as subsoil texture becomes finer. Here, theoretically, moisture equivalent (a readily duplicated laboratory measure that approximates the percent of the weight of water 24 hours after a soaking rain in a soil sample) rather than soil texture, is the principal criterion involved in establishing SI. The direct relationship of moisture and texture and the convenience of textural classification by simply feeling a pinch of soil with the fingers makes the use of texture a practical tool for the practicing forester. Moisture equivalent plays a role because subsoils furnish water, the amount depending on the proportion of silt and clay in the

Figure 5.4 Plantations of slash pine were established specifically to provide for naval stores operations, beginning in the 1930s. Highest-quality sites, in this case SI 80, were chosen. The 23-year-old stand had been periodically prescribed burned to reduce the fire hazard and to facilitate gum collection from the chipped faces of the trees. (authors' collection)

horizon sampled. Thus, a table listing SI for locales with a sand subsoil is 64; for a sandy clay, 72; and for a heavy clay, 77.

For longleaf pine in the southeastern coastal plain, SI improves with increasing latitude and with depth to mottling in the soil. Mottling occurs in poorly drained soil as a result of oxidation, hydration, and reduction of the iron elements that coat the particles of soil. The three chemical reactions take place as oxygen becomes available or diminishes with rising and lowering amounts of water in the soil. Rust red from iron oxidation, yellow from hydration, and bluish-gray from reduction of the ferrous coatings of soil particles mix to give the mottled colors.

For slash pine, SI varies from 75 to 90, with the quality of the site based solely on soil texture, the wide range likely due to soil drainage which, in turn, varies with the proportion of sand, silt, and clay in the soil. SI along creeks and in flatwoods is higher than at more-elevated situations where rainwater drains rapidly.

Figure 5.5 On difficult planting sites like this, erosion control measures, including mulching, might be required. Even unaided, some shortleaf pines and broadleaf cover have become established.

Shortleaf pine SI also relates to soil depth and consistency of subsoil and these, in turn, depend on soil moisture and drainage. A very friable subsoil that begins six inches below the surface of the soil has an SI of 66, a very plastic subsoil at the same depth is charted at 48, while a very friable subsoil 18 inches below the land's surface has an SI of 71.[2]

Fastest growth for shortleaf pine takes place in the deepest surface soil, the most friable subsoil, and where the subsoil clay content measures less than 20%. Slope also influences growth rate; seedlings grow best on level land. Some species' drought resistance has been attributed to their capacity to absorb water when moisture is limited, to retain moisture in its needles during drought, and to maintain high solute concentrations in the foliage when recovering from drought.[3] Although SI theoretically is not related to stocking density, spacing for loblolly pine in plantations showed a gain of 6 to 8% for trees planted 12x15 feet over those at 10-foot spacing.[4]

Soils formed from the same parent materials, developed under similar conditions, and supporting similar vegetation, have SIs for loblolly pines that depend on soil erodability. SI decreases as much as 10 units with each increasing soil erosion class: class 0, no erosion; class 1, less than 25% of a horizon removed; class 2, 25 to 50% of a horizon removed; class 3, 50 to 75% of a horizon removed; class 4, more than 75% of a horizon removed. Under noneroded virgin soil conditions, SI measures between 90 and 105, and about 50 if most of the surface layer has eroded away.

Multiple Regression

Multiple Regression techniques for relating certain soil properties with the rate of height growth in the Piedmont province found SI for loblolly pine to range from 32 on subsoil described as very plastic and within 2 inches of the surface soil to 91 for very friable subsoil under 18 inches of surface soil. In the Atlantic and Gulf Coastal plains, site potential increases with progressively poorer drainage, irrespective of subsoil texture. However, with drainage constant, SI increases as subsoil becomes finer textured. Depth to the subsoil influences productivity as much as 30 SI units in progressing from 6 to 42 inches.[5]

TABLE 5.2
Excerpts of a Coile Soil-Site Table for Loblolly Pine.

Texture of subsoil	Surface Drainage of Land	Site index at various depths of subsoil: 6 inches	18 inches	30 inches	42 inches
sandy, loamy sand	Good	80	85	85	90
	Imperfect	90	90	90	95
	Poor	90	90	95	95
loam, clay loam, sandy clay, light clay	Good	85	90	100	105
	Imperfect	90	95	105	110
	Poor	90	100	105	115
silty clay loam silt loam	Good	90	95	105	115
	Imperfect	90	100	110	120
	Poor	95	105	115	125

Source: Adapted from Coile (1952) and Walker (1958)

Philip Wakeley, a long-time forest researcher in the South, developed the five-year intercept method for ascertaining future height growth of southern pines. The technique assumes that, once they reach breast height, trees of a given species continue growing at comparable rates for the following five years. It also assumes this is so for a wide range of plantation spacing and on comparable sites.

Variation by Species

SI varies dramatically by species. Thus, slash pine grows faster than longleaf pine for the first 25 years on most sites. Similarly, Virginia pine has a higher SI rating than shortleaf pine where the two species are associated. Typical SI ratings for other southern trees growing on similar sites range like this: Atlantic white-cedar, 45 to 75; Virginia pine, 65 to 77; pond pine, 31 to 76; white pine, 80 to 85 in the Appalachians; sweetgum in the bottomlands, 80 to 120; oaks (white and black) in the Piedmont, 70; loblolly pine, 50 to 120; and chestnut oak in the Southern Appalachian Mountains, 58.

Plantation Establishment

Artificial regeneration usually involves planting seedlings produced in intensively managed nurseries. At state, federal, and private nurseries, cones and hardwood fruits are dried, the seeds are extracted (usually by drying), and planted in beds.

Planting is done where and when natural seeding is not available to hasten stand regeneration, to introduce genetically superior trees, and to more likely assure even stocking of the new forest. Planting should be done promptly on harvest of the earlier stand or on seedbed preparation by machinery or by fire, lest broadleaf brush and undesirable hardwood sprouts encroach. Even with prompt planting of healthy 1-year-old nursery stock, protection from undesirable hardwood competition may be essential.[6]

Figure 5.6 Believed to be the oldest pine tree plantation in the South, these loblolly and shortleaf pines were lifted from nearby woods in 1873. The seedlings, spaced 20x20 feet, by age 90 years had grown to an average dbh of 18 inches (loblolly) and 17 inches (shortleaf) and had produced 21,000 board feet per acre.

SPECIES TO PLANT

SOUTHERN PINES

Species for reforestation may not be those that covered the land prior to timber harvest or land cultivation. Slash and loblolly pines often replace longleaf pine in the lower Coastal Plain and loblolly pine replaces pond pine in the pocosins of organic soils along the Atlantic coast. For the region, loblolly and slash pines compose the greatest number of seedlings utilized for reestablishing forests. High gum-yield slash pine seedlings are available for naval stores plantations.

Free-to-grow loblolly pine seedlings in the Georgia Piedmont can be expected to be eight feet tall after the fifth growing season, outgrowing even the rapidly developing slash pines in that province. In the North Carolina segment of the Piedmont, loblolly pines outgrow shortleaf and white pines. The species has shown promise as a replacement for the xeric scrub oaks in the beach-like sand hills of West Florida, in the Ozark and Ouachita mountains, and a bit northwest of its natural range in South Carolina. Loblolly pine has been found to adapt to the mountains of North Carolina, frequently replacing shortleaf pine in zones where the latter is the only native pine, especially if littleleaf disease of the shortleaf pine is prevalent. In bottomland sites, the species also produces superior yields to planted sycamore.[7]

Though the littleleaf malady is not a problem in the aeolian silts of northern Mississippi, where shortleaf pine is the only native pine, loblolly pine is favored there. Erosion control is the primary objective in reclaiming these fragile sites following abandonment from cotton farming. The longer

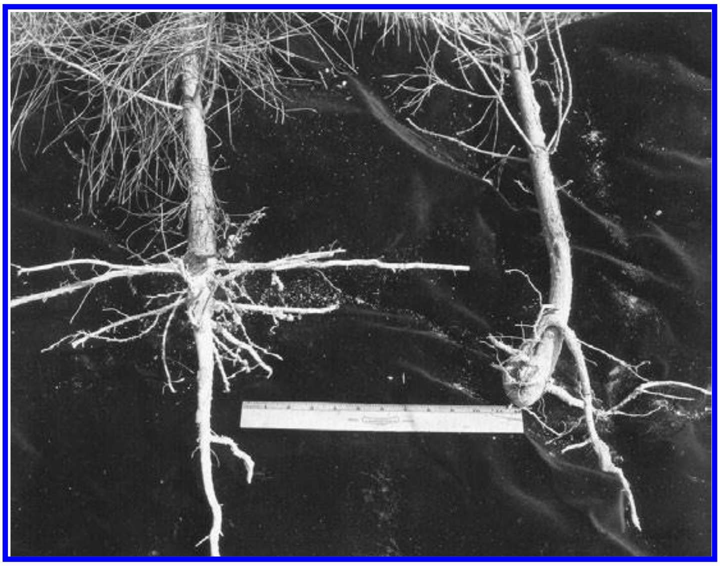

Figure 5.7 Planting practices affect root placement and subsequent survival and growth. The severely U-rooted seedling on the right will likely be subjected to early mortality and later windthrow. (USDA Forest Service photo)

needles of loblolly pine remain in place better on the ground, sheltering the surface of the soil from the impacting force of raindrops, and therefore lessening surface runoff and its accompanying sheet erosion.

Needle litter also aids in developing a new humus layer. Because of a more constant temperature under the canopy than in the open, soil animals multiply rapidly, working the soil and slowly incorporating the organic matter into the mineral horizon. Almost every property of the soil in these impoverished sites is improved by the introduction of the pines. Organic matter, nitrogen, and calcium levels are higher, soil pH is slightly raised, depth of the rejuvenated surface horizon greater, water infiltration more rapid, and pore volume—containing air and moisture—greater. Here, the deep, rich silty soil produces stands ready for thinning a decade after planting. While such rapid growth requires removal of competing understory and overstory hardwoods, controlling that vegetation often results in an increase in annual plants that deplete moisture in the surface foot of soil. In these wind-blown deposits of brown earth in the Mississippi bluff hills, loblolly pines typically grow 30 feet tall and six inches dbh in 15 years.

In northern Alabama, loblolly pine is a preferred species for afforesting dry site spoil banks that result from mining operations. In the Alabama hills, height growth approaches two feet per year, a little less than for sycamore, the recommended species for adjacent wetlands. On such acidic sites, applications to the planting hole of cottonseed meal and ground tobacco stems rich in nutrients improve growth. In East Texas, land reclamation following surface mining also effectively utilizes loblolly pine. There, the spoil from all levels is mixed with the overburden and replaced in the mined-out trench.

As loblolly pine is introduced into the once-predominant shortleaf pine forest of the Ouachita Mountains, so now shortleaf pines are planted to the north in the Ozarks of Missouri, where a variety of broadleaf trees naturally predominates. Loblolly and slash pines planted in the Post-Oak Belt of Texas make height growth comparable to trees planted in the pines.[8]

Virginia pine is also favored for old fields and eroded sites lacking a seed source. This tree is now planted for its value for wood pulp, where two decades earlier it was considered a weed. In eastern Tennessee, it grows as well as other southern pines in their early years on a variety of sites.

Figure 5.8 Longleaf-pine seedling treatment. Clipping the foliage of nursery-grown stock to a 5-inch length before planting increases first-year survival by 10 to 30%. (USDA Forest Service photo)

Pond pine in the swamps does well when planted on berms or ridges of a plow furrow. The bottoms of the furrows are too wet to sustain optimum growth for seedlings planted there. Landowners often replace the serotinous pond pine with more valuable loblolly and slash pines, even though this requires extensive site preparation that includes drainage.

Eastern Redcedar

Eastern redcedar has long been used for the manufacture of cedar chests and closet paneling because of the belief that the odor of the wood discourages moth larvae from feeding on woolen clothes. Hence, an interest remains in reestablishing forest stands of this species in the South. (However, it is not the wood's odor, but the air-tightness of a well-built chest that protects garments from insects.) Small trees are harvested for fence posts, as the interior heartwood is resistant to decay when in contact with mineral soil. Some stems are harvested for oil extraction, when the aromatic compound is shipped to France for the perfume industry.

One of the oldest reforestation efforts in the South concerns this species in the Ozark highlands. In 1902, seedlings were lifted from a nearby glade and planted at a density of 1200 per acre. By

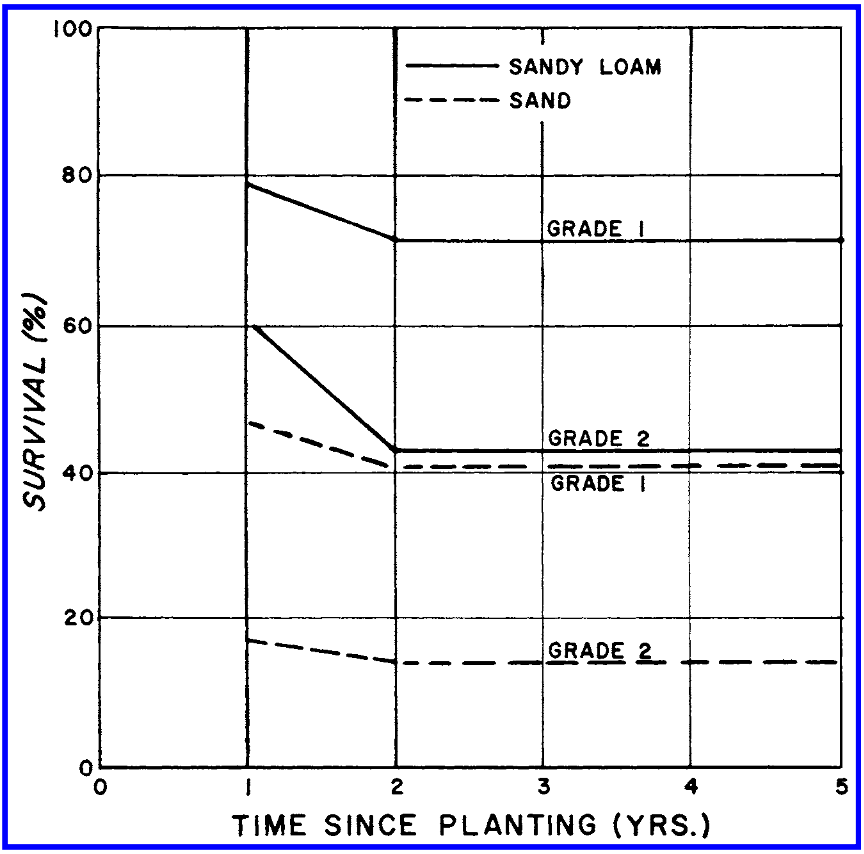

Figure 5.9 Morphological quality of longleaf pine seedlings is important for survival of outplanted seedlings, as the soil has but minimal influence. (USDA Forest Service, after Shipman, 1960)

age 11, the plantation provided fence posts; by age 44, the trees averaged only 6.6 inches dbh; but in the lower 32 feet of the boles there were almost 6000 posts per acre. On shallow soils—those less than 12 inches deep—only fence posts should be anticipated from plantation establishment.[9]

Eastern redcedar provides better soil amelioration than loblolly pine in the aeolian silts of northern Mississippi, where growth sometimes exceeds that of loblolly pine and deep soils produce sawlog-size trees. Those planted in loess material more than two feet deep average more than 50 feet tall in 50 years. (Aging redcedar by increment coring may be undependable; repeated initiation of cambial activity during the growing season in some years results in more than one growth ring.

White Pine

White pine plantations usually succeed on old fields, where annual height growth averages 30 inches after a couple of years. Stems attacked by white pine weevils suffer greatly in height growth as lateral branches take over the terminal position, leaving a crook in the main stem. The weevils do not attack all trees, which enables a satisfactory number of stems that have escaped infestation to be retained as crop trees. Attacks cease when trees reach about 15 feet tall.

Conversion of derelict stands of various species to white pine is appropriate, particularly along ridges and in upland areas of dense jungles of rhododendron and mountain laurel. Some foresters recommend mixing this species with others, such as yellow-poplar and shortleaf pine, to diminish the risk of serious injury or mortality by insects, disease, drought, and storm. Variation in tolerance

Figure 5.10 Fertilization with a complete N-P-K formulation stimulates growth, even of leguminous black locust trees, the roots of which display nodules that contain nitrogen-fixing bacteria. The replaced soil in this site, reclaimed following surface mining, now provides for vigorous growth of the trees. (Texas Utilities photo)

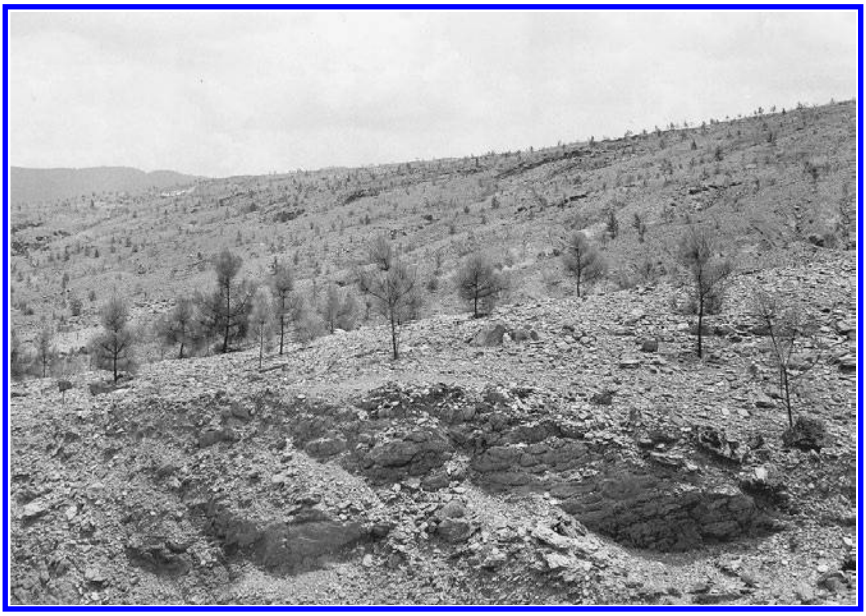

Figure 5.11 Two years after hand-planting, these loblolly pines survive on a badly abused gravelly chert site. (authors' collection)

to shade among these species suggests small checkerboard block plantings rather than random mixing or row planting. Otherwise, early overtopping of the slower-starting white pine occurs, necessitating a silvicultural release of the higher-value trees. Foresters warn against planting this

Figure 5.12 Two-year-old pitch pine stock was planted in the barren hills of the Copper Basin in Tennessee. Twenty-five years later, the trees in this perimeter of the 50-plus (some claim much more) square-mile area of the highly acidic soil appear healthy. (authors' collection)

Figure 5.13 This abused site was reclaimed with pitch pine seedlings. Fertilization with ammonium nitrate or phosphate aids in successful establishment of the seedlings.

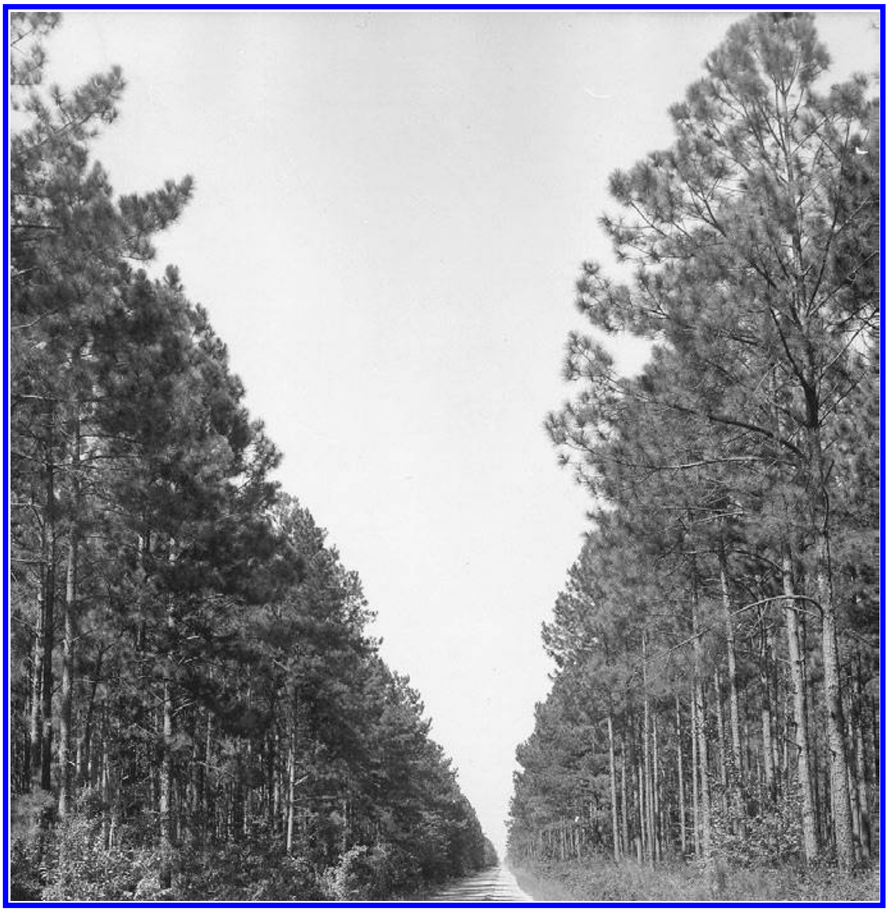

Figure 5.14 A plantation of loblolly pine (left of the road) and slash pine (right) in an organically rich Carolina bay site. The trees were planted following logging of pond pine, burning the residual material and draining the land. Growth rates for the species were similar. Draining would likely now be prohibited by wet-site maintenance regulations. (North Carolina University photo)

species in poorly drained bottomlands. In spite of the allelopath juglone exuded by black walnut, this species and white pine have been successfully planted together.[10]

BALDCYPRESS

For very wet sites, baldcypress and its pondcypress variety are planted in the hopes of reestablishing this valuable tree in the region. Nursery production is readily accomplished. One-year-old seedlings, 30 inches tall, are inserted into holes made in the ground below water level with sharpened broom sticks. Planters thread the stiff, long taproot into the holes, trusting that the root does not get intertwined with the tail of a water moccasin, so common in these swamps. (Only when peering beyond the hinged ivory fangs into the pure white throat of that reptile does one appreciate its other name, the cottonmouth moccasin.) Neither stem clipping to reduce transpiration nor deep planting improves survival or growth. Height growth ranges from 6 to more than 30 inches in the first year and 6 to 7 feet in four years. Trees average 12 inches dbh in 50 years, though the trunk will be almost all sapwood, rather than heartwood, so desirable for use where exposure to decay is probable.

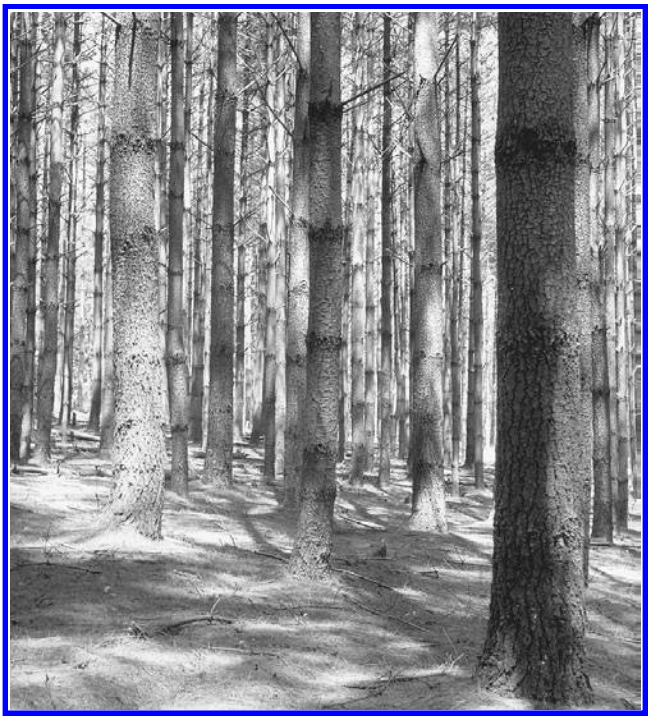

Figure 5.15 Planted white pine in an abandoned agricultural field in the southern Appalachians. Note the self-pruning habit of some of the trees, now a rare genetically inherited characteristic because the high-quality stems free of the knot-forming limbs were virtually eliminated in the logging of the virgin forest. Stems with this branching habit are sought in tree-improvement practices. (authors' collection)

Chemical repellents and wire cages might be effective in protecting seedlings from nutria, the rodent that destroys stands of newly planted seedlings.[11]

Christmas Trees

The introduction of Christmas trees into the United States is generally attributed to the Hessian soldiers, George Washington's antagonists during the American Revolution. These warriors from Europe fighting in the South would have been especially homesick, for few naturally grown trees —apart from the spruce and fir of the high elevations in the Appalachian Mountains. Hard pines are not full-crowned and eastern redcedar foliage is prickly and allergenic.

Marketing conifers from the North and West into the region by merchants ultimately encouraged foresters in the South to test various species for Yule-tree purposes. Among those tried, and at first found desirable, was Arizona cypress, which exuded a rich aroma and retained the bluish-green color of its smooth, miniature, scale-like leaves. Its form varies from genetically columnar to pyramidal and from tall and slim to short and squat. Excellent survival of planted stock encourages plantation establishment.

Even though the natural range of this species is in the dry mountains of the U.S. Southwest and Mexico, Arizona cypress demands favorable soil moisture when planted in the South. Deep soils of coves and lower slopes are preferred sites. Fire injures the succulent tissues of the branches and the trees are easily misshapen by soil waterlogging that encourages the main stems to lean and then to bend as they respond to the forces of gravity. Ice storms deform, weighing down branches and bending the main stem.[12]

Other problems, however, have discouraged intensive promotion of this true cypress (as opposed to baldcypress). The branches are weaker than most other Christmas-tree species and, hence, are unable to support ornaments. Also, the juniper blight, caused by a fungus, *Phomopsis juniperovora*, causes foliage of infected branches to turn brown and limbs to die. Pruning a branch leaves a hole in the otherwise naturally cone-shaped crown. Infection, proceeding from lower branches upward, may leave a third of the trees in a plantation worthless. Certain individuals appear resistant to the blight.[13]

Often confused with the blight is frost damage, which occurs after sudden drops in temperature cause needles to turn brown and trees to die. But frost damage can be identified by the false growth rings that develop in the spring following the cold period which, in turn, occurs after growth first begins.[14]

When trees are harvested, leaving stumps a few inches high and a single vigorous branch near the base, the branch turns upward, developing a new leader and eventually a new tree. Pruning as it grows will improve the shape of the crown.

Virginia pine has now captured the Christmas-tree market in the South. Trees planted at wide spacing provide access for several shearings required each growing season, for weed control, and for green pigment applications just prior to harvesting. The paint colors the foliage a dark green and provides a glue to aid needle retention.

Sand pine is also planted for Christmas trees. A “varnish stage” that appears in the spring causes resin-coated needles to become a fire hazard.

Broadleaf Trees[15]

Among the deciduous hardwoods utilized in reforestation in the moister sites are cottonwood and yellow-poplar, the latter especially in the Piedmont. Small landowners, anticipating significant income two or three decades hence, plant black walnut, North America’s highest-quality furniture wood.[16] Willow oak is planted for its pulp and energy biomass. Upland hardwoods planted in the South include northern red, black, southern red, chestnut, and bur oaks; white ash; and sweetgum. Sometimes checkerboard mixtures of several species, 9 to 25 trees of a single species to a block, rather than random mixtures, prevent early overtopping of slower-growing trees. Species assigned to a particular site should have similar growth rates for that site to avoid competition for light.[17]

For hardwood seedlings, both mortality and first-year growth are strongly affected by:

- Rainfall the first season after planting
- Slope aspect
- Slope steepness
- Friability or plasticity of subsoil
- Rodent consumption or injury
- Density of competing vegetation

Provenance

Tree nurseries in Texas, for example, may have to depend on seed from Georgia trees to supply their needs. Or landowners planning a direct-seeding operation may find longleaf pine seeds available only from an Alabama supplier who, in turn, bought cones from pickers in the southern part of Georgia. As a rule of thumb, when local seeds are not available, substitutes should be obtained from east or west of the planting locality, rather than to the north and south of it.

Sometimes, seeds from remote provenances are intentionally sought. Loblolly pine from the southern extremity of its range has inherited a longer growing season; when trees from that race are grown far to the north, that extended seasonal growth period enables the production of more wood each year. But that same southern-provenance adaptation may result in wood less resistant to the stress of the accumulation of ice on branches.

Naturally, longer growing seasons for races of trees planted to the north of their parental provenance also subjects them to other injuries. For instance, infection by *Cronartium* fungus spores, causing fusiform rust, takes place on newly formed needles in the spring. If seedlings are introduced into locales where early budding coincides with sporulation, more infection occurs.

For longleaf pine, planting stock has been raised from seeds collected in both northern and southern Alabama and the seedlings planted in south Georgia. The southern Alabama source seedlings were over 5 feet taller after 10 years than those of the more northern Alabama provenance. Seed source for this species has been shown to affect survival, and may relate to forkedness, resistance to brown-spot needle blight, bole crook, and the length of time seedlings spend in the grass stage.

Provenance may be exhibited in races within species. Sand pine, for instance, occurs in two widely separated zones in Florida. The west Florida Choctawhatchee race when planted always survives better than the peninsular Ocala race, possibly because its seedlings become more or less dormant from mid-December to mid-February and, therefore, better able to withstand the transplant shock.[18] Ocala stock, on the other hand, grows actively during most winters. It is not clear whether the darker color of the foliage of the Choctawhatchee race is related to its ability to survive, its nutrition, or its photosynthetic capacity. Cones of the Choctawhatchee race release seeds every autumn, in contrast to the serotinous nature of the Ocala stock.

Provenance may also result in the development of a strain that dendrologists classify as a variety of a species. South Florida slash pine is such a variety. Seedlings from seeds from the northern part of its range in the lower zone of the peninsula have morphological characteristics more closely resembling typical slash pine than do those trees from a more southerly source. South Florida slash pine planted in South Florida is more resistant to fire (because of its thicker bark), insects, and disease than the typical variety. The typical variety, on the other hand, exhibits better survival in its early years, makes better early growth, and is more resistant to wind damage.

Geographic strains of loblolly pine planted in the Tennessee Valley do not differ in resistance to snow and ice damage. In the Ozarks, however, trees introduced from Maryland were unharmed while stock from south Alabama and the Arkansas Coastal Plain were damaged by low temperatures.[19]

Although plantings of loblolly pine seedlings from various sources within the Lost Pines of Central Texas survive better than other more-eastern sources in East Texas, considerable variation in survival occurs for progeny of Lost Pines' stock. Pines growing in this low-rainfall zone, 100 miles west of the main southern pine region, are not truly drought-hardy ecotypes, as 25 to 30 inches of rain falls there. Clay subsoil near the surface provides as much available moisture for plant growth as twice this amount of rainfall on deep sandy soils to the east. There seem to be no apparent differences in bole form between seedlings from the Lost Pines and other sources after five years in the field when grown outside of the Lost Pines area. Within the zone, however, native trees are short-boled and exhibit much taper.

An equation—in which average temperature by season, range of temperature by season, and frequency of precipitation—enables foresters to predict plantation success beyond a species' natural range. For loblolly pine, three areas best fit the formula—southern New Jersey, the Tennessee Valley north to Knoxville, and southwestern Florida. Indeed, the climate of Placerville, California, where introduced loblolly pines grow fairly normally and produce seeds in plantations at the Institute of Forest Genetics, fits the equation.[20]

Trees not in the optimum climatic zone probably favor natural selection of traits associated with survival. To the north, cold winters result in more-rigid selection for resistance to frost, with less-stringent selection for fast growth. Likewise, natural selections for drought hardiness occur in areas where rainfall is deficient during critical periods in the life of trees. Seeds collected in drought areas may also be superior to local seeds for planting in ordinarily wetter climes, because even low-lying flatwoods suffer periodic droughts. Hence, local seeds might not always be the best for a site. A source originating in the zone of optimum growth could be superior even when planted in other climes.

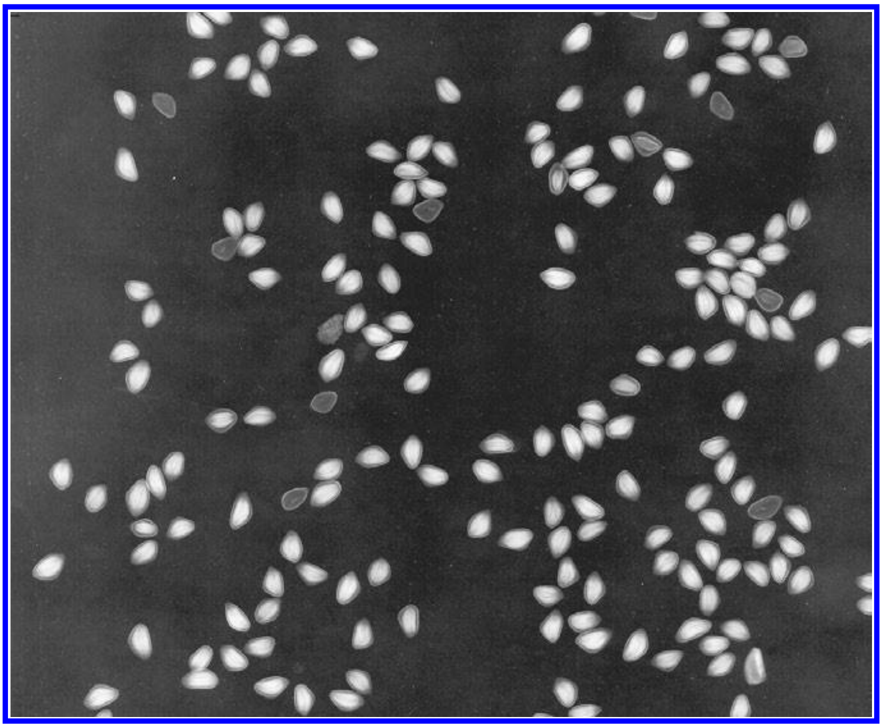

Figure 5.16 Seeds X-rayed for soundness. Pine seeds extracted from dried cones are analyzed for viability by radiographs. Seeds with gray centers are empty; the white ones are sound. Those shown to be partially "filled" have been damaged by seed-attacking insects or by fungi. (Texas Forest Service photo by Ron Billings)

For slash pine, trees from the northern provinces of the species' range can be utilized practically anywhere within that range. Movement of seeds from coastal to interior areas or from south to north entails more risk, but the latter is not commonly done because of the inherently slow growth of the South Florida variety of slash pine trees.[21]

Naturally occurring growth-regulating factors influence the growth of eastern hemlock. Nights longer than eight to nine hours accelerate bud formation, cool temperatures encourage early bud development, nutrient deficiencies hasten the termination of growth, and radial increment is not affected by the distribution of precipitation throughout the year. These factors, along with other inherited characteristics possibly relating to provenance, suggest caution when introducing hemlock to sites greatly different from those in which seeds for seedling production are collected.[22]

Seed Viability

About a quarter million seedlings per acre of nursery bed are required to produce the recommended 40 pine seedlings per square foot. To assure an adequate number, seeds are tested for viability before planting and adjustments made if viability is low. Seed soundness provides a simple way to estimate viability—simply cut a sample of seeds with a sharp knife. If they are not hollow, they will likely germinate; if hollow, they definitely will not.

Nursery managers test seed for viability more elaborately by soaking them overnight in tap water and then cutting along the longitudinal plane, slightly off center, to expose the embryo in the larger portion. The larger section is then immersed in a solution of tetrazolium chloride and stored in darkness for 25 hours at 68°F. The excised embryos are examined under a stereoscopic microscope within an hour after being removed from the dark, or fixed with formalin for later study. Munsell Color Charts facilitate comparisons. Tetrazolium chloride is reduced to carmine red in the presence of dehydrogenates that are present only in living tissues such as viable embryos.[23]

Yellow-poplar seeds from the upper crowns of trees have higher germination rates than those produced lower on the trees. Often, too, for this species, small fruit have more sound seeds than larger ones—viable brown endosperm tissues have a whitish color when the seeds are soaked in water.

Electrical conductivity of leachate from soaked pine seeds also provides a reliable indication of seed vigor and, hence, germination percentages. This technique comes in handy when time does not allow germination tests in seed flats and the chemical staining of embryos. [24]

Seedling Production

Figure 5.17 Mechanized tree-lifting machine. Pine seedlings are removed from four-foot-wide nursery beds and bundled. Trees in the beds to the right have been harvested, and the beds now await spring planting. (authors' collection)

Seedlings in southern nurseries receive supplemental nutrient elements, applications of pesticides (fungicides, insecticides, herbicides, and nematocides), and irrigation water. Lifted in early winter

Figure 5.18 Tube-grown pine seedling about 6 weeks after germination. Note the well-established root system. The 3-inch-long plastic or heavy paper tube, cut along one side, will fall off as the tree grows in diameter. (USDA Forest Service photo)

and bundled in moist moss or a clay slurry, the sooner they are planted the higher the survival rate will be.

Gibberella fujikuroi, a fungal growth regulator, has been shown to promote growth on trees in which stagnation had been induced by shortening the day length for greenhouse-grown seedlings. Height growth was increased 100% and root growth similarly enhanced. As needles are lighter in color with increasing concentrations of the chemical, nutritional interactions with the growth regulator may occur.

Containers of various materials and sizes provide for rapid seed germination and seedling growth. Nursery workers use these in shade houses and greenhouses as well as in open nursery beds. The most effective means for stimulating outplanted seedling height growth of most species is to grow them in containers, each container supporting a single seedling. Initially, several seeds may be planted and the germinated seedlings then thinned to encourage the most vigorous.

Pruning of longleaf pine seedling roots in nurseries increases infection by needle blight spores, as the coulter wheels on the pruning machine spread the spores just as surely as though they had been disseminated by heavy rain. The reduced growth resulting from the grass-stage inoculation with *Scirrhia acicola* can be compensated for to some degree by dipping roots in a fungicide and by prompt transplanting on lifting from the nursery bed. Inoculating the soil, and thus the roots, with mycorrhiza fungi also improves seedling vigor.[25]

Storing seedlings during the time between lifting from the nursery bed and outplanting can be hazardous to the trees if the holding shed is also used for storing apples. Ethylene, a plant hormone gas, reaches 150 ppm as it is given off by the fruit during normal ripening. Concentrations as low

Figure 5.19 Seeds planted in especially prepared soils in these containers germinate, and the seedlings then grow rapidly. They are carried in these trays to the field for outplanting.

as 0.1 ppm cause leaf abscission, kill buds and roots, and retard subsequent tree growth. Terminal growth is especially retarded for Fraser fir, often stored in these facilities in the North Carolina mountains.[26]

Site Preparation

Landowners usually prepare sites before planting, utilizing heavy equipment like bulldozers that push sharp blades to cut and pile brush and logging slash. The windrowed residue is frequently burned. Soil is then scalped, disked, or furrowed with plows. Prescribed fire possibly precedes or follows the use of the large machinery. Herbicide application to reduce potential competing vegetation prior to planting has also been very successful. Landowners of small tracts resort to less expensive techniques; they utilize prescribed fire and herbicides to eliminate brush and ground cover that will compete with the planted seedlings. For longleaf seedlings, any control of competition hastens the elongation of terminal buds of trees in the grass stage.[27]

A typical prescription for prescribed burning prior to planting in the lower Piedmont is for ignition in early March late in the morning, when the wind is northerly at 3 miles per hour, fuel moisture (measurement of water in the leaves, grass, and twigs on the ground) ranges from 2 to 7% at ignition, the relative humidity from 20 to 40%, and the temperature above 60°F. Under these conditions, fire has been shown to move downward on northeasterly slopes at about 3 miles per hour. Two years after such a fire, free-to-grow milacre stocking of planted pines has been tallied at 80%, in contrast to 7% on adjacent unburned lands.[28]

Early in the use of fire in the South, foresters argued about the effects on the soil. Would the reduced amount of organic matter, due to its oxidation, affect nutrient and water relationships? The removal of organic litter may be considerable—a pair of winter and summer fires along the Atlantic

Figure 5.20 Site preparation machinery. Root rakes windrow brush and weed trees prior to planting and direct seeding operations.

seaboard consumed 9 tons per acre. Yet, where accumulated litter was less than 3 tons per acre, the fuel was inadequate for carrying a fire. With rare exceptions, prescribed fire has little effect on soil movement and erosion.

Planting

Southern pines and hardwoods are usually planted as one-year-old stock, in contrast to nursery-grown seedlings as old as 5 years in the Far North. Spacing of 8 x 8 feet is a good rule of thumb, although 10 feet between rows of trees allows trucks to later maneuver conveniently when a plantation is thinned. Narrow spacing allows for a better chance for adequate seedling survival, but the trees soon compete with each other for available moisture, nutrients, and sunlight. Thinning to reduce competition must be done early in closely spaced plantations. Spacing at 8 x 8 feet provides for 680 seedlings per acre; 6 x 6, 1210 per acre; and l0 x 10, 435 per acre.

Retired agricultural land should be planted promptly on abandonment if a natural seed source is not available. The soil is then in a favorable condition for encouraging plant growth, residual fertilizer may effectively stimulate growth of the seedlings, and soil moisture is not yet depleted by invading brush and grass.

The chief difficulty in artificial generation is getting seedlings through the first year after planting, the success of which is possibly dependent on racial strains and nursery practices, as well as precipitation, control of competing vegetation, and site quality. One-year-old seedlings grown in better nursery soils sometimes are too large for successful plantation establishment. For most species, and especially the pines, stock should have 6- to 12-inch tops with at least half of the total length in roots. For plantations that fail because of faulty planting, mortality begins within a few days of planting, noted by the turning down of the seedling tops as they wither.

When low rainfall is the cause of failure, water stress may be noted by mid-June. If the site had been prepared just prior to planting, removing weedy material, moisture stress might be delayed until late August. Failures from drought are inevitable, in spite of expensive and extensive site preparation, especially in the western zone of the southern region.

Figure 5.21 Burning and chopping a sandhill site. This area in western Florida, covered with scrub oaks and wire grass, was burned in May and chopped with heavy equipment in July prior to winter planting. (USDA Forest Service photo)

With slash pine, survival of more than 80% is common, even in the droughty sand hills of West Florida. But north of its natural range, inadvertent planting in frost pockets is catastrophic. There, utilizing south-facing slopes with good air drainage for this species alleviates the problem.

Most plantation failures, apart from extremely low rainfall during the summer following planting, can be attributed to:

- Allowing roots to dry between the time the seedling is removed from the seedling tray or planting bag and inserted in the soil.
- Failure to insert the seedling deep enough into the ground (usually because the planting slit or furrow is too shallow).
- Failure to pack the soil around the seedling. Any root exposed to the air after planting guarantees failure.

When subfreezing temperatures are anticipated, baled seedlings should be stored where they will be protected. Freshly planted stock subjected to freezing temperature is frost-heaved out of the ground.

Figure 5.22 Tree-planting machines expedite reforestation. Rear wheels pack the soil around the roots after the worker has placed the seedling in a slit made by the plow. (authors' collection)

Pulling needles at the top of planted pine seedlings will tell if the seedling is held securely by the soil. If the needles come loose, the tree is in tight, if the whole seedling comes from the ground, the planting technique lacks adequate soil compaction around the root. Planting cannot be too deep, but shallow planting leads to early mortality. Planting so deep that only the terminal bud is exposed provides better survival on droughty sand hills than "standard" planting to the seedling's root collar.

Lateral roots of seedlings grow in the direction of the long axis of the slit or machine-made trench, thus growing in a plane surface. Such orientation affects competition between trees and the utilization of soil moisture and nutrients by those trees

Principal Plantation Pests

Fusiform rust, a principal plantation pest, seems most prevalent on dry sites—those once in longleaf pine and on which loblolly pines have been planted. Frequency of occurrence of scrub oaks, the diseases' common alternate host, could be a factor in spreading the disease.

Different geographic strains of *Cronartium fusiforme* may account for differential rates of infection among trees from widely separated sources. Thus, a strain of the fungus capable of infecting trees from one source may be incapable of infecting another. Variation in time of the tree's breaking dormancy in the spring and in the development of each subsequent growth flush among the source material may also result in differences in rust resistance. Both resistance and susceptibility appear inherited.[29]

Notably, seeds treated before storage with the chemical triadimefon produced seedlings without galls. How long this systemic effect will last is unknown.[30]

An interesting relationship occurs between attacks by the Nantucket pine tip moth and the occurrence of fusiform rust infection. One often finds the galls at the same stem location as the insect attack. Controlling the moth might therefore reduce the attack.[31]

Figure 5.23 Reforesting abandoned agricultural lands. The highly erosive loess silts of northern Mississippi have been a problem for soil conservationists since they were first cutover and plowed for cotton production before the Civil War. In the 1940s, congress provided funds to rehabilitate these fertile, wind-deposited sediments. Dams, catch basins, and loblolly pine plantations helped to restore the land to eventually produce high-quality hardwood forests. (USDA Forest Service photo by Dan Todd, 1962)

Workers in East Texas observed less rust on poorly drained soils than on those with better drainage. They found too, the higher the site quality, the greater the infection, while dense stands had less rust than sparse ones.[33]

Stunting of planted loblolly pines in sandy sites in North Carolina's Coastal Plain has been found to be associated with the presence of lance and pine cystic nematodes. Stunting is much more complex than a simple case of nematode damage, as all of the factors of site contribute to the occurrence of the pathogen. Greenhouse tests show these parasites feeding and reproducing on pines. Lance nematode activity causes height-growth reduction, while the cystoid species that damages roots does not seem to seriously impair terminal growth. These endoparasites also cause considerable internal injury to lateral and mycorrhiza-enhanced roots.

Red-headed pine sawflys, along with other *Neodiprion* species, defoliate loblolly pine reproduction, almost exclusively in plantations. Larvae destroy needles down to the fascicle sheath and then bite out pieces of outer bark and phloem. A single complete defoliation kills trees, though a tree will survive if less than 25% of the needles are consumed. Stem growth greatly diminishes for a year or two after an attack.

Reproduction weevils, more commonly called pales weevils (the name of the more prevalent member of the genus *Hylobius*), attack young seedlings of all southern pine species in freshly cutover stands. Pitch-eating weevils, also of the genus *Hylobius*, breed in the roots of the stumps of freshly cut pine trees, infesting nearby newly planted seedlings. Webworms also damage seedlings, possibly more so in shade (where light and moisture competition reduces vigor) than in the open.

Figure 5.24 *Cronartium fusiforme* infection. The deformity, occurring on main stems and branches, is the most destructive disease of the southern forest. Breakage and death from girdling occur, especially on slash pines. Oaks, particularly water oaks, are the alternate hosts. (Texas Forest Service photo by Ron Billings)

Seedling Growth

Current year's height growth (CY) of loblolly pine planted seedlings depends on the previous year's growth (P). This is shown by the equation CY = 0.35 + 1.02(P). The relationship, in turn, depends on:

- Height:diameter ratio of the previous year
- Proportion of the main stem bearing foliage
- Length of terminal buds
- Number of branches formed
- Total height until the present year[34]

After southern pine seedlings are a couple of years old, annual height growth is readily identified. The first internode of the season is the longest of several occurring during the growing season, each subsequent internode a bit shorter as the season progresses. The first internode may be 3 feet, the last 3 inches. The first, or primary, whorl of branches arising from the node is also the largest and longest. Trees up to 10 or more years old can be aged this way. Pruning does not affect the technique, but trees attacked by tip moths cannot be so aged.

For loblolly pine, roots do not persist in the surface layers of bare soil when afternoon temperatures consistently exceed 95°F. On the other hand, cold seldom limits root growth, elongation continuing as long as soil temperatures remain above 40°F. This ability of roots to grow in winter when the soil is soft from excessive moisture enables expansion into zones free of ground cover and where otherwise the soil is impenetrable when dry.

Soil temperature depends largely on the capacity of the soil surface to absorb or lose heat. Since heat gain is produced by radiant energy from the sun, minimum temperatures are affected

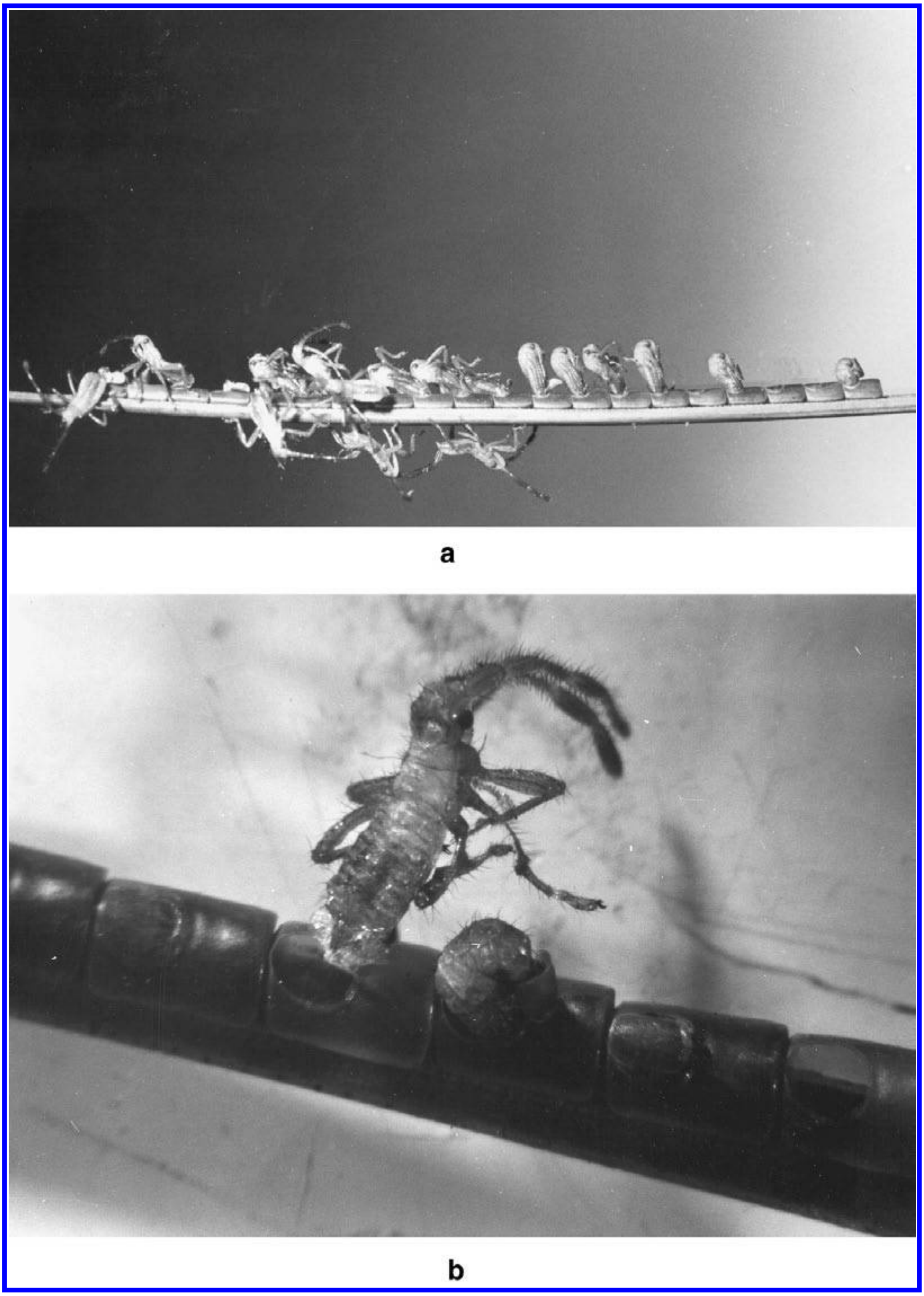

Figure 5.25 Leaf-footed pine seedbug *Leptoglossus corculus* nymphs emerging from eggs (a) deposited on a pine needle; enlargment (b). Adults damage both seeds and cones of southern pines, becoming a serious menace in seed orchards. (Texas Forest Service photo by Ron Billings)

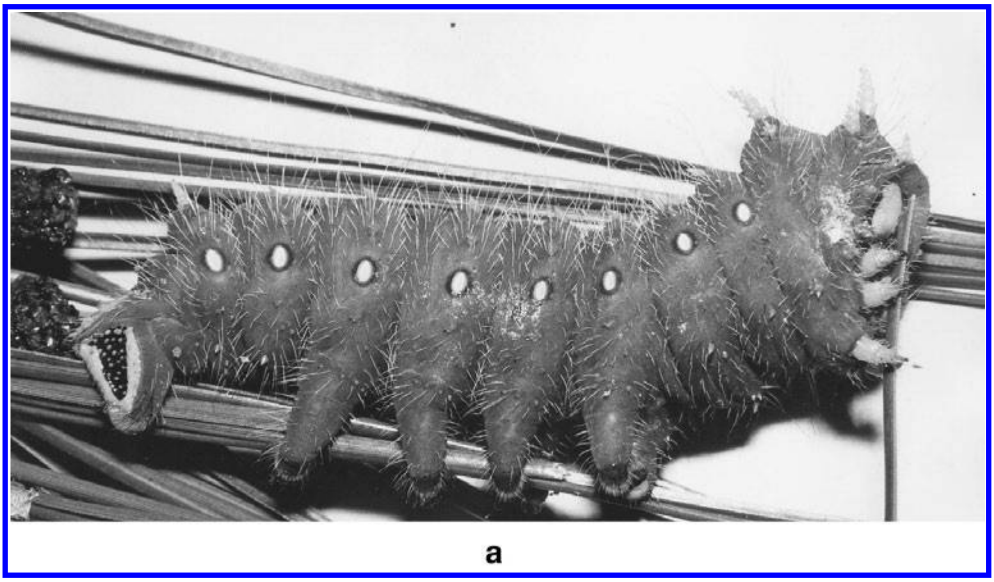

Figure 5.26 Larvae of the imperial moth feeding on southern pine needles (above) and enlargement of the head (below). This insect is especially prevalent in seed orchards during cone-picking times. Note how the *Basilona imperialis* larva grasps and nibbles the foliage. (Texas Forest Service photo by Ron Billings)

Figure 5.26 (continued)

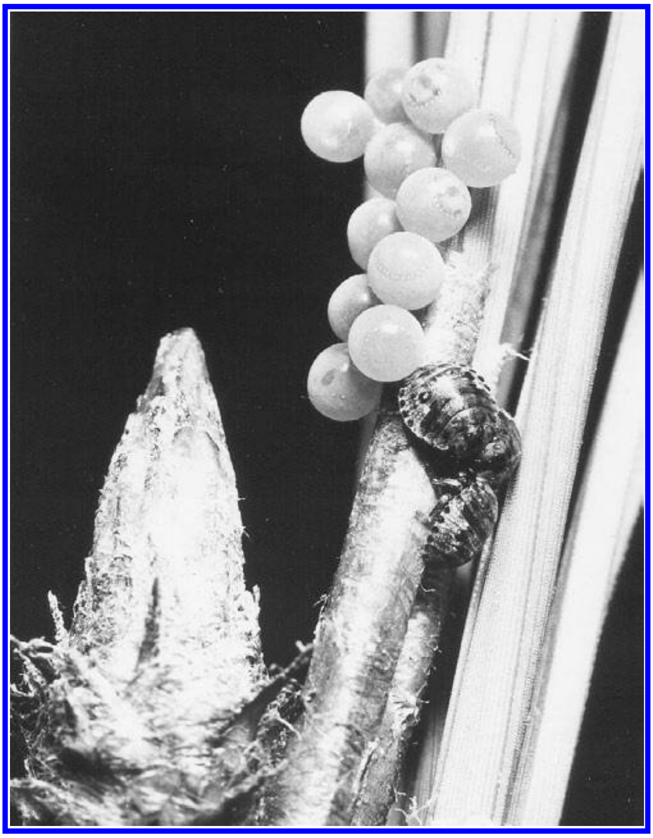

FIGURE 5.27 Pine tree seed orchards suffer when sap-sucking shieldback pine seedbugs attack seeds in immature cones. Seeds then abort. Here the insect is laying eggs in the foliage. Note the growth of the exposed bud. (Texas Forest Service photo by Ron Billings)

by vegetative shade, which allows less long-wave radiation to reach the soil from the sky than would occur in barren areas. As ambient temperatures are decreased by shade, plant cover reduces the range of soil temperatures near the ground.

Loblolly pine seedlings have a high degree of tolerance for poor drainage, especially important in Coastal Plain flatwoods, where imperfectly drained, bluish-gray, clay loam soils predominate. Most such soils, in which both surface and internal drainage are poor, are devoted to woodlands. Pines are the most valuable species, yielding high-quality timber. Generally, less-valuable broadleaf species dominate the more permanently inundated sites.

Mulching

Mulching of seedlings enhances growth by reducing evaporation of water from the soil and by checking competing vegetation. Mulches can be of organic material such as straw or pine needles. Organic mulching increases rainwater infiltration, thereby enhancing soil moisture availability for seedlings during periods of drought.

Four-foot-square black plastic sheets with a 3-inch hole in the center through which a seedling protrudes, placed on the surface of severely eroded abandoned agricultural land, encourage survival and growth. After three years, the plastic-mulched seedlings are a third again taller than unmulched ones.[34] The dark color of the sheet absorbs the sun's rays, thereby warming the soil beneath and activating soil microorganisms favorable to tree growth.

Direct Seeding

The ease with which longleaf pine is direct-seeded tends to reverse the trend away from the species' use in reforestation. With direct seeding, fine rootlets are not destroyed, as when nursery stock is lifted. Seeds are sown on moist soil between Thanksgiving and Christmas—before migratory birds that consume many seeds reach their peak numbers in wintering grounds in late December. Longleaf pine seeds seem to be a preferred food of even some insectivorous birds. A slight covering of soil over the seeds enhances germination chances.[35]

Assuming 10 to 30% of the seeds will produce vigorous seedlings, about 10,000 dewinged seeds (3 pounds) are distributed on an acre. Eighty percent milacre stocking is usually achieved when 3000 seeds per acre germinate. A milacre (1/1000 of an acre, or a 6.6-foot square) is stocked when it has at least one seedling. More than one does not change the stocking tally, but does bring about seedling competition.

Prescribed fire must precede direct seeding of longleaf pine for the seeds to make contact with the mineral soil. The removal of the ground cover, however, exposes the seeds to thieving birds and rodents. Two species of seed-eating shrews, members of the short-tailed *Blarina* genus, and an assortment of other rodents feed on seeds. Coating the seeds with nontoxic rodent, rabbit, and bird repellents effectively reduces animal theft.

Direct seeding of slash pine was accomplished as early as 1920 on "crawfish" (also called "crayfish") land in the flatwoods. For this species, sowing is done in October and November along the Gulf Coast and as late as mid-February in the upper Coastal Plain. A pound of seeds per acre, amounting to about 14,000, is broadcast by hand, distributed with agricultural cyclone seeders, dropped from the air, or placed in hoed spots.

Direct seeding Atlantic white-cedar is unlike that for any other species. More than 2 million dormant seeds per acre have been found under mature stands in the surface 3 inches of the litter of the forest floor. Half of the seeds that fall remain dormant the first year after dissemination. Many remain viable for several years. The surface litter from under a mature stand is collected and the material sowed in spots. One bushel of organic matter is sufficient for seeding 20 spots. Some sunlight to heat the soil is necessary. Under hardwood foliage, seeds sprout satisfactorily if even a little light penetrates the canopy. As these seeds have a low starch content, favorable moisture and light for early growth following germination are essential. Flooding and air pockets that form in the soil around saplings reduce survival.

Poor yellow-poplar viability necessitates dissemination of large quantities of seeds. To obtain 800 seedlings per acre may require 200,000 seeds. While germination is better on drier, west-facing slopes, survival likely will be best on the moister east sides of the hills. Covering seeds with a thin layer of soil and protecting the seed spot with a screen aids success. Yellow-poplar seeds retain viability for as long as 4 years in the litter of the forest floor.

Direct seeding of eastern redcedar has been used successfully when stratified and scarified seeds were inserted in holes made in the ground and then covered with soil. Even broadcast seeding of this species calls for covering the seeds with mulch.

Other species to direct-seed include cherrybark red oak and the shade-tolerant Nuttall oak. The latter, not a separate species until 1927, when it was named in honor of the pioneering botanist, does well providing food for ducks in green-tree reservoirs. The birds, of course, consume much of the acorn supply intended for reforestation.[36]

Direct seeding has also been effective with pitch, shortleaf, and loblolly pines and some oak species. Storing seeds in a cold, damp place and soaking them in hydrogen peroxide prior to planting improves germination. Chances for successful direct seeding improve when sites are furrowed or disked shortly before seed dissemination.

VEGETATIVE PROPAGATION

SOUTHERN PINES

In a search for shortleaf pine strains resistant to the littleleaf malady, tree improvement specialists developed techniques for vegetative propagation. Air layering of young branches results in new trees that are clones of the tree on which the branch was attached. Hundreds of branches can thus be taken from a single high-quality scion and grafted to trees of common stock. The air-layered branches are then planted as seedlings, all having the form and quality of the parent. Even air-layered needle bundles produce roots and buds, with the latter breaking dormancy to become new trees.[38]

Small needle bundles or foliar spurs, called dwarf shoots, are useful for propagating slash pine. Removing these short shoots does not damage parent trees, in contrast to propagation by cuttings. These dwarf shoots arise in the axils of a scale leaf borne on the branch. Needles appear only on the spur and, with the needle bases, are covered by bract-like scales. Roots originate from finger-like protuberances of the callus tissue, while buds develop from the special meristem. The new seedlings that arise first express no apical dominance, but are branched and broad-crowned. Soon, one of those branches assumes dominance, the progeny appearing like a typical seedling.

NATIVE COTTONWOOD

Cuttings are especially effective for propagating cottonwood forests. Ridges and flats adjacent to streams, provided they are not permanently inundated, are favorable sites for this regeneration practice. As rooting ability decreases with age of the parent stock, cuttings should be from new growth of 1- to 3-year-old trees. The cuttings should be about 18 inches long, more than 3/8 inch in diameter, and with lateral branches pruned flush. Cuttings inserted their full length vertically in the soil usually have 100% survival. Some workers prefer to leave the top two buds exposed above ground. From uppermost buds new trees arise; roots develop from those buds a few inches below the soil's surface.

To control competition, the principal cause of mortality for this form of regeneration, cultivation is essential at least the first year, when the roots of grass absorb water and nutrients that the young cottonwood trees would otherwise consume. Burning the sod prior to planting, as an alternative to plowing the ground, improves soil aeration and removes overhead competition for sunlight. Immersing the basal two inches of cutting stock in a solution of a plant growth regulator, such as indoleacetic acid, improves rooting, while treatment with gibberellic acid improves top growth.

Cottonwood cuttings respond well to commercial fertilizer applications. However, piney-woods' rooters in the bottomland forests across the South are especially attracted to nutrient-enhanced trees, sometimes pulling the stems from the ground in order to get to the fertilizer pellets in the planting hole.

Cottonwood cuttings serve as living riprap for erosion control in moist gully bottoms of the Bluff Hills along the eastern edge of the Mississippi Delta. There, where silt deposits bury a short length of stem, the cottonwoods endure. Indeed, they will continue to sprout new roots as soil builds up around the stem for depths of 6 feet or more, layer after layer of the roots extending perpendicularly from what once was the above-ground stem. Subsequent washing away of the deposits by heavy rains exposes the strata of roots.

HYBRID COTTONWOOD

Imitating the great cottonwood planting effort in Europe following World War II has not been effective in the South. Resupplying the wood box of the continent was considered essential after the destructive harvests for military requirements, battles fought in those forests with tree-crushing

Figure 5.28 Two-year-old cottonwood saplings. These trees arose from cuttings taken from locally grown parent trees and planted in a prepared site in the rich silty soil of the Mississippi Delta. For success, herbaceous weed competition must be controlled by mowing for at least the first year. (USDA Forest Service photo)

tanks, and the fires. Western nations were at a loss to provide wood for paper and housing. (Eighty percent of Germany's homes were destroyed.) The Food and Agriculture Organization, a unit of the United Nations, established the Institute for Poplar Culture's experimental woodlands in Italy's Casale Monferati region. There, many cottonwood species from throughout the world were planted. Hybrids, too, were tested; and among these, a particular cross of North America's eastern (sometimes called southern) and Europe's black cottonwood grew especially straight, strong, and fast. *Populus euroamericana* was soon grown in nurseries from which cuttings were taken for outplanting throughout the continent. In a few years, the trees produced wood for lumber and paper pulp.

The trees produced from these cuttings are clones, with identical genetic characteristics, because all have originated from the original hybrid cross. A single cutting in a nursery bed can produce a dozen cuttings from its sprouts the first year; the residual root will provide nourishment for two dozen sprouts the second year, and so forth, until the soil is exhausted, perhaps in 5 or 6 years.

Forests can now be found arising from *Populus* cuttings far distant from the Po River delta of Italy's Alps. Unfortunately, it is not known if stems inserted in the ground far to the south of Cairo beside Egypt's Nile River, plantations along the Turkish border of Greece, or cuttings used to

Figure 5.29 Southern cottonwood cuttings planted for windbreaks. These 4-year-old stems, planted on land requiring rehabilitation, are true clones, as every tree originated from a branch of a single parent.

stabilize the sands of Jordan's eroded hillsides are also of this famous hybrid. Stems of that hybrid and many others are now so common that records of a stand's origin are no longer maintained.

Hybrid poplars have been successfully developed in the northeastern United States and marketed throughout the land and abroad. Some show promise in the South on topographic situations ranging from the Appalachian Mountains to the Coastal Plain. Clones of the commercially advertised

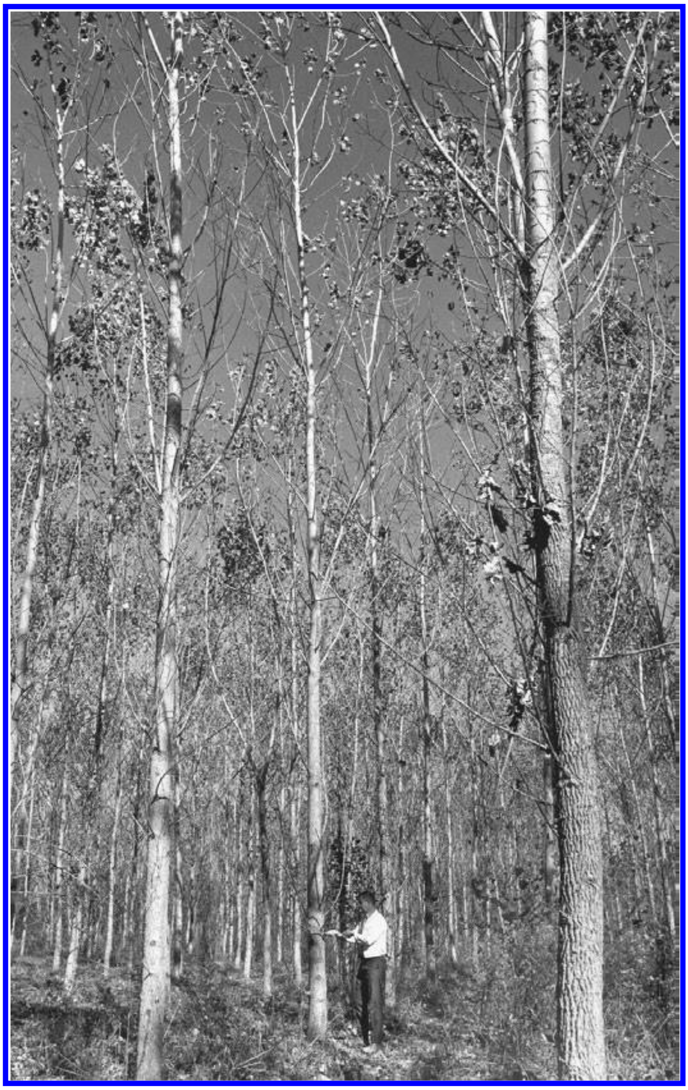

Figure 5.30 Fast-growing southern (also called eastern) cottonwood trees planted in the overflow of a southern river bottom. The 6-year-old stems could now be thinned for pulpwood. Slowly dissolving fertilizers placed in planting holes encourages growth, but the procedure also encourages piney-woods rooter excavation for the salt, and the animals will then pull the cuttings from the ground.

Androscoggin hybrid grow 80 feet tall and 10 inches dbh in 13 years.[37] However, genetic improvement of the South's native cottonwood has made the importation of hybrids unnecessary. The USDA Forest Service laboratory in Mississippi in 2 years produces trees 7 inches in diameter at the base and 40 feet tall. The wood is used in cattle feed and in energy biomass plantations as well as for lumber and paper pulp.

Other Species Vegetatively Regenerated

American sycamore, gaining importance for "sycamore silage," is readily reproduced from cuttings. Trimmed to 20 inches and stored in moist sawdust until outplanted, cuttings do well on cutover land. When the site is first prepared by furrowing, especially desirable in the Piedmont province, the resultant trees also provide paneling lumber as well as fiber for pulp and fuel for power generation.

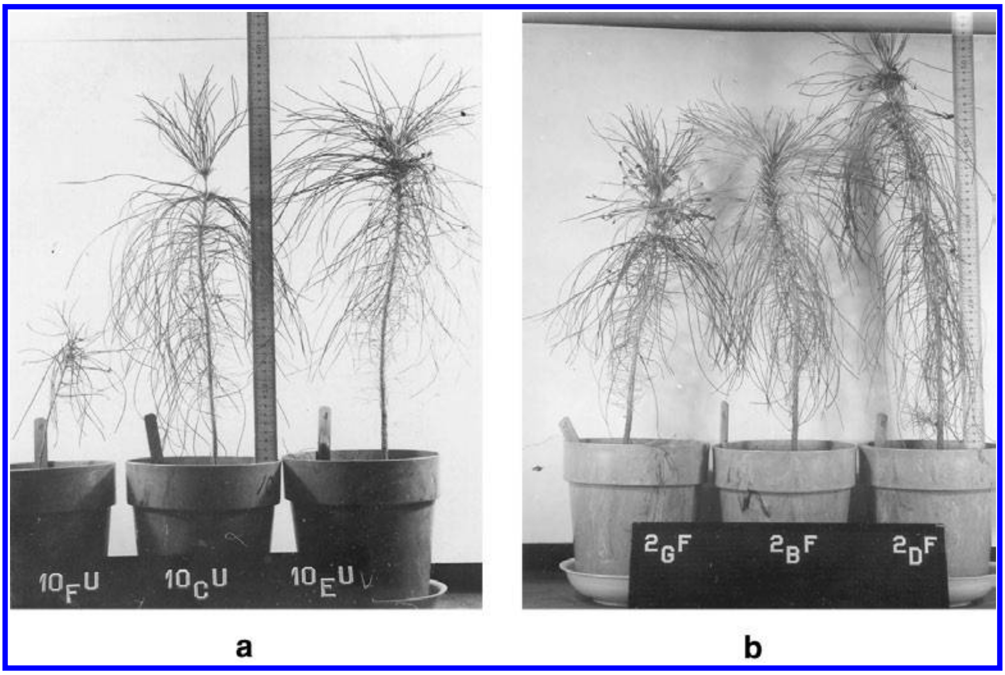

Figure 5.31 Shortest, mean, and tallest of unfertilized (a) and fertilized (b) seedlings in a progeny group. Study indicated a strong probability of the inherited capacity of slash pines to adsorb and utilize nutrients.

Yellow-poplar is readily propagated vegetatively. Greatest success occurs when cuttings are taken in summer from lower branches of dominant trees 30 years or older. Dipping cuttings in indolebutyric acid encourages rooting. (Entire seedlings of this species have been split longitudinally from terminal tip to lowest root (thereby doubling the available supply of stock), coated with lanolin, and successfully out-planted.While coppice will be considered in a later chapter on regenerating the forest, we introduce the subject here, for forests may be initially established by the sprouting of roots, stumps, and pieces of twigs lying on or under the ground. Many oaks and hickories arise this way, "seedlings" actually being sprouts from persistent material. So prolific may be this form of reforestation that workers must go over site-prepared land prior to planting cottonwood cuttings to remove bits of stems and roots of broadleaf trees, lest they sprout and compete with the more valuable planted trees.

Other Hybrid Trees

The principal hybrid of slash pine is with longleaf pine, intended to produce a cross that resembles longleaf pine in form and branching habit, but without the grass-stage characteristic of longleaf pine seedlings. The cross may also exhibit drought resistance and less susceptibility to the brown-spot needle blight of longleaf pine and fusiform rust of slash pine. A slash pineoccurring in nature, while not exhibiting the dwarf condition of longleaf pine seedlings, seems to exhibit no particular advantage over either parent.[38]

Artificially produced hybrids of shortleaf and loblolly pines seem not to have fusiform rust infection, even when growing in the middle of a heavily infected slash pine plantation. Crossing slash and shortleaf pines produces trees that show resistance to Nantucket pine tip moth infestation and fusiform rust infection. Improved early vigor and form also take place.

Sonderegger pine, the hybrid of longleaf and loblolly pines, was first noted in nursery beds in Louisiana. Seeds of the cross, which breeds true, are from the longleaf pine parent; pollen comes

Figure 5.32 Arrows point to the fertilized and unfertilized planted yellow-poplar trees planted in a Piedmont cove. Complete fertilizer (N-P-K) capsules were placed in the planting holes of the treated stems.

from loblolly pine. *P. sondereggeri* behaves like longleaf pine in that seeds germinate in the fall and there is but one internode in the main shoot of seedlings. The embryonic-stage foliage, resin flow, and susceptibility to needle blight are also similar to that of longleaf pine. Like loblolly pine, good height growth occurs the first year after germination and three non-persistent branches occur in a whorl at the end of the main shoot. While tree form is poor, due principally to taper, rapid radial growth takes place.

Eleven isozymes have been found in Sonderegger pines, nine of which were common to both the longleaf pine and the loblolly pine parents. Geneticists suggest that certain isozymes serve as genetic markers for seed orchard selections since frequency of the isozyme occurrence approximated Mendelian ratios. Suppresser genes may be involved.[39]

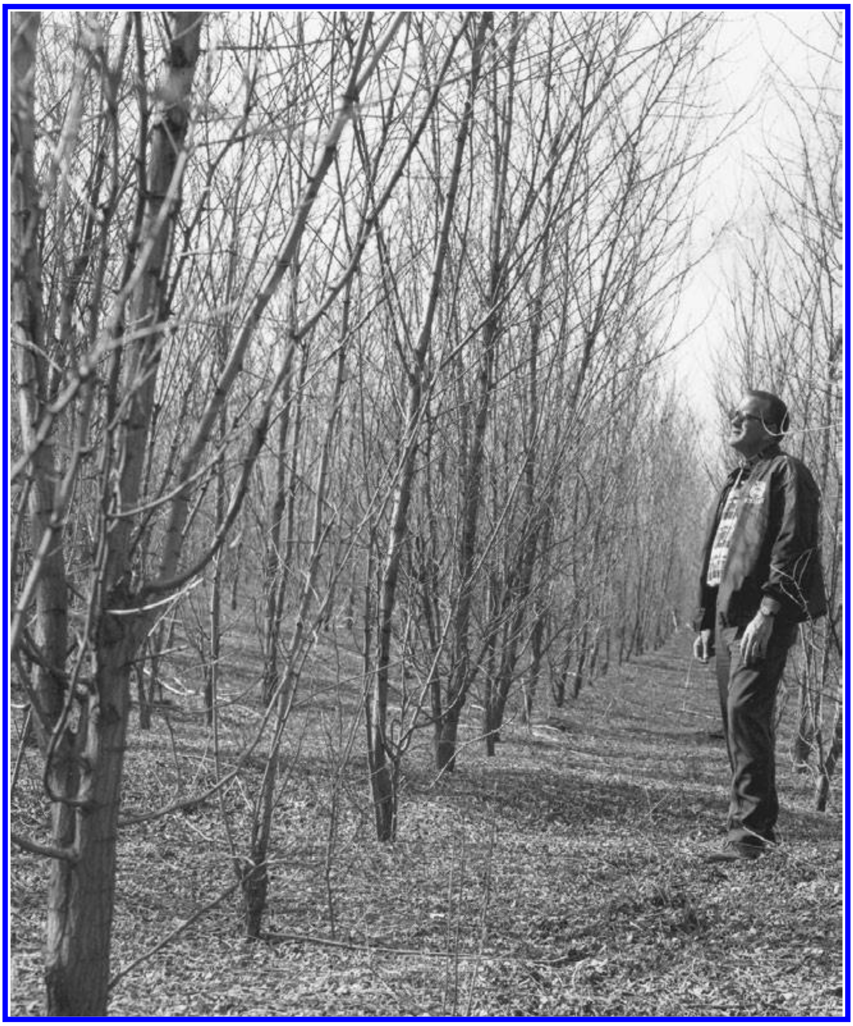

Figure 5.33 Black locust trees, now 5 years old, planted on disturbed land in the Southeast. The legume's ability to "fix" (convert) nitrogen taken from the atmosphere to a form that plants can use not only encourages the tree's growth, but also stimulates growth of microbes in the soil that depend on the element. (Soil Conservation Service photo)

Tree Improvement

Foresters have referred since the 1950s to the more inclusive term "tree improvement" to embrace their work in genetics. Tree improvement (see also Chapter 7) involves the selection of the trees most favorable to a site, perhaps inherently, as well as to the alteration by breeding and selection of the genetic makeup of natural vegetation. The task is designed to produce "supertrees" from which seeds will be collected for seedling production for future forests.

Superior stock may include genetic material resistant to disease and insect attack. For instance, variation in susceptibility to the pitch canker fungus occurs among half-sib and full-sib families of Virginia Pine.[40]

The southern tree for which most genetic work has been done is slash pine. For this species, foresters noted early that in the portion of its range where climate—principally rainfall and length of growing season—is optimum, trees grow faster than elsewhere. The fastest growing stems dominate. Perhaps they also produce superior seed for the next crop. If some stems outgrow others when all are subjected to identical environmental conditions, trees inherently superior in growth could result through natural selection. This is assumed when foresters set aside tracts as seed production areas from which they collect cones grown on phenotypically (visually) superior stems.

Selfing affects growth rates of trees. Seeds from slash pine female strobili pollinated by male strobili from the same tree in one case produced seedlings a foot shorter at age 5 than were those from cross-pollinated sources.

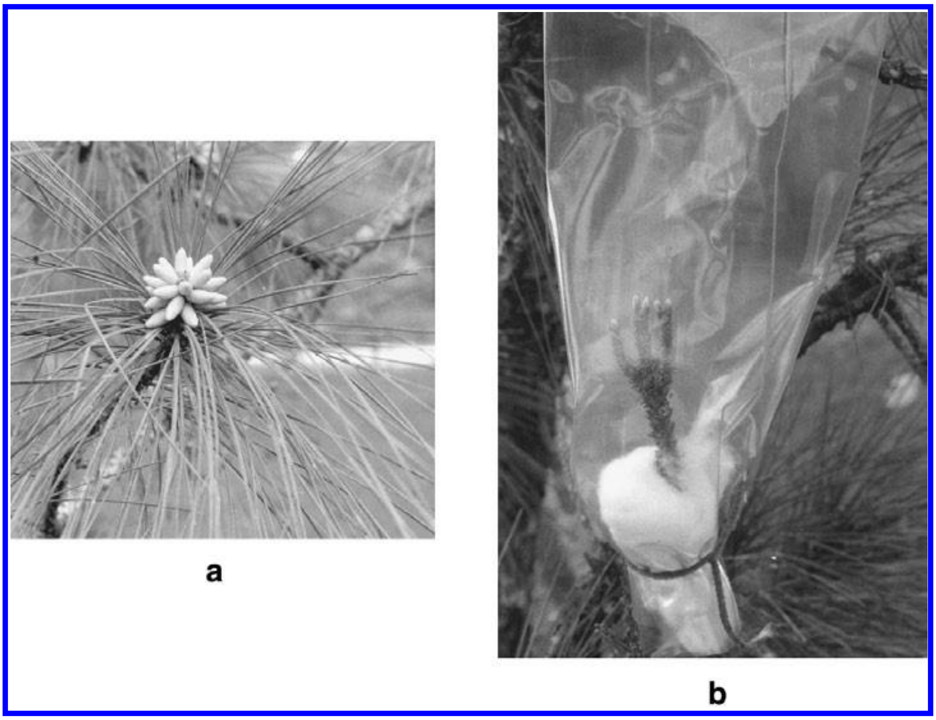

Figure 5.34 Strobili (flowers) of slash pine. Pollen collected from selected male strobili (a) will be injected into the protective cover of selected female strobili (b) in tree-improvement operations. (USDA Forest Service photo)

Southern pines are successfully grafted in tree-improvement work. Among the many techniques employed, the widely used cleft graft "takes" any time of year. Scions obtained from mature trees are grafted onto 2- and 3-year-old common stock. Grafted trees transferred to the field seldom overcome transplant shock. If grafted trees are pot-grown, they often are root-bound, with their roots continuing to grow in circles after being removed from the pots and outplanted in seed orchards. Root-bound trees remain subject to windthrow. A major problem with grafted stock developed for seed-orchard outplanting is the "milk bottle" constriction that mimics the 1940s glass container with the narrow neck. Stock overgrowing the scion misshapes the stem, and the graft blocks the downward movement of carbohydrate in the phloem tissue. Death of the tree eventually follows.

Phenotypes

Seeds for reforestation should be collected from stems phenotypically of high quality, those appearing to have desirable traits. In addition to visual factors such as form and branching habit, inheritance also involves survival and rate of growth, insect resistance (especially to the Nantucket pine tip moth), wood specific gravity, gum flow (significant for naval stores production), and tracheid length (important for pulp quality). Characteristics such as crown width, crook, and susceptibility to chlorosis among seedlings in nitrogen-deficient nurseries are also inherited.

Eastern redcedar trees vary genetically, according to provenance, in color of winter foliage, crown form, and growth rate. Resistance to infection by crab-apple rust may be inherited. Progeny from seeds collected in the Cedar Basin of central Tennessee are among the greenest in winter. There, the broadly conical crowns of trees with mostly scale-like needles (this species produces two kinds of needles) exhibit favorable form for Christmas trees, as well as timber and posts.

Among the broadleaf trees, the distinctive growth forms of black locust—from pinnate to palmate—and the various rates of growth are probably inherited. In utilizing this legume for mine-spoil reclamation in surface-mined sites, seeds should be collected from fast-growing, straight-boled stems.

Polyploidy occurs in trees as in other plant and animal organisms. About 0.0002% of slash pines exhibit abnormalities attributed to polyploid cells. External symptoms of polyploidy include suppressed root and shoot growth, empty seeds due to aborted pollen grains, and low capacity for survival.

Nutrient Fertilization

Just when it appeared economically promising for stimulating growth of southern pines with nutrient fertilization, the energy crisis of 1973 occurred. As considerable amounts of natural gas are used as raw material for nitrogen production and because of the escalating costs of transportation dependent on oil, fertilization was recommended only for special situations such as nurseries, seed orchards, especially valuable trees (e.g., black walnut), recreation areas, and severely eroded or surface-mined sites. Current research has shown excellent responses to fertilization of both loblolly pine and slash pines. In the South, nitrogen and phosphorus, among the elements, most often enhance the growth of pines when applied to soils.

Flowering for both male and female strobili increases with applications of ammonium nitrate, especially when used in conjunction with growth-promoting substances such as gibberellic acid and benzyladenine. However, over-fertilizing with nitrogen compounds may actually decrease seed yields in seed orchards and seed-production areas and depress germination percentages of seeds produced therein.[41]

While all southern forest trees growing in moderate to poor sites likely respond to applications of fertilizer, plantations of slash pine respond best to nutrient amendments. First-year seedling demand approximates that for field crops, nitrogen being the element most limiting to growth. Chlorosis of foliage indicates deficiency in nitrogen, an element utilized in either nitrate or ammonium forms.[42] In a clay loam soil in which water levels were controlled at four levels, (from 4 inches above the ground to 4 inches below), survival and growth were best after 2 years where water levels were maintained at a depth of 4 inches below ground level. Applications of 1000 pounds per acre of 8-8-8 fertilizer improved needle length, foliage color, and foliar nitrogen, phosphorus, and potassium in the plastic soils of the southeastern Tidewater.[43]

For broadleaf trees in the river bottoms, complete fertilizer (nitrogen, phosphorus, and potassium) applications provide responses. Rates as high as 1000 pounds per acre of diammonium phosphate have been used to assure the early growth of yellow-poplar trees along Piedmont streams.[44] This favorable response occurs in sites not considered deficient in nutrients for this species. Survival appears uninfluenced by applications of nitrogen and phosphorus available in the inexpensive diammonium phosphate formulation.[45]

To arrive at foliage symptoms of nutrient deficiencies for longleaf pine, a curious forester in the 1930s, L.J. Pessin, grew seedlings in pots. Lacking phosphorus, needles occurred two to a bundle rather than the usual three, thin needles resulted when sulphur was withheld, and chlorosis occurred with low iron, nitrogen, and calcium shortages. Growth in Pessin's pots was poorest in potassium- and iron-deficient cultures, while best growth occurred in low-phosphorus trials. As this species grows naturally in soils low in available phosphorus, longleaf pines probably require little of the element. Complete fertilizer and nitrogen alone sometimes stimulate radial growth. Water, however, is always the most important factor in latewood growth of the cambium layer.

Fertilization stimulates the growth of grass and herbaceous weeds that utilize ground water to such a degree that pine-seedling survival and growth are greatly reduced. To overcome this, both herbicides and cultivation may be necessary to control the weeds.

Southern pines planted on excessively drained sandy soils in the Coastal Plain frequently exhibit Liebig's Law of the Minimum. For example, differences in phosphorus, potassium, and calcium in foliage relate to fertilizer treatments, but a substantial increase in foliar potassium occurs only with applications of nitrogen, phosphorus, magnesium, and sulphur, as well as potassium. Thus, potassium deficiency limits growth and the ability of pines to respond to fertilization with other nutrient elements.

Establishing forests on surface-mined and other difficult sites is often enhanced with nutrient fertilization. All essential elements are frequently required on such lands.

Foresters utilize Munsell Color Codes to show three distinct classes of foliar nitrogen and potassium levels in crowns, according to color photographs. The method allows for more-efficient use of fertilizer while enabling classification of site quality.[46]

Mycorrhizae

Symbiotic mycorrhizae and pines depend on each other for sustaining life. Forest managers introduce them where soils have been sterilized or the root-infecting fungus is absent. Southern pines will not grow in the absence of mycorrhizae fungi of the species *Cenococcum graniforme* or *Thelephora terrestris*. The particular species present in the soil usually depends on soil moisture. The microscopic fungus growths serve like root hairs, providing channels through which moisture and nutrients move from the soil to cells in roots. As root systems are smaller under low-moisture regimes, the proportion of rootlets infected with the fungi increases.

Apparently, *C. graniforme* lacks competitive ability in moist humus, as it is most abundant in dry summers, and increases tenfold as available moisture diminishes. The black mycelium is easily distinguished from the light-colored mycelia of other ectotrophic fungi. Its ready identification provides silviculturists with a clue to soil moisture regimes and, hence, site quality, especially for Virginia pine. The presence of excessive mycorrhizae growth may indicate a phosphorus deficiency.

Seedlings of slash pine introduced into islands of the Caribbean as seeds from the North American continent failed to survive, though all obvious characteristics suggested the sites on which the seedlings were planted to be typically those for *Pinus elliottii*, a species earlier called *P. caribeae*. However, when seedlings grown in Florida nurseries were carried to the islands, soil clinging to the roots contained adequate mycelia to inoculate the soils of the distant lands with mycorrhizae. Why prevailing wind, out of the west, had not carried mycelia spores to the islands remains a mystery, for even in Australia, where no pines are native, mycorrhizae were present to support radiata pine, the seeds of which were carried by pioneering settlers in the early 20th century from California's Monterey peninsula.[47]

Pisolithus ectomycorrhizal influences development of seedlings, but the influence depends on soil pH and nitrogen. For loblolly pine, the amount of mycorrhizae diminishes as soil pH rises and increases with enhanced soil nitrogen. The pH effect is reflected in above-ground tree growth—best growth occurs when soil pH is between 4.8 and 5.8.[48]

Afforestation

When afforestation is the aim, pitch pine has possibilities for sand dune stabilization. Balled trees have been used satisfactorily.

In the Tennessee–Georgia Copper Basin, pitch pine and Virginia pine are recommended species. Lateral root development on these eroded and toxic sites is more rapid than for other tree species. Pitch pine lateral root growth exceeds 6 feet in 6 years, enabling adequate absorption of moisture and nutrients, even during droughts. However, survival will probably not exceed 60% in the Basin, suggesting close spacing of 4 x 4 feet for plantation establishment.

Afforestation involves the balds in the highlands of the Appalachian mountains where, it is assumed, the sites have always been treeless. Well-drained, the balds occur below the climate's tree line in a predominantly forested region. Red spruce and Fraser fir transplants 3 to 5 years old (an exception to previous comments about southern planting stock) lifted from nearby woodlands do well, provided they are fenced to exclude browsing livestock, white-tailed deer, and black bears. Fraser fir is also introduced by planting stem cuttings. Deer appear to have a greater taste for fir than for spruce. Shielding from wind and using roofing shakes or brush at this high elevation may also be necessary. Growth as well as survival improves with wind protection.[49]

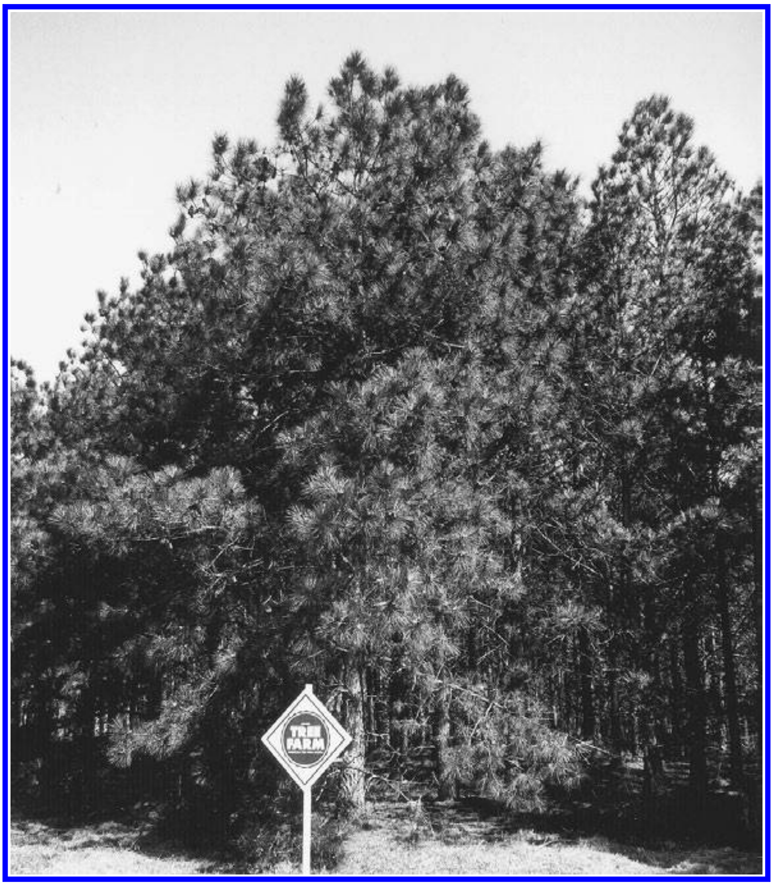

Figure 5.35 These 14-year-old loblolly pines were planted as 1-year-old stock on surface-mined land. Horizons of overburden more than 50 feet deep were mixed and replaced in trenches following removal of coal seams. The absence of weed seeds in the soil now at the surface precludes vegetation competition. (TU Services photo)

Reclamation

Enthusiasm for black locust for erosion control and rapid forest establishment on surface-mined lands peaked in the years of the Great Depression. With recent citizen insistence that disturbed sites be reforested, the legume regains significance in the forester's repertoire of trees available for planting. A humus layer formed by the litter develops several years sooner than it does under pines, perhaps because leaf fall begins the first autumn after plantation establishment. After crowns close, these trees liberate in their decaying foliage about 60 pounds of nitrogen per acre per year. This soluble nitrate form of nitrogen is promptly utilized by plants or lost in drainage water; little is stored in the soil. In contrast, the bacteria housed in nodules on roots of legume trees raise the available nitrogen levels at the 0- to 20-inch soil depth to as much as 600 pounds per acre. Such higher amounts of soil nitrogen stimulate the growth of other species, notably Virginia pine, yellow-poplar, oaks, and hickories that subsequently seed in to form an understory. Black locust, however, grows best on alkaline, well-drained, loamy soils.

Though beyond its natural range, loblolly pine is a preferred species for reclaiming dry-site mine spoil in northern Alabama. Adjacent wet sites do well with American sycamore. Organic matter added to the soil improves growth because of better nutritional fertility and soil physical properties. Surface-mine reclamation in Texas also utilizes loblolly pine. In this case, the overburden, removed prior to extraction of the lignite seams, was thoroughly mixed when placed back into the mined trenches. The soil parent material thus became the new topsoil, a medium rich in nutrients (except for nitrogen), and seedbank-free. This contrasts with the more costly earlier method of separating overburden by horizon and replacing it in the mined-out site in the same order that it was removed. Loblolly pine and several broadleaf species grow well when planted in these reclaimed areas.[50]

Induced infection of the mycorrhiza fungus *Pisolithus tintorius* has been shown to enhance water absorption and nutrient uptake by seedlings of loblolly pine on reclaimed surface-mined sites. The treatment significantly improved survival and height growth in the early years. (In contrast, fertilizer additions without the *P. tintorius* reduced growth by stimulating competing vegetation.)[51]The shape of the boundary of a reclaimed mine site affects encroachment of woody plants. Transects adjacent to concave forest boundaries have twice as many colonizing stems as those next to convex boundaries. Through time, a concave–convex reversal in boundary form occurs, producing a “cove concentration” where the greatest boundary extension rate is in coves being colonized. Thus, planting trees to form concavities along a straight forest boundary enhances colonization of a mined area.[52]

Oilfield waste areas, common in the western sector of the southern forest, are difficult reclamation sites. Salt in the effluent, three times as saline as sea water, kills trees over areas as much as 100 acres in size. In such soils, seeds do not germinate and seedlings are killed. Ditches allowing for drainage of soluble salts (as much as 5000 parts per million) in the soil, are made by tractor-drawn machines laying a vinyl tile liner in a mole-like subsoil tunnel. The vinyl tube, fed into the mole hole, is perforated on the upper side to allow inflow of leachate saline water into the channel. From these tubes, the effluent flows to settling basins. The sites are then ready for planting.

The Export Dilemma

The demand for southern wood for shipment abroad continues to increase dramatically, producing the need to fully occupy land designated for forests with trees. Intrusion on the region’s timber supply occurs as the Japanese build plants for chipping hardwoods,with the chips sent to other Asian nations as raw material for particleboard and paper. As the build-up of the export demand will require intensive reforestation, the subject concludes this chapter.

Local industries discourage the sale of raw wood to foreign consumers, fearful that competition will raise stumpage prices and bring about a shortage of fiber for domestic consumption. In the case involving hardwood chips, the stems from which this material comes were considered weed trees until recently. As such, these undesirable stems were killed with herbicides or bulldozed, windrowed, and prescribed burned in order to release the more valuable pines from competition for soil moisture, nutrients, and sunlight. (The South’s best hardwood-producing lands, apart from the Delta, are now largely under water in the region’s many lakes.) Meanwhile, industrialists complain of losing mill jobs if logs are shipped abroad, but the demand for wood increases employment in the forests.

While wood-using industries lobby to restrict the sale abroad of wood from national forests and hope to discourage construction of foreign-owned utilization plants, others—particularly state foresters—encourage such sales to increase stumpage prices and, therefore, enable small, nonindustrial landowners to enjoy a return on their investment and, as a result, stimulate an interest in growing trees for the market. If the South does not provide this export wood, it will be made available to industries abroad by the timber operators of Australia, Chile, New Zealand, the tropics, and South Africa.

Foresters and what they can do to increase the productivity of southern woodlands have been omitted from the debate. Across the South, productivity currently is perhaps one-fourth the volume of wood that forested sites are capable of producing with even minimal management. Often the value of stumpage has not been adequate to allow the owners of small tracts to employ professional assistance. When the threat of scarcity becomes a factor, knowledge is available to multiply growth of tree volumes by at least four times.

The threat of scarcity can be ascertained readily from the every-decade federal surveys of the American forestry situation. These surveys document volumes, species, size classes, and other statistical criteria for the nation's timberlands. A 10-year advance notice of a shortage is all the region's landowners require to gear up to meet the demand with the professional skills available, for the South possesses the finest soils, the finest climate, and the finest species for growing wood.

6 Protecting the Forest

Field foresters are responsible for diagnosing the ailments of a forest, prescribing the remedies, and carrying out the treatments. Many of the ailments encountered relate to insect infestations and disease infections, the latter caused principally by fungi. Forests also need to be protected from harmful bacteria (or the lack of helpful bacteria), nematode activity, nutrient deficiencies, chemical toxicity, and fire.

Southern forests have an advantage over those of the western United States, Canada, and the tropics. Forested tracts in this region are relatively small in contrast. Thus, clearcut harvest units and plantations are not as extensive, reducing greatly the potential for disastrous insect and disease outbreaks. Streams dissecting the land also divide even the larger tracts into manageable compartments.

Until establishment of the Environmental Protection Agency (EPA) in 1969, chemicals were used without restraint to control or reduce the injury attributed to destructive agents. Because availability of chemicals approved by EPA for silvicultural purposes changes rapidly, this book does not name specific pesticides and their applications. No sooner are regulations published than new and cheaper compounds become available or, on the other hand, an allegation of danger to certain life forms occurs. Also, foresters try various chemicals as they appear on the market, rejecting them when they appear to be economically ineffective.

INSECT PROBLEMS

Prevention of severe insect attack is generally directly proportional to the quality of forest management. Vigorous trees are not easy prey. Logging injury to residual trees and soil, fire damage to trees, and lessened vigor of mature stems as natural succession progresses toward a more shade-tolerant forest type, tend to place trees in jeopardy to insects. Timely silviculture, like thinning, is a preventive measure that may sometimes make insecticide applications unnecessary.

As a general rule, no insecticide need by applied if many holes, appearing like birdshot, encompass the bark of a tree and the needles have already turned red. Insects have left such trees, and if the intruder is the southern pine beetle, the trees will surely die.

Pales Weevils

Pales weevils compose one group of pests. Serious losses of young seedlings of all southern pine species occur in freshly cutover stands as a result of bark-gnawing by the adults. As many as 90% of the seedlings in a single plantation might be attacked. Infestations can increase as clearcutting and seedling planting increase.

Small holes, numerous enough to girdle trees or to kill the current season's succulent shoots, are chewed into the bark, usually at night or on cloudy days. By day, the insects hide in the soil near the base of seedlings. Weevils even go beneath the ground to a depth of five inches to girdle roots. As breeding takes place in the roots of pine stumps and logging slash, the problem is most prevalent in freshly cutover areas. For this reason, tree planting is often delayed a year or two after loggers harvest merchantable pine stands to give time for the stumps and slash to begin to decay. Burning the slash can also be performed. As hardwood slash is not suitable for weevil breeding, sites formerly supporting deciduous trees can be planted promptly. When natural regeneration is anticipated, an abundance of seeds must be available, the many members of the *Hylobius* genus

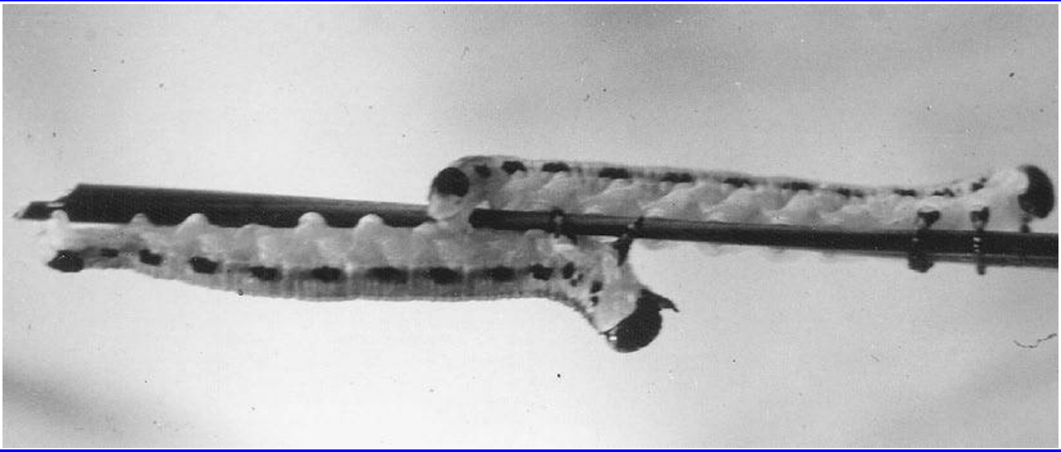

Figure 6.1 Black-headed sawfly larvae. Feeding by *Neodiprion excitatus* on loblolly pine needles may cause serious losses, as occurred in the Texas Lost Pines area in the 1980s. (Texas Forest Service photo by Ron Billings)

getting their share. Enough seeds to produce vigorous seedlings must be available for adequate restocking.

Sawfly

LeConte's sawfly also destroys conifers. Sometimes called the redheaded sawfly, the greenish, one-inch long, hairless larvae strip whole trees of foliage, which kills the trees. Many species of the genus *Neodiprion*, to which the sawflys belong, are defoliators. Some are gregarious, others not. Some defoliate terminal branches, some only one-year-old needles, and some are so particular as to prefer pure stands 25 years of age in understocked old fields. Trees often do recover, even from repeated yearly attacks, but growth is reduced. Females cut slits in needles in which they lay eggs. Hatching in the spring, the larvae feed in clusters for several weeks before falling to the ground. There, if not consumed by birds, they spin shiny brown cocoons from which adults emerge in the autumn of the year.

Southern Pine Beetle

Disastrous attacks of the southern pine beetle have periodically ravaged the forests of southern pines, especially loblolly and shortleaf pines, from the 1950s to the present. No doubt occasional outbreaks occurred in the virgin forest, but a different tree species composition and fewer pines per acre than in second-growth forests and plantations probably limited the seriousness of the attacks to an endemic degree.

Dendroctonus, the genus to which the southern pine beetle is assigned and which means "killer of trees," was first described in 1838. The known distribution of its members has been periodically mapped. *D. frontalis*, the subject of our present concern, attacks trees of all ages, but especially those weakened by drought, lightning, fire, and wind. Epidemics usually follow long periods of hot, dry weather; but, after years of intensive research, the underlying causes of the outbreaks remain unknown. A number of outbreaks have been found to occur in stands grown on fine-textured, clayey ultisols.[1]

As far back as 1925, the possibility of increased sap density during drought periods was suggested as a contributing factor. A droughty situation is at least partially indicated by the dense stands now encountered—there being only so much water in the soil to sustain the vigor of a limited

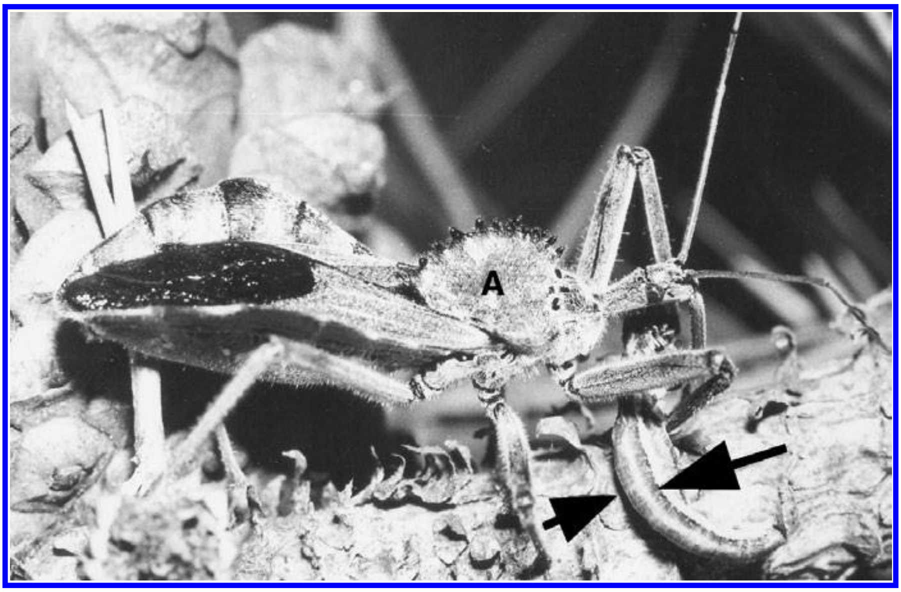

Figure 6.2 Wheel bug (*Arilus cristatus*) predates on sawfly larvae. An example of natural biological control, the mouthparts of the cogwheel-shaped head (A) of the large insect, a true "bug," suck fluids from the small worm (arrows). (Texas Forest Service photo by Ron Billings)

number of trees. High costs for thinning, compared with the income a landowner receives for the partial, low-volume harvest, and the prohibitive cost of making precommercial thinnings, has dramatically increased the acreage of southern pines susceptible to attack by the beetle. Extremely dense stands have the same effect as drought.

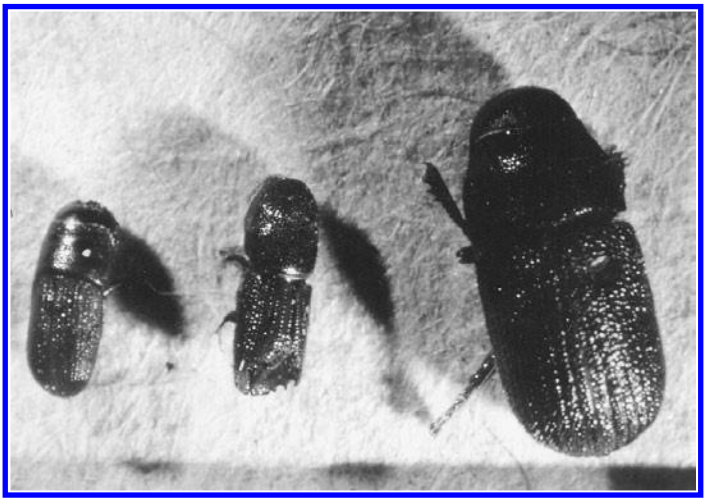

Figure 6.3 The southern pines' great adversaries. Left to right, adult southern pine beetle, *Ips* spp., and black turpentine beetle. (Texas Forest Service photo by Ron Billings)

Principal attacks begin in the spring, about the time the dogwoods bloom. Death of trees takes place soon after infestation. As 4 to 6 generations of the insect are produced in a year in 30- to

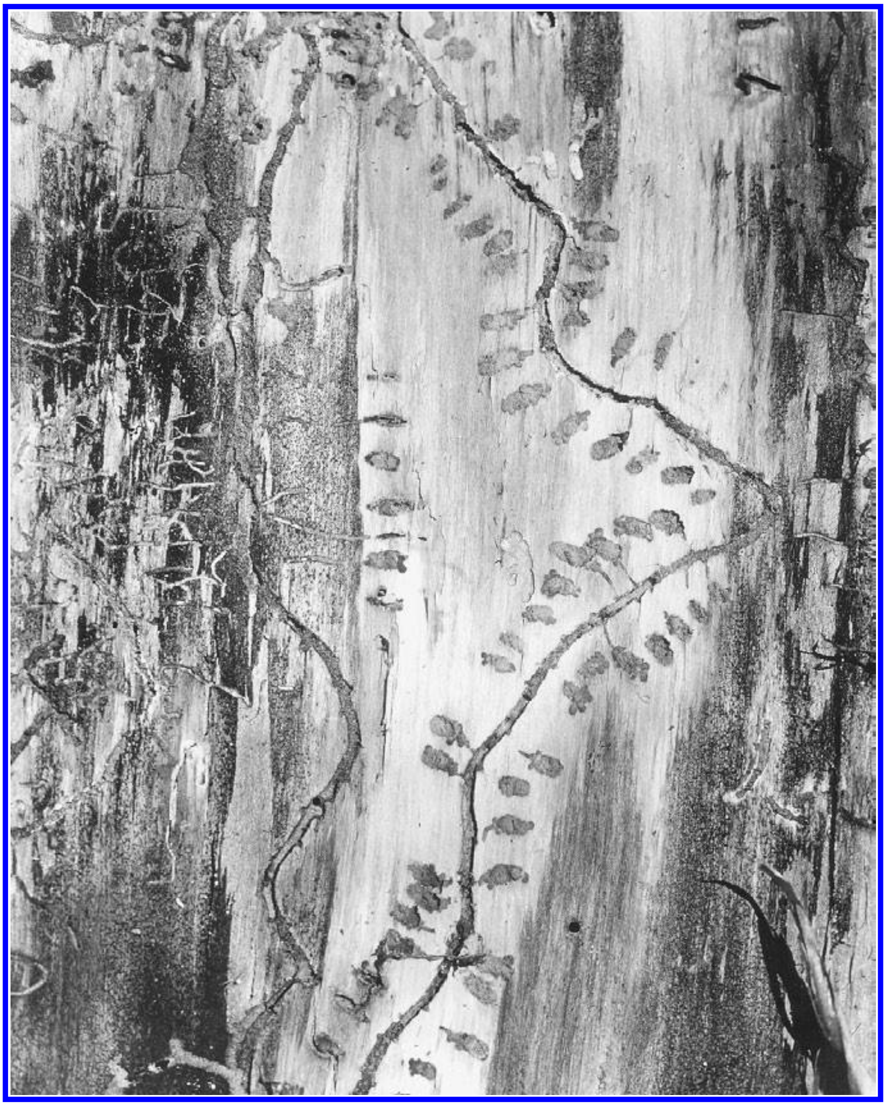

Figure 6.4 S-shaped tunnels in the inner bark of a southern pine tree killed by the southern pine beetle. Note that where the gallery passes through the darker, blue-stain fungus-infected zone (to the right) that followed the beetle attack, the larvae galleries are long (abnormal) in contrast to shorter side cavities elsewhere. Powdery frass fills these darker galleries, evidence of a secondary attack by the southern pine sawyer. Blue-stain infection may utilize nutrients or exude a toxic chemical to the detriment of tunnel-carving beetles. (Texas Forest Service photo by Ron Billings)

40-day overlapping cycles, some trees are attacked as late as autumn. Overwintering may occur in any stage of the insect's life cycle.

During epidemics, new attacks occur in large, irregularly spaced groups with a definite directional pattern, the initially infested stems serving as "springboards" for infestation of surrounding healthy trees. Single-tree attacks also occur, again in a directional pattern, often hundreds of yards between the insect's chosen trees. Why the beetle selects some stems and passes over others remains a mystery. Tree death usually occurs shortly after infestation—stems attacked early in the growing season are dead by midsummer, those hit in the autumn die during the winter.

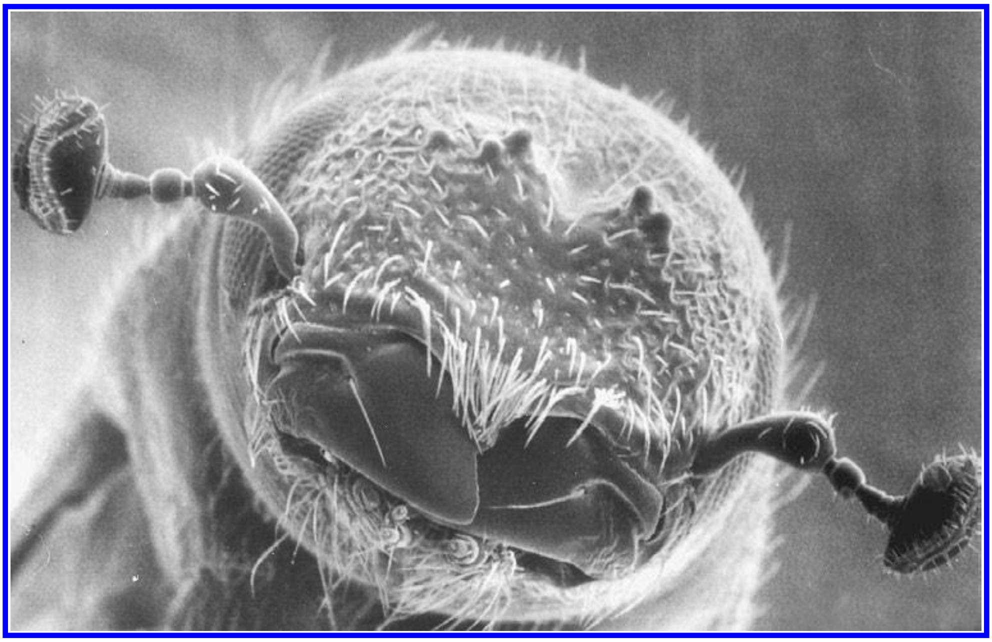

Figure 6.5 Head of an adult southern pine beetle greatly enlarged. Note the horns (which indicate a male), compound eyes, club-like antennae, and mandible mouthparts that play havoc with the inner bark. (Texas Forest Service photo by Tom Paine)

Foliage at the top of the crown begins to fade about 10 days after initiation of attack, small yellowish-white pitch tubes appearing like wads of gum, then forming around the adults' entry holes in the bark of the lower bole of the tree. Reddish-brown boring dust soon accumulates in bark crevices, in cobwebs on the trunks, and at the bases of the trees. At this time, the gnawing action of the insects, recently hatched from eggs and in the larval stage, can be clearly heard as they girdle the tree's cambial growing tissue.

Mid-trunks of trees are first attacked, with the beetles moving up and down the bole. Evidence of attack in stems retaining green foliage is the stripping of bark by birds seeking larvae and adult beetles. Large trees then take on a buckskin appearance.

Winding S-shaped galleries on inner bark and wood surfaces, with tunnels that criss-cross, assure the observer of proper identification. Eggs laid in the nuptial chambers extending from the galleries like *cul de sacs* in the phloem hatch to produce whitish larvae with glossy reddish-brown heads. At first, the young winged adults, the size of a grain of rice, are soft and white. Soon they harden and turn dark brown. Each of these adults, with notched head and rounded hind part, escapes through a pin-size hole chewed in the bark. Wind then carries them great distances to infect other trees.

Low temperatures kill broods over-wintering in the phloem in all stages. As pine bark has high insulation capacity, a rule of thumb is that 5 days of 58°F weather is necessary for controlling the beetle's epidemic attacks. (If bark were not a good insulator, cold weather would kill trees, as the moist growing tissue (the cambial layer) lies just under the bark.)

Blue stain in the wood, caused by the fungi *Ceratostomella ips* and *C. pini*, relates to the cessation of water conduction and the drying of the xylem in trees killed by the southern pine beetle. While not causing structural damage to the wood, the appearance of blue stain does reduce lumber value to such a degree that prompt salvage of logs of beetle-killed trees is desirable. Salvaged logs, of course, depress the timber market.

Woodpeckers, ardent consumers of southern pine beetles, are encouraged as biological control agents, but many of these birds are killed by the ice storms that also eliminate the beetles.

To save infested trees, even with chemicals approved, or "labeled," by the Environmental Protection Agency, is impossible. Simply cutting the infected trees and those healthy stems surrounding the southern pine beetle "spot" for 50 feet outward, and felling the trees inward, is the recommended practice. Salvage is appropriate if the logs are merchantable. The once-touted pheromone trap, capturing adults in sex-attracting chemicals isolated from the hind gut of adult insects and synthesized for commercial use, was a disappointment.

In addition to timely and periodic thinning, beetle damage can be forestalled by maintaining protective overstories, eliminating food plants for nymphal-stage insects by extensive site preparation prior to planting, removing high-risk stems (those likely to be toppled by wind, for example), and not assigning species in planting operations to sites for which they are ill adapted.

Lesser Bark Beetles and Borers

The pine engraver bark beetle is an insect of lesser importance in the southern pineries because it kills only already weakened trees. Several species of the genus *Ips* attack all of the southern pine species following fire, logging damage, windthrow, lightning strikes, or during severe drought. As physiologically weakened stems are prime targets, these are termed secondary insects. They breed in slash piles—the limbs and tops left after logging—as well as in dead branches of living trees. When the tiny black or brown, hard-shelled beetles attack, pink, brown, or white pitch tubes about the size of a wad of chewing gum form at the entrance holes on tree trunks. Trees of low vigor may have no pitch tubes, but the attack is then indicated by reddish boring dust in bark crevices and in spider webs at tree bases. For *Ips*, the galleries are I-shaped (in contrast to S-shaped for the southern pine beetle). From these, the adult carves nuptial chambers where eggs are laid and from which the cream-colored larvae further excavate the galleries that girdle a tree.

Another secondary insect pest of the southern forest is the southern pine sawyer, so named because the larvae tunnel through the wood to degrade the lumber. The sawyer attacks recently cut logs as well as trees already entered by bark beetles and other stems of reduced vigor. The mottled, reddish-gray, inch-long adult deposits its eggs in funnel-shaped pits gnawed through the bark and into the phloem. The one-inch-plus flattened white grubs feed on phloem tissue, expelling coarse shredded frass through ventilation holes in the bark. Next, they saw their way deep into the wood, negotiate a U-turn, and then return to near the tree trunk's surface. There, enlarged excavations serve as pupal chambers. Pencil-size holes in the bark in the spring of the year indicate the adults' exit.

Ambrosia beetles also attack weakened standing trees, although those recently felled, and unseasoned timber are the principal hosts. Eggs of the reddish-brown adult, an elongated beetle about 1/4-inch long, produce larvae that excavate small cells extending from primary tunnels running parallel with the grain of the wood. There, "gardens" of ambrosial fungus are cultivated for food for both larvae and adults. Evidences of activity by any of the several genera of this group of pests are the dark-stained pinholes made in the outer surfaces and the piles of yellowish-white fluffy boring dust that accumulates around the bottoms of the trees.

The flat-headed pine borer (the name "flathead" traditionally given to human timber fellers in the South) as an adult resembles a knight in dark metallic-bronze armor. It is the grubs, the larvae, that are distinguished by their flat heads. These members of the *Buprestis* genus burrow in the wood of stumps for several years. Adults later enter living trees through trunk or branch wounds in which they lay their eggs.

Another flat-headed grub is the turpentine borer, so named because of its activity where gum naval stores operations are carried on in the longleaf and slash pine forests. The white larvae tunnel the wood of the basal portions of trees for three years, leaving densely packed boring dust mixed with resin in the hollows. The elliptical emergence holes, from which adults leave one tree to seek another, can be seen on the dry faces of trees that have been "worked" (by chipping) for turpentine or on fire scars where raw wood is exposed. While boring by larvae occurs low on the trees, the one-inch-long adults feed on pine needles high in the crowns.

Slash pine scions in tree-improvement grafts are damaged by *Pityophthorus pulicarius*, a small insect that attacks the tips of dying branches and terminals in the process of natural pruning. Fresh sticky frass pushed out as it bores into needle tips at their bases or through old needle scars on the twigs tell of this bark beetle's presence.

Black and red turpentine beetles, first noted in 1948 as a problem for southern pines, have become serious pests. Their importance may be due to logging practices—heavy machines churn up the ground, puddle soil, bruise roots, and skin trees. In addition to outbreaks under these conditions, attacks occur on low, poorly drained sites logged during wet weather. Avoiding ground disturbance minimizes the problem.

Nantucket Pine Tip Moth

Among the most damaging insects to southern pines is the Nantucket pine tip moth. This is especially so for shortleaf and loblolly pines less than 10 feet tall, although terminal buds 25 feet above the ground may be attacked. Some trees inherit resistance to the malady.

The tip moth overwinters in the pupa stage, with rarely seen adults emerging in the spring to deposit eggs, laid singly, two days later on old-growth needles, on developing buds, or in the axils where needles join the stem. After several weeks, the larvae chew their way out of the eggs and then build delicate webs in the leaf axils where developing needles emerge from twigs. From this position they bore into needle sheaths to feed. Caterpillars then tunnel their way down the centers of young stems and through bud and twig tips, severing conducting tissues as they work and, as a result, altering the form of the tree. Some larvae remain on the outside of the twigs. In the warmest parts of the South, six generations can occur in a single year.

The dead tree tips look like disintegrating spikes. Severe infestations leave trees with deformed branches called witches' brooms. Trees may be repeatedly attacked, which permanently deforms them with crooks and forks. Reduced height growth by up to 6 inches per year occurs, and some trees die.

Slash and longleaf pines' resistance to attack may be related to the inability of the cream-colored caterpillar larvae to rapidly crystallize the oleoresins of these highly viscous species. The inconspicuous red-mottled adults drown in the bud's resin flow. Attacks by this insect (and by sawflies) increase the proportion of compression wood in the merchantable part of the bole, which lowers the wood's quality.

Silvicultural recommendations include planting pines only on favorable sites, mixing resistant and nonresistant species, and planting trees under a broadleaf overstory (the pines to be released later). In spite of the many predators, both bird and insect, and the high degree of these organisms' parasitism on tip moths, populations of the insect do not appear affected by them.

White Pine Weevil

White pine weevils, a serious menace in northern stands, have become potentially troublesome in the Southern Appalachians, beginning in the mid-1950s. Earlier immunity has been attributed to the absence of young trees in sufficiently contiguous stands for continuous breeding of the weevil. Dense brush in mountain stands has also been suggested as a reason for the earlier apparent resistance to attack by this insect.[2]

Pruning all but one branch of the last whorl improves the form of weevil-injured trees. The branch selected for retention should be the most vigorous. Annual growth losses of 60 to 70% occur until the trees are about 15 feet tall. As the weevil adults seldom fly higher, eggs are not laid in buds above this height. As the weevils repeatedly attack selected stems, thinning is delayed until

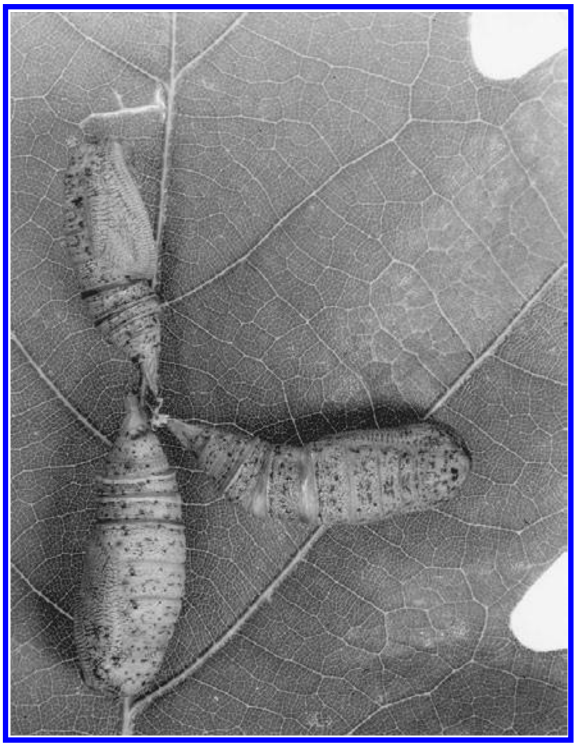

Figure 6.6 Elm spanworm, the pupa of the snow-white linden moth. The insect attacks many broadleaf forest trees of the South, economically impacting the future wood supply.

after trees reach that height; trees with the insect-caused crook are then removed. In dense stands, a sufficient number of apparently resistant trees escape the predation.

Elm Spanworm

The elm spanworm, first noted in 1951 in the region, had within 15 years defoliated more than a million acres in North Carolina, Tennessee, and Georgia. By the early 1970s, forest entomologists considered peak infestation had been reached; from that time until the present, defoliation appears spotty. Hickories, oaks, black walnut, maples, and American beech, in that order, are preferred hosts. Adverse effects of repeated defoliation are manifested for several years in reduced vigor, growth loss, and mortality.

Long-distance migrations of the adult, known as the snow-white linden moth, account for the pest's rapid spread. Within a week after emergence from the pupal stage—in crumbled, folded leaves or in strings of self-spun silk—the adult female lays her barrel-shaped, olive-green eggs in irregular masses, usually in June, on branches and bark. These hatch the following spring. The greenish-brown "looper" larvae feed on succulent new foliage, defoliating a host tree in about a month. The pupal stage then lasts about two weeks.

Biological control measures, such as the introduction of egg parasites placed on egg masses, might be appropriate. Currently labeled chemicals sprayed on young larvae control the insects' reproduction. (See Chapter 4 for a discussion of the gypsy moth.)

Tent Caterpillars

Many species of broadleaf trees are preferred habitats for the eastern tent caterpillar, whose dense white silken tents appear in the crotches of limbs. In these tents live countless numbers of the black, hairy larvae that sport bluish-gray sides and a prominent white stripe down the back. At maturity, they are two inches long. Only occasionally is defoliation in the forest serious. Foliage sprays in the spring of any of several all-purpose labeled insecticides effectively control tent caterpillars.

Pitch-Eating Weevils

Pitch-eating weevils sometimes kill planted loblolly and shortleaf pine seedlings where overstory pines have been cut within three months of planting. As stumps decompose rapidly, the danger of attack by *Hylobius picivorous* is short-lived. To avoid the risk of attack, harvests anticipating natural regeneration should be done in good seed years, for there is little danger of pitch-eating weevils destroying a bumper crop of seedlings. On the other hand, where advanced reproduction is present, final harvests could be delayed until those seedlings are 3 years old. Prompt harvest is then essential because of the loss of shade tolerance by these conifers as they advance through the seedling to the sapling stage.

Larvae of pitch-eating weevils feed beneath the bark in roots of stumps, working as deep as 3 feet in the soil. Adults deposit eggs in cambial layers above the ground, where they riddle the bark as they girdle seedlings. Puncture wounds in the bark indicate active feeding. Dipping nursery stock in an insecticide prior to planting protects seedlings to be planted.

Cottonwood Borers and Beetles

Apart from the elm spanworm, the tent caterpillar, and the gypsy moth, hardwood trees of the southern forest are not greatly injured by insects. For young cottonwoods, a short-lived, fast-growing, and hardy tree, the twig borer is the most serious pest. Terminal shoots are attacked in much the same way as tip moths invade the buds of pines. Height growth is stunted, main stems are deformed, and boles branch into forked stems. Dipping seedlings and cuttings into a systemic insecticide just before planting in the field provides protection.

Root and stem borers of cottonwoods also damage plantations. White or pink larvae make tunnels up to 6 inches long in the pith and wood of young root crowns and stems bases, and the stems break off at the tunnels. To allow the escape of the adult moth, the insect maintains the hole, which then becomes an obvious indication of insect infestation.

Simultaneously, cottonwood leaf beetles consume foliage, occasionally stripping entire trees. The black- and yellow-striped larvae of these beetles give off a pungent odor when molested. Normally, lady beetles feed on leaf beetle eggs and pupae, thereby checking population growth. The drift of insecticides used in cotton fields nearby may aggravate attacks on cottonwood trees, as agricultural insecticides, being nonselective, kill lady beetles and other predator insects of leaf beetles.

Evergreen bagworms (infesting both coniferous and deciduous trees) consume foliage, leave behind their ugly pendulant "ornaments," and kill trees. Larvae carry the bag during the period in which they feed and survive in this form. Females of *Thyridopteryx* spp. never leave the protective case of silk-like material secreted by the insect. In this shelter they lay their eggs and there they die.

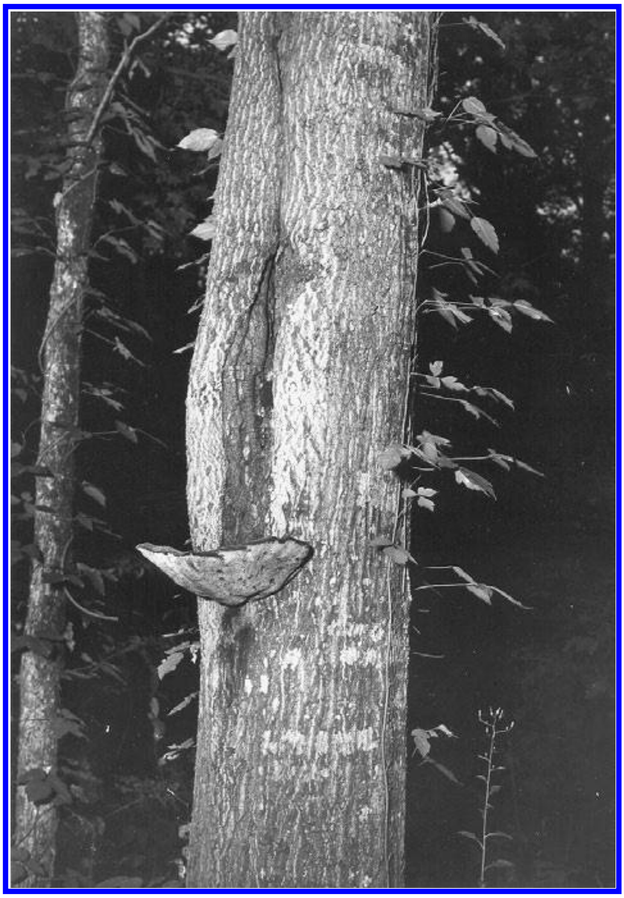

Figure 6.7 Fruiting body of *Polyporus hispidus*, a trunk canker, on Nuttall oak. Conks like this shelf fungus produce the spores that infect trees, causing wood decay. (authors' collection)

FUNGUS DISEASES

HEARTROTS

Red heart rot, caused by *Fomes pini*, and butt rot, caused by the fungus *Polyporus schwenitzi*i, are among the more serious fungus infections that decay the wood in living southern pine trees. Spores of *F. pini* enter the tree through broken branches and other injuries to the bole of the tree. Mycelia grow upward and downward, releasing chemicals that destroy wood fibers and decay the heart of the tree, leaving a reddish-brown material that is considerably softer than solid wood. Hence, the name red ring rot also describes this disease. Not all infected trees exhibit on their boles the elephant-ear-shaped fruiting bodies from which the spores are disseminated. It is this interior heartrot material that the threatened red-cockaded woodpeckers excavate for their nests.

Ironically, careful management of the southern pine forests led to the demise of the bird over much of its range. Foresters, in thinning these woods to enhance the vigor of the trees left in the forest, removed diseased stems. Red heart rot was the primary offender; sending these infected trees to the mills halted spread of the disease. But in so doing, opportunities for the bird to nest disappeared and, with those opportunities went the birds. Foresters now either set aside whole tracts in which the birds can freely colonize or they protect one infected stem within perhaps each 10 acres of stands scheduled for thinning or harvesting. While the red cockaded woodpecker may soon

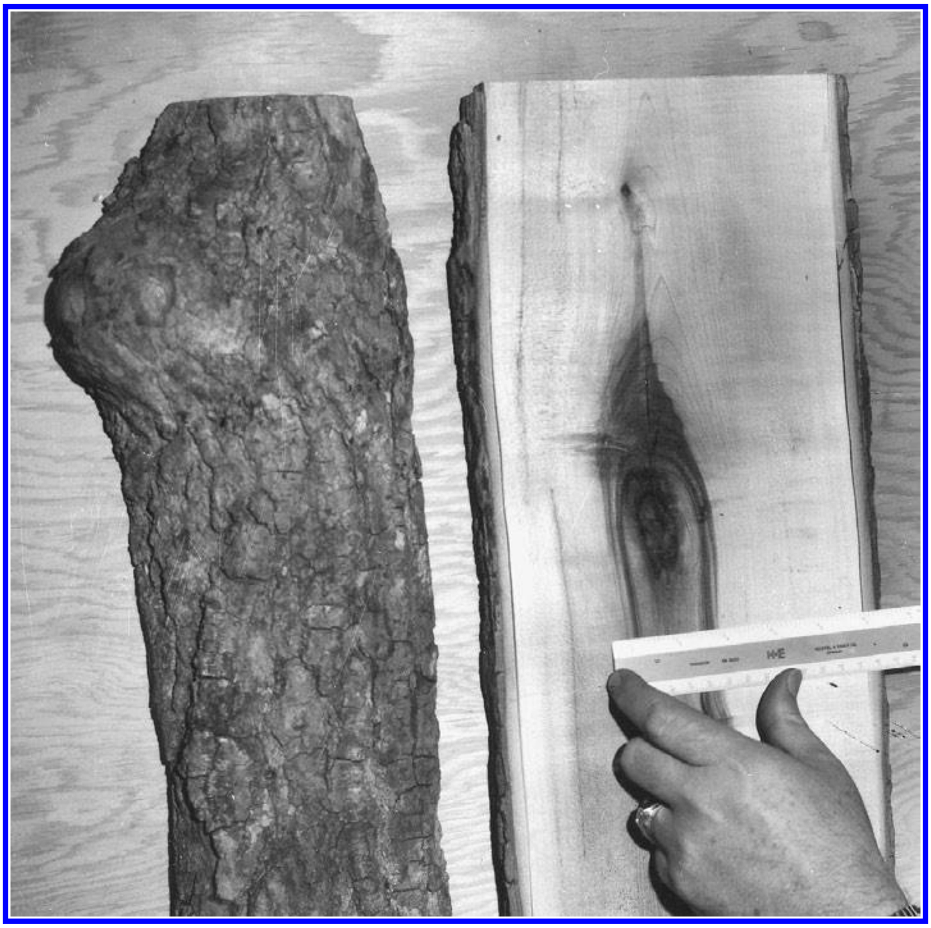

Figure 6.8 Knots, an indicator of rotting wood. Inside the log, the defect is obvious. Such infections prevent use of the wood even for the hidden parts of upholstered furniture. (USDA Forest Service photo)

be removed from the U.S. Fish and Wildlife Service's Threatened Species List, management practices on both public and private lands protect the bird's habitat. Meanwhile, F. pini spores now spread to healthy stems from diseased trees.[3]

Butt rot infections on southern pines occur as *Polyporous schweinitzii* spores make contact with wounds made at the bases of trees. Such wounds are attributed to logging damage or to fire. Trees so infested are also among the first to be harvested in thinnings or selection harvests.

Annosus Root Rot

Three principal species have custom-tailored maladies—for slash pine, it is annosus root rot; for longleaf pine, brown-spot needle blight; and for shortleaf pine, littleleaf disease. The occurrence of annosus root rot is related to the amount of organic matter, sand, and clay in the soil; the pH of the top 6 inches of soil; and the amount of grass covering the soil. Thus, severely damaged plantations established on cutover and abandoned agricultural land contain little organic matter in the soil and proportionately greater amounts of sand or clay content than for uninfected woodlands. Soils under diseased trees also have higher pH and less grass cover than do healthy stands. Losses to the disease increase with time following thinning, and with the number and frequency of thinnings.[4]

Figure 6.9 Infected oak sprout. This tree contracted a fungus infection from its decaying parent stump. (authors' collection)

The disease is almost always found in thinned plantations, though occasionally it occurs in natural forests. This may be attributed to the time required for the disease to build to epidemic proportions, which is at about the time, perhaps 20 years of age, that stands are ready for thinning. Trees dying naturally use up soluble carbohydrates in roots, leaving dead tissue—a poor medium for the growth of this fungus—in contrast to the healthy roots left following the harvest of living trees.

Spores circulating in the air fall on the wood of freshly cut stumps within a few minutes of harvest. The spores germinate on these stump tops within a few days of exposure of the raw wood. The fungus mycelia grows down the stump, into the roots, and through these roots to those of nearby residual tree stems. Living trees are probably infected through root grafts or by close contact with infected stumps. A diseased root, in one case, infected a healthy tree by simply being placed against its root. It took about a year for the disease to become apparent in the 12-year-old tree.

Since infection follows thinning, slash pines on susceptible sites should be managed on short rotations with minimal thinning, then clearcut at an early age, perhaps 30 years. Final harvests of diseased stands should not be delayed until it is obvious that the losses cannot be offset by increased growth of residual trees following thinning. While planting at wide spacing reduces the need for thinning and resultant losses from annosus root rot, the possibility of damage from bole-deforming fusiform rust increases with wide spacing. A several-year delay between the final harvest and

Figure 6.10 Burl on oak. The tumor, a hypertrophic symptom of a fungus infection, is due to excessive division of cells of abnormal size. Cabinetmakers fashion beautiful table tops from wood cut from burls.

planting may be desirable to permit *Fomes annosus*-infected stumps and roots to decompose, as the fungus disappears with the decay of host material.[5]

An early treatment for annosus root rot included the application of coal-tar creosote to tree stumps as soon as trees were cut in a thinning. Borate compounds have been similarly used. Biological control, through competition or the antagonism of the *F. annosus* fungus with other fungi-inoculated stump surfaces, is effective. Fungi that decay wood hasten decomposition of stumps, thus eliminating the channel for infection. Thinning may be best done in the summer when fewer of the windblown basidiospores of the fungus contaminate the air.

A summary list of activities that may reduce losses from this disease include planting rust-resistant and healthy stock, reducing and managing oaks, delaying fertilization, planting alternative species (such as longleaf pine), and considering alternative silviculture (such as using a shelterwood system).[6]

Fomes annosus also causes a stringy white sapwood rot of tree butts and roots of eastern redcedar. Trees break off at the site of the pocket rot. Often, perennial conks of the fungus begin to appear at grooves on roots or on root collars at the ground line a few months after the trees die. Browning of foliage, decaying taproots that enable trees to be easily pushed over, and exuded resin in rifts in the bark are other symptoms. The heartwood of *Juniperus* may contain a chemical toxic to the pathogen, as such toxins appear for other wood-decaying fungi.

Fomes annosus occasionally infects white pine. The same pathogen induces a butt rot in conifers of Scandinavian forests.

Brown-Spot Needle Blight

Brown-spot needle blight of longleaf pine, caused by *Scirrhia acicola*, reduces growth of grass-stage seedlings, thereby extending the nanism period well beyond 10 years (and up to at least 25 years) and causing many trees, after successive defoliation, to die. The disease is less serious in

Figure 6.11 Fomes annosus infection has begun to naturally thin this stand of slash pine. A few trees per acre infected each year will spread to eliminate a typical stand in about 20 years. Planned thinnings aid in avoiding the waste of diseased trees. (authors' collection)

the range of the host tree in the Atlantic Coastal Plain than it is farther west. The blight's occurrence in the South Carolina Fall Line Sandhills can be attributed solely to inoculation of nursery stock, introduced from beyond the Fall Line. Rarely was the disease found in virgin seedling stands, perhaps because the partial overstory of these forests inhibited *S. acicola* development. On the other hand, badly diseased nursery stock has been successfully outplanted, possibly because the dead needles reduced transpiration of scarce moisture supplies in the soil.[7]

How the disease is transmitted—Sexual ascospores of *S. acicola* mature within 2 to 3 months after infected needle tissues, at first straw-yellow, turn brown and die. Throughout the year, these spores are carried great distances by wind to inoculate the soil. Asexual spores, called conidia, are then exuded from jelly-like globs in the soil, from whence they are washed or splashed by rain. In the spring, the conidia infect young elongating longleaf pine needles near their tips. Conidia are also washed into the soil from the dead and severed foliage on the ground. Increasing immunity of seedlings with height growth likely relates to the greater height to which rain splash must carry the infecting conidia spores than to the tree's physiology or morphology. Other pine species may have some infection, but prompt height growth precludes serious damage to them by *S. acicola*.

Because fungicides are costly, prescribed burning is the best control technique. Some infection will follow the fire because rain splash delivers spores from the uncovered soil to the foliage of seedlings. Two cool, winter burns may be required if, and when, infection has killed more than one-third of the seedling's foliage. Two years may need to lapse between fires to allow time for fuel—the "rough" of grasses and forbs—to build to adequate levels.

Figure 6.12 Careful observation of the base of slash pines, often hidden beneath needles, shows the fruiting bodies of *Fomes annosus*, the causal agent of annosus root rot. The underground traveling disease infects through root contact.

Littleleaf Malady

The littleleaf malady of shortleaf pine is most severe in severely eroded areas where heavy, poorly drained subsoils underlie a shallow surface layer. Poorly drained soils provide habitat for the water-demanding swarm spores of the *Phytopthora cinnamomi* fungus. Poor internal drainage also reduces aeration, and that, in turn, influences the tree's physical condition and chemical reactions in the soil. Low site indexes are a clue to the littleleaf hazard potential; however, stands less than 20 years old are seldom attacked. As susceptible trees age, vigor generally declines, including the regenerative capacity of roots, the organs attacked by the pathogen.

Diseased shortleaf pines are deficient in nitrogen and calcium, according to foliar analyses. Fertilizer applications of 200 pounds per acre of nitrogen as ammonium nitrate reduce the prevalence of the disease through root-growth stimulation. New feeder roots allow for improved absorption of nutrients and water. Some trees already suffering from the malady also improve if fertilized with nitrogenous material. Fertilizers should never be worked into the soil, lest the feeder roots be damaged by the tools—and inoculum introduced—or by the chemical salts.

Perhaps the best remedy for littleleaf disease is a long-range plan that encourages hardwoods and pines other than shortleaf pine to take over the site. Seeding leguminous lespedeza is a recommended practice. Like deciduous leguminous trees, this nitrogen-fixing exotic from the Orient improves the soil. Diseased trees should be harvested promptly upon discovery to avoid bark beetle infestations developing in the weakened stems. From these initial attacks, the insects might migrate to other trees in the stand.

A littleleaf-hazard-rating scale utilizes the degree of erosion, consistence of subsoil, depth of permeable soil, and degree of subsoil mottling. Trees likely to exhibit the malady occur in rough and gullied soils with extremely firm subsoil, where permeability near the surface is poor, and where mottling is strong. (See Chapter 2.)

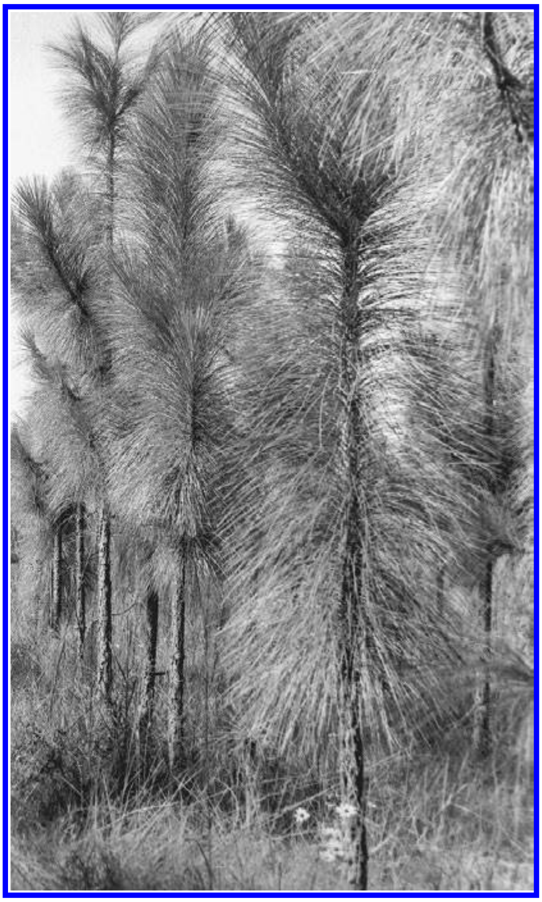

Figure 6.13 Bordeaux-sprayed longleaf pines. The fungicide (consisting of copper sulphate, hydrated lime, and water) was sprayed on trees (now 7 years old and 10 feet tall) while still in the grass stage. Brown-spot needle blight retains untreated seedlings in the grass stage for as long as 25 years. (USDA Forest Service photo)

Fusiform Rust

The most serious fungus pest of slash pine (and to a lesser degree loblolly pine) is *Cronartium fusiforme*. (Some authorities call the causal agent *C. quercuum*, which suggests the alternate host relationship—*Quercus* being the genus to which oak trees belong.) Infection results in spindle-shaped swellings of trunks and branches. When the mycelia strands reach the cambium, a hormonal reaction occurs, and rapid wood growth takes the shape of a spindle, or fusiform. This gall is entirely low-density earlywood. Both size and number of cells in infected wood are much greater than in uninfected portions of the same tree. The fungus can produce a hormone-like growth-regulating substance similar to a carcinoma. When exuded, it stimulates cell division and growth, much as gibberellin, produced by another fungus, now serves commercially as a plant-growth regulator.[8]

While trees of all sizes are infected by spores of the fungus, seedlings and saplings suffer the most. Mixing species for planting lowers the incidence of fusiform rust, but rarely do trees of different species grow at the same rate on the same site. One likely dominates to the exclusion of others. Loblolly pine usually grows faster than slash pine in the Piedmont and conversely so in the Coastal Plain. *C. fusiforme* cankers lead to wind breakage.[9]

Figure 6.14 Littleleaf malady of shortleaf pine. This disease occurs on heavily eroded soils of the Piedmont province, especially in South Carolina. Reduced foliar nitrogen accompanies the short-needle syndrome. (USDA Forest Service photo)

Many oak species serve as alternate hosts to slash and loblolly pines for the disease. Wind disseminates aeciospores from pines to oaks in March, and yellow fungal spots soon appear on lower leaf surfaces where urediospores form. These urediospores inoculate other oak foliage, increasing the amount of innoculum as microscopic sporidia available for distribution to pines a year later. Since neither aeciospores nor urediospores can penetrate to infect tough, mature oak leaves, intensity of infection depends on a race in the spring between pathogen development and the unfolding of young, succulent oak foliage. Infection of the incipient leaves readily occurs.

Any silvicultural treatment that stimulates tree growth is likely to increase *Cronartium* infection. Such procedures as cultivation to control weeds in plantations, nutrient fertilization, and irrigation encourage trees to break dormancy early in the spring, allowing for a longer period for infection to occur through spore contact with new foliage. Transmission from oaks to pines readily takes place in early spring, infecting young and succulent pine needles. Similarly, winter fires that kill foliage, but not the tree, give rise to new lush needles earlier than normal in the spring, prolonging the period of fungi spore inoculation.

In some instances, callus growth is so rapid that cankers on trees heal over. Wood-rotting fungi often infect the dead wood. Pruning infected branches is a useful practice if cankers are less than 15 inches from the main stem, unless the boles are already infected. Any pruning, even of uninfected limbs, should be done before spring growth begins.[10]

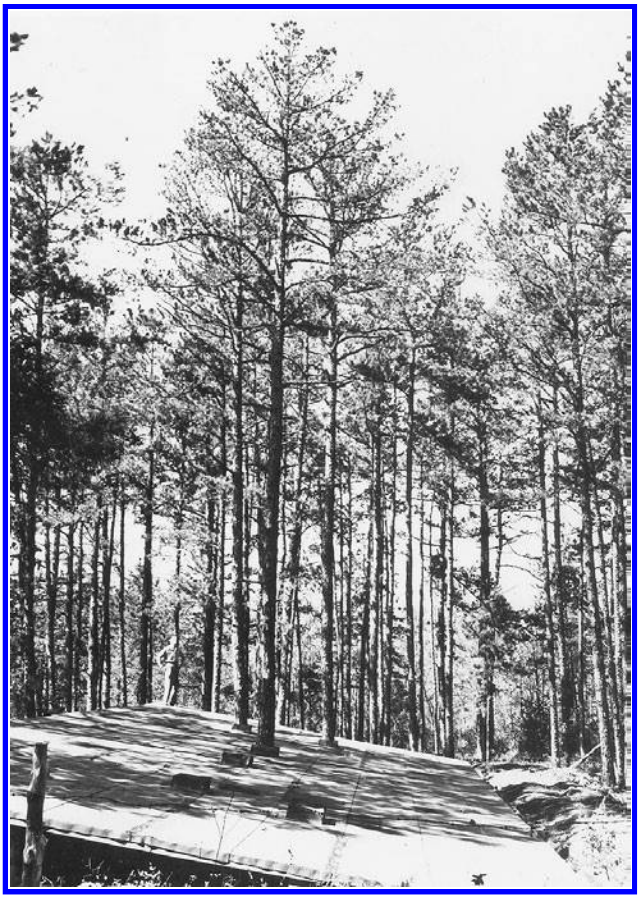

Figure 6.15 A drought-study shelter. Built around shortleaf pine trees subjected to prolonged drought, the caps indicate where dead trees were removed. The experiment was designed to see if drought could induce the littleleaf disease. In contrast to littleleaf-infected stems, nitrogen in foliage of drought-induced infection was normal. (USDA Forest Service photo)

Cures for the disease are yet unknown. However, acti-dione, a fungicide once showing promise for western white pine blister rust control, when mixed with roofing tar and smeared on cankers in the spring, has been used successfully.

Systemic fungicides provide some control in slash pine plantations. Applied as a slurry to roots at lifting time at the nursery or periodically sprayed on foliage, one such chemical (triadimefon) absorbs and translocates the fungicide throughout the seedling. Applications of sewage sludge, providing 300 to 600 pounds per acre of nitrogen, lowers rust infection in plantations of nursery-run loblolly pine stock (while increasing volume growth).[11]

Microscopic stain techniques aid in diagnosing rust. With aniline blue dye, intercellular hyphae can be observed through a microscope as the haustoria host cells penetrate the wood.

Development of rust-resistant trees remains a possibility. Suggested evidence of success, however, may lead to later discouragement if the infection reappears—perhaps two decades later.

Forest managers learn to estimate the probability of fusiform rust occurrence in newly planted stands based on geographic location and planting method. Infection is more prevalent where oaks of various species are abundant. The disease occurrence is related to soil drainage, the amount of sand in the surface soil, the frequency of rain, and the relative humidity at the time of sporulation—in spring, basidiospores are released from telia on newly emerging oak leaves during periods of high humidity and carried by wind to succulent immature pine needles.[12]

Cronartium cerebrum, the canker that resembles brain tissue, is closely related to *C. fusiforme*. Though not uncommon, it is seldom a serious menace.

White Pine Blister Rust and Emergence Tipburn

The infamous white pine blister rust, caused by *Cronartium ribicola*, is not a serious injurious agent in the Southern Appalachian Mountain range of the principal host species. Few white pine stands grow above 3500 feet in the region and the disease seldom occurs below that zone. Members of the *Ribes* genus, the rust's alternate host, on the other hand, are abundant only at the higher elevations, particularly in narrow belts along the main mountain ranges. (See Chapter 3.)

A more serious malady for white pine is emergence tipburn, a needle blight of unknown origin first described in 1908. Long before acid rain became a politicized household word, foresters recognized the possibility of industrial contamination of the atmosphere as a cause of declining tree vigor and death.[13] Fertilization to enhance vigor of affected trees is a possible cure.

Spot Die-Out

Spot die-out is exhibited by small groups of dead trees, usually less than an acre in area, in Piedmont plantations of loblolly pine usually over 10 years old and on severely eroded sites. Tree tops produce tufted foliage, tree growth rate declines, and several years later death occurs.

Poorly drained, shallow surface soils seem to impede root growth and thus encourage the malady. Plume grass serves as an indicator plant to alert the forester to potential plantation failure. In such locales, eastern redcedar or game food perennials better serve management's ends than do the pines. Redcedar improves the soil; herbaceous perennials encourage wildlife that, by their presence, also contribute to soil amelioration.

Oak Wilt

Oak wilt, for which root grafts serve as principal pathways of local infection, does extensive injury to broadleaf forests. Contaminated sap-feeding beetles carry spores from dense mycelial mats to fresh wounds of healthy trees. Flies, bark-borer insects, pileated woodpeckers—birds restricted to areas of old and defective timber when oak wilt is prevalent—or squirrels that strip bark from fungus mats lying just under the bark may also carry the innoculum.

A fruity odor of the wood of trees infected with the oak wilt pathogen tips off the observer of the malady's presence. For white oaks, vessel cells in the sapwood become clogged with tyloses. Black streaks then develop in the sapwood. Summer felling of oak stands may aid in reducing spread, particularly if a fungicide and insecticide mixture is applied to the wilted trees. Cause, effect, and cure of the disease remain a mystery.

Other Fungus Problems

No discussion of diseases in the southern forest can avoid consideration of the destructive chestnut blight, caused by *Endothia parasitica*, covered in the chapter on the ecology of broadleaf forests (Chapter 4). Unfortunately, introduced Chinese chestnut trees resistant to the blight do not have the quality of the wood and fruit and the favorable form of American chestnut. Hybrids of American chestnut and Chinese species, too, have failed to provide both high-quality wood and disease resistance.

Pitch canker fungus is especially infectious on Virginia pine. A copious flow of gum far in excess of that accompanying any other disease signals its presence. Trees will be alive below, and dead above, the canker. Bark persists on the sunken canker and on the pitch-soaked wood beneath.

Figure 6.16 Pitch canker on Virginia pine, caused by *Fusarium lateritium*. The tree is alive below and dead above the infection site. Trunk cankers develop on trees of any size, spreading until the trunk is girdled, the tree dies, or is broken off. (USDA Forest Service photo by G. Hepting)

The fungus eventually girdles the tree trunk; the tree then breaks at the site of the canker or dies. Caused by a *Fusarium* sp., this canker may be confused with a disease of a rust infection, *Cronartium appalachianum*. Of recent concern for managers of oak forests is *Hypoxylon atropunctatum*, a fungus that causes decay of phloem and the sapwood of members of the white oak *Leucobalanus* subgenus.

A gunky (at first) and then hard gall that occurs on small branches and the canker that subsequently appears on the stems of eastern redcedar is caused by *Gymnosporangium juniperi-virginianae*. This is the cedar-apple rust. While the only injury to the conifer is by the appearance of the gooey gall among the needles on a branch, the disease plays havoc in apple orchards. Redcedar trees should not be planted in the vicinity of orchards; their removal may be necessary to protect the fruit crop.

Figure 6.17 The tragedy of the American chestnut is recorded in the demise of the chestnut tree as a commercial timber of high value and a shade tree of symmetrical beauty (top). *Endothia parasitica*, the causal agent of chestnut blight, arrived in North America from China via Italy in the early days of this century. Infected trees die at about the time they reach seed-bearing age. Dead sentinels (bottom) like these in the Blue Ridge Mountains, stood for decades because of the resistance of the wood to rot, until resourceful entrepreneurs harvested the snags for decorative pieces. (USDA Forest Service photo)

Figure 6.18 Sweetgum blight. The fungus or virus that kills stands of trees, first reported in 1950, is unknown. The severe drought that year may have played a role, even for this bottomland woodland. On these moist sites, the species, because of the color of its wood, is marketed as redgum. (USDA Forest Service photo)

Nectria canker, Dutch elm disease, and oak wilt affect broadleaf forests. Butt rots develop where windborne spores enter wounds made by logging and fire. These and a few other diseases of southern forests bear witness to the complex ecological relationships involved in these ecosystems. Hitherto unknown maladies continue to appear, often for a season or two, and disappear before research has been able to confirm the problem to be more serious than a strange quirk of the weather. Many fungi that attack tree flowers, the strobili of pines, fruit, and seeds probably have not yet been observed, much less studied and named. The next generation of forest pathologists, with electron microscopy and genetic manipulation, will continue the never-ending task of discovery and management intervention to assure an adequate supply of wood for the nation's future. An example is the live oak decline in Texas, a wilt disease first appearing in the 1990s attributed to *Ceratocystis fagacearum.*

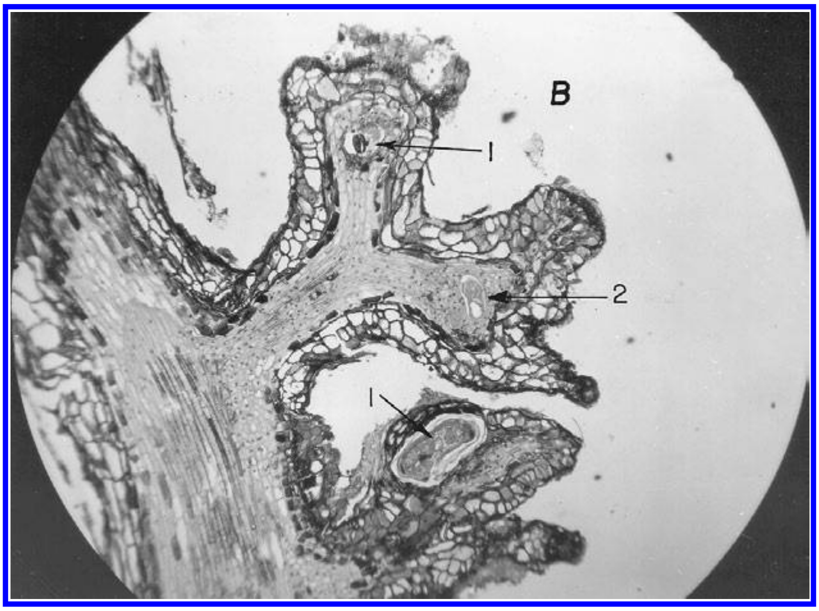

Figure 6.19 Nematodes, minute slender, unsegmented worms, parasitize forest trees. To show their relative size, they are here marked in this photo-micrograph as they thread through a root cell: 1 indicates a female, and 2 denotes a giant cell. Giant cells in an organ occur as a result of tumor growth. (USDA Forest Service photo)

Animal Injury

Birds and mammals consume great quantities of seeds, both while the fruit and cones remain on the trees and after they fall on soil and ground cover. Squirrels cut cones from conifers, gnawing the cones apart to find the seeds. Great quantities are buried in caches that, when forgotten by the furry thieves, may germinate to form dense clumps of seedlings.

Covering seeds with sod reduces wildlife consumption. While this encourages germination, seedling mortality often follows due to the competition of the surrounding grass for soil moisture. Birds and rodents also pluck seed coats shortly after germination from extended cotyledonous seed leaves, thus injuring the seedling and causing additional mortality.

Deer populations may be so high, especially in the New Jersey pitch pine barrens and plains, that the animals browse pine trees. To counteract this, forest managers sometimes place screens over seeds and seedlings. Beavers, nutria, hogs, and cattle play havoc with broadleaf trees, as noted in Chapter 4. Cattle may trample pine saplings.

Crickets get blamed for losses among pitch pine seedlings. They make puncture holes in the bark or cambium of trees. In these they lay their eggs. Small twigs weakened by the wounds break off the tree, thereby further reducing vigor. Control is seldom economically justified.

FIRE

Wildfire

While fires are not nearly so instrumental as insects in destroying southern forests, there are notable exceptions. In a career spanning five decades, one of the authors recalls few such pyric holocausts as the Okefenokee Swamp fire of the 1950s, which burned for weeks on an island in the swamp.

Figure 6.20 Bird-peck on a yellow-poplar bole. Such defects may affect the quality of lumber sawn from the logs of these trees. (Tennessee Valley Authority photo)

Watchers in tower lookouts from afar observed a phenomenon as suddenly, as if with a sponge, the fibrous organic soil of the "land of trembling earth" lost its moisture to evaporation. Wind speed rose, and the fire raced beyond the boundary of the swamp, jumped four-lane U.S. Highway 1, and consumed the trees on more than a quarter-million acres. Every available piece of equipment and experienced firefighter in the region were utilized in its control.

In contrast to the western states, blowup fires seldom occur in the South. That is principally because lightning storms in the South are accompanied by rain. In the West, it is dry lightning that races down the bole of a tree from its crown, exploding and igniting chips that fly in all directions as the charge descends the dry bark to the tinder-dry ground. With heat, wind is generated; and the fire, often in inaccessible and rugged terrain, cannot be readily attacked. Many other similar discharges occur simultaneously as bolts strike tall trees at the summits of the mountains.

In the South rain keeps the bark and the ground beneath lightning-struck trees moist. Fires are slow to get started. The relatively level terrain and accessibility to most of the forests further discourage the development of wildfires in the woodlands of the South. Mountain ranges exhibit exceptions to these generalities. So, too, did the summer l998 conflagrations in northeastern Florida.

The infrequency of blowup fires in the South can also be attributed to the fire prevention and suppression in the region. Wildfires kept the fuel minimized, and later prescribed burning did likewise. Some recent near-blowup situations have occurred where the fuel had been allowed to build up.

Figure 6.21 Red cockaded woodpecker at its longleaf pine nest tree. The resinous coating on the bole as well as the hollowed out heartwood destroy much of the bole for lumber. The resin discourages snake intrusion; the cavity is often excavated in red heart rot, which is caused by *Fomes pini*. Families of the territorial bird, now on the federal endangered species' list, use a particular tree for several generations. The weakened, flammable trees break off in the wind and readily succumb to fire. (USDA Forest Service photo by R. Conner)

Prescribed Fire

Even with its air-polluting effects, including the release of large amounts of carbon dioxide into the atmosphere and the potential hazard for humans with respiratory problems, prescribed burning is expected to become an even more important silvicultural tool. Florida's 1990 law, for example, specifically authorizes its use, while recognizing that the increasing population will mean greater concern over liability issues. Nuisance complaints likely will inhibit the use of fire as a silvicultural tool as the urban–wildland interface spreads into areas of previously remote timberlands.[14]

Inevitably, some fires will escape to damage and kill trees and to increase soil erosion. However, research in the Southern Appalachian Mountains shows that, even on steep slopes, soil movement does not increase following burning for site preparation and only minimal amounts of nutrients are lost from the site. Under controlled conditions, infiltration rates, mineral soil exposure, and root mats are not affected, partly because logging slash and stumps form debris dams. Nutrients in the ashes promote vigorous shrub and herbaceous growth that soon protects the soil.[15]

Figure 6.22 Burrows of the pocket gopher (*Geomys* sp.) in the surface mineral soil beneath a mor humus layer. These rodents are particularly destructive in the sandy soils supporting longleaf pine, sometimes pulling a seedling by its roots into the burrow. (USDA Forest Service photo by F. Hayward)

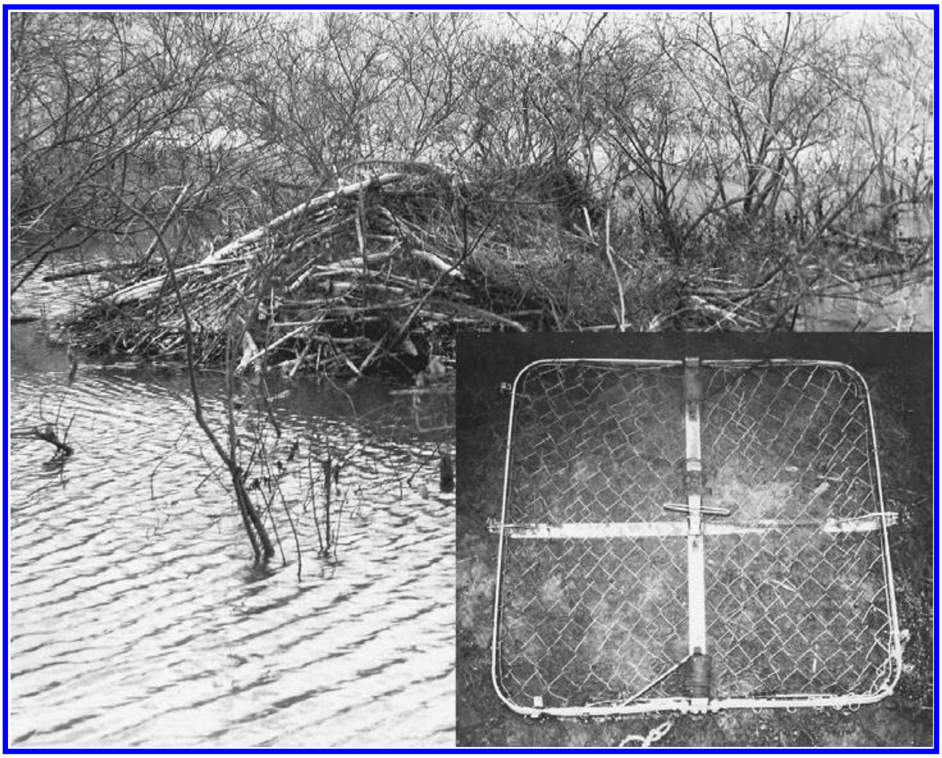

Figure 6.23 Beaver lodge and trap. The lodge, located in a flooded area to provide protection from intruders, is entered from below the surface of the water. The 5 x 5-foot trap snares the animals without injuring them. Uncontrolled populations of the mammal cause flooding and the loss of extensive volumes of valuable timber.(USDA Forest Service photo by R. Conner)

Species Relations

Fire is the chief enemy of pond pine. As much as 18 inches of organic surface soil may be consumed in a single severe fire, leaving at the surface a mineral glei (a bluish-gray sticky layer of clay in wet soils) stratum. Nutrient deficiency follows such a fire, even though base elements, like the cations of calcium and potassium, are released by the oxidation of the organic matter in the heat of the fire. Following a hot fire, the exposed stratum is often a hardpan, making reforestation impractical. Wildfire even inhibits coppicing of this prolifically sprouting species.

Switch-cane abundance provides a clue to the fire history of a pond pine pocosin site. The reed-like grass, growing as high as 15 feet, regenerates by sprouting after fire. When lands are protected from fire, switch-cane tends to be replaced by evergreen shrubs. Burning under prescribed conditions is desirable, thus preventing the near inevitable holocaust in these stands.

Fires seriously injure eastern white pines because of the thin bark of young trees. Stems not

Figure 6.24 Field mice girdle hardwood trees. Often, multiple sprouts arise from buds at the root collar of attacked stems. For quality timber, all but one of these eventually must be pruned, a costly procedure.

killed outright are butt-wounded and soon infected by rot-causing fungi. The uniformity of kill for shrubby growth by prescribed burning is so poor and the risks of fire escape so great in the rough topography of the species' range that foresters seldom recommend the procedure, even for controlling brush prior to planting.

Fire must be excluded from eastern hemlock woodlands. The thin bark makes the mildest prescribed burn an unsound silvicultural practice. The high-elevation spruce and fir forests are also easily destroyed by fire, moss and peat on the forest floor being consumed to a depth exceeding two feet. Consequently, seeds stored in the humus are lost. Soil destruction may be so deep that root systems are exposed to a depth of a foot below the original ground level. To the detriment of the vegetation, rapid drying of the new surface soil horizon follows. After wildfires occur, yellow

Figure 6.25 Fire in a slash pine flatwoods stand. The hottest fires do not kill sawpalmetto, new growth of the nuisance dwarf palm originating from a primordia (bud) buried deep within heat-insulating tissues. In these savanna stands, fire sets back ecological succession, discouraging intrusion by other species and reinvasion by pines. (Georgia Forestry Commission photo, inset)

birch, fire cherry, sweet birch, pin cherry, and other broadleaf species of minimal economic value encroach on the land. Blackberry brambles and ferns take over many sites; 20 years after a fire only an occasional conifer is encountered in areas formerly covered with evergreens. The successional cycle of brush, birch, and red maple before red spruce and Fraser fir naturally become established may require 500 to 1000 years.[16]

The distribution of eastern redcedar stands is largely governed by fire, as rising heat kills mature trees. Even the coolest fires cook the cambium under the thin, shreddy bark, which often does not exceed a quarter-inch in thickness. However, litter under redcedar trees quickly absorbs moisture and is readily decomposed by micro- and macrofauna. Thus, with ground vegetation and litter scarce, fuel is often inadequate to sustain a fire. Complete exclusion of fire encourages establishment of redcedar reproduction.

Fire is important in the management of Atlantic white-cedar, as stands of all ages are readily destroyed. A second burn before a new stand has time to replenish the supply of seeds stored in the forest floor generally eliminates the type. Severe fires in dry swamps consume overlying peat that contains an abundance of seeds. Fire may also eliminate most other woody growth in this cover type and set the ecological stage back to a quaking bog or to open water. Light surface fires may remove white-cedar trees from mixed stands because of the more rapid growth of hardwood sprouts, especially in areas with large deer populations. The absence of charcoal in the upper layers of peat and charred peat lying on the ground denote the lapse of considerable time since a severe fire burned over a woodland.

Fire may destroy longleaf pine stands that have passed from the grass-stage but are not yet 20 feet tall. While in the grass-stage, the bud is below the heat zone of the burning foliage. Later, the bark is sufficiently thick to serve as an insulator against the heat of a wildfire. During this intermediate period, heat rising from the burning grass and litter (together called rough) on the ground kills foliage and terminal buds, and the bark of these young trees is then too thin to endure much heat.

Trees vary in their capacity to withstand heat. The cambium of sweetgum, for instance, may be heated to its lethal temperature of 140°F about twice as quickly as will southern pine and baldcypress stems of the same bark thickness. This accounts for the ability of fire to kill sweetgum in prescribed-burning operations for weed-tree control without damaging nearby pines. It also points up the necessity for fire exclusion in the management of sweetgum.

Fires that wound tree bases provide infection sites for diseases. As heat kills the cambium beneath the bark, charred wood and bark slough away and rot-causing fungi spores contaminate the wood. Resistance varies by species and tree vigor—yellow-poplar appears to have among the most and scarlet oak among the least resistance to infection.

Figure 6.26 Ice-storm damage on slash pine. Planted north of its range, the trees suffer. These stems will probably right themselves if a thaw occurs within 10 hours.

WEATHER

ICE

Weather destroys southern forest trees in ways other than lightning. A layer of ice forms when rain solidifies on branches and trunks that are at or below freezing temperature. Ice damage bends trees until they break, and weighs down branches that break, leaving entryways for spores of the kind of fungi that decay the wood of living trees. For slash pine, serious injury occurs only if the species is planted north of its natural range. Its shallow root makes it susceptible to uprooting by heavy loads of ice on its branches. The high-density summerwood of slash pine, however, enables its stems to escape injury caused by sleet. Temperature as low as 8°F in the absence of rain does not injure seedlings, and many stems badly bent by ice following an ice storm recover by the end of the growing season.

Pine stands recently thinned for pulpwood are extremely vulnerable to glaze damage. Row-thinning encourages the injury more than does the more costly judicious choice of which stems to take and which to leave. Severely bent trees can be saved by prompt and drastic pruning of branches weighed down by ice. Trees bent less than 60 degrees from vertical generally straighten satisfactorily without pruning. The long, dense foliage of longleaf pine makes the species especially susceptible to ice damage, as the needles accumulate a heavy load. Ice damage in an East Texas storm of the early 1940s is clearly visible in the late 1990s, lateral branches of loblolly and shortleaf pines having taken over when terminal shoots were bent or broken by the weight of ice. A deformity on the bole marks the time of the storm in the life of the tree.[16]

Glaze storms in the hardwood forests of the mountains account for poor tree form, windshake in the lumber, and wormy and diseased timber at middle age. (Glaze-caused wounds provide entry ports for insects and fungi spores.) Late freezes kill buds and new foliage, and trees die in the process. Broadleaf trees suffer less from ice glaze than the conifers because hardwoods are shorter, less slender, heavier boled, and more tapered. The excurrent nature of conifer branching transmits stresses more directly to the bole than is the case for deliquescent hardwoods. Pines also have fewer numbers of branch orders and, therefore, stresses build up more greatly before reaching main stems than for broadleaf trees. (Yellow-poplar seems to be an exception to the rule.)

Hail defoliates trees, breaks bark, and cuts through boles as large as 5 inches in diameter. Resin deposits mark the scars, and callus layers of new wood show in lumber. The evidence appears as long as 4 years after a hailstorm.

Wind

Wind plays havoc with shallow-rooted species like loblolly and slash pines, and those growing on thin soils, such as Fraser fir in the highlands of the Southern Appalachian Mountains. Large areas of fir forest are felled in a single storm. Windthrow of fir and its kindred spruce is attributable to the dense, compact, and virtually impermeable subsoil, usually only 12 to 18 inches below the surface of the ground. In these shallow soils, stabilizing roots penetrate only along occasional minute cracks in the rock that underlies the surface of the land. A perched water table occurring at varying times and for varying periods of the year softens the surface soil. Strong winds at that time topple trees.

For longleaf pines, clay soil hugging the surface of the ground indicates susceptibility to windthrow. Following a single rain accompanied by tornadic winds, over 90% of the trees in a stand where depth to clay is less than 2 feet may be windthrown.

Restricted root development along with water-saturated soils encourages windthrow even for deep taprooted shortleaf and longleaf pines. Intense thinning also encourages weather damage; open stands in which there is little crown canopy to impede wind movement may suffer severely. Also, wind causes radial stress cracks and wind shake, which both degrade lumber, the more so where stands have been opened by thinning or storm.

Heat

Sunscald, closely related to fire injury, causes blistering of the smooth, thin bark on saplings. Eastern white pine and yellow-poplar in the South are especially susceptible. The injury, obvious by the ooze of sap, may extend up to 30 feet in the bole of a tree and cover a "face" of the stem. Though heat sufficiently hot to kill cambial cells radiating on southwestern-facing slopes is often responsible, the malady is not necessarily due to high summer temperatures. Heat exceeding 110°F for several days is believed responsible for killing trees with thick, leathery (sclerotic) leaves, like southern magnolia, even when moisture is available.

Rapid dropping of air temperature after sunset in winter also causes sunscald. North and east sides of trees are less susceptible to injury because temperatures do not fluctuate as much on these faces. The damage usually occurs in the fall or winter, after latewood growth is complete and before earlywood is laid down in the trunk the following spring. Again, eastern white pine suffers greatly. Foresters avoid the malady by conservative thinning or by using shelterwood regeneration harvests on south- and west-facing slopes.

Floods

Flooding is especially injurious to many species. Baldcypress, willows, and cottonwoods along rivers are almost alone among the kinds of trees that survive complete inundation for more than a month. While yellow-poplar does not suffer dormant-season flooding, as few as three or four days of growing-season flooding may kill all the trees in a stand of this species, often found in second bottoms of the Piedmont.[17]

When temperatures rise after rain ceases in ponded areas exposed to sunlight, respiration of the trees increases. So, too, does microorganism activity. Oxygen deficiency and carbon dioxide toxicity then result. Sprouting from root collars indicates that death of roots does not precede death of the above-ground part of a tree. Thus, as roots are not killed by flooding, death of roots by flooding cannot be responsible for the death of trees.

Along the Atlantic Coast, storm winds carrying salt spray damage loblolly pine. Stands within one-half mile of salt water may be killed; individual stems 2 miles inland may suffer. Flooding by waves or tides damages trees of all ages and sizes, especially where plugged drainage channels cause saline water to overflow into inland locales of low elevation. However, even where salt concentrations exceed 5000 pounds per acre, leaching is rapid. With good drainage, toxic salts continue to leach for several months after a storm passes.

Figure 6.27 Pine trees killed by a hurricane's salt spray. Far inland along the Atlantic coast, this phenomenon can be considered natural air pollution.

Air Pollution

Air pollution can be of natural or human origin. Terpenes dripping from coniferous tree foliage form liquid particulates suspended in the atmosphere. The sun's rays reflecting and refracting on and through the minute droplets, accompanied by temperature inversions, give the air the haze that led early explorers to name the summits of Virginia the Blue Ridge and the span of hills that serves as the dividing line between North Carolina and Tennessee the Great Smoky Mountains. It may be more accurate to say that the opaque and transparent droplets caused the temperature inversion,

Figure 6.28 Wave action at the shores of the many manmade lakes across the South severly erodes shoreline, destroying valuable timber and tree-growing sites and filling lakes with sediment. (authors' collection)

just as particulates of solid and liquid effluents pouring from industrial and residential chimneys cause the smog that results in upside-down climate—it is warmer on the hilltops than in the valleys.

Trace gases—carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons—in the atmosphere allow the passage of light, causing the greenhouse effect that warms the globe. In the absence of the gases, longer-wave heat rays return to the upper atmosphere. Trees theoretically aid in retarding global warming (attributed to carbon dioxide) by storing carbon. Even if wood is burned, it is recently formed carbon that is released, and this is promptly replaced by new wood growth. This recycled carbon contrasts with the nonrecycled carbon of fossil fuel.[18]

A great increase in tree-plantation acreage could possibly retard warming of the earth. Some 465 million hectares of newly planted trees are suggested as necessary to sequester the current levels of excessive atmospheric carbon. Hence, in the South the return to forest of abandoned cotton fields and the cutover virgin forests of the first half of the 20th century has provided an abundance of wood fiber as a carbon dioxide "sink." The sink includes long-lasting wood products, such as the lumber in buildings.[19]

Acid Rain and Ozone

The threat of the effect of air pollution on the forests of the South is well known. The effect, however, is not. Ozone contributed by electrical motors and industrial stacks, sulphur from coal-fired electrical generating plants, and nitrous oxides from other industrial and vehicular exhausts now receive the most attention. Preliminary studies suggest that the seriousness of acid-rain damage to forests of the South may be considerable.[20]

Acid-rain deposits in sandy soils of the South could so lower pH that phosphorus could be tied up and thus unavailable to pines. In the Coastal Plain, pine stands have responded favorably to applications of phosphate even where total phosphorus in the soil was analyzed as adequate. Soil pH also controls the availability of other nutrients, with plants absorbing or adsorbing certain elements at one pH, while optimum movement into plants of other nutrient cations or anions requires a higher or lower soil pH.

Figure 6.29 The amazing ability of tree roots to hold soil is demonstrated here. Employing radioactive phosphorus, roots of trees have been shown to extend great distances, thus protecting trees from windthrow.

The gases sulfur dioxide (SO_2), nitrous oxides (NOx), and ozone (O_3) pollute by dry deposition. "Rain" at this point is a misnomer. Transformed into weak acids when combined with moisture in the atmosphere, minute droplets of acidic precipitation fall upon the land and waters.

Among the more notorious tree-killing episodes possibly associated with air pollution is in the Fraser fir stands high in the mountains of North Carolina. While an aphid known as the balsam woolly adelgid is likely responsible, ozone pollution may so weaken trees that resistance to infestation is low and necrosis common.

A recently attributed cause of the pine decline in the Southeast has been the trees themselves. Several million acres on lands once in cotton and other agricultural crops have been planted to pines. The trees on these reforested lands exude terpenes from their foliage which, in turn, raises the ozone level in the atmosphere. The great amount of sunlight and the generally high temperatures in the region react with these emitted oily hydrocarbon droplets to form the ozone molecule. Ozone, more so than the acid rain forming sulphur and nitrous oxides, is shown to be the likely principal cause for the contemporary retarding of pine growth. Ozone also is especially injurious to white ash.

The causes for the pine decline are evasive because droughts, floods, insects, and diseases interfere with the conduct of research. Genetics may be involved, for trees of the same species growing side by side respond differently to introduced air pollutants. Also, stands of trees are manipulated dissimilarly by both nature and man—the lack of adequate thinning for the last three decades has resulted in dense stands that, in turn, reduce growth and vigor. Soils, too, vary, as do ambient levels of all atmospheric components.

Emergence tipburn, a needle blight of white pine of unknown origin, may also be caused by ozone in the atmosphere. Symptoms include browning of the current year's needles, beginning at their tips, usually in midsummer. Sometimes the entire crowns of small trees are affected, not necessarily the whole crowns of large trees. In 1961, the disease's symptoms became evident within a 7-day period throughout the species range in the Southeast. Foliar dwarfing, chlorosis, and stunted shoots follow dieback of needles for several years for trees so affected. Shriveled or

Figure 6.30 Plastic tents for acid-rain studies. Gases and ambient air piped into these structures in which trees have been planted enable researchers to analyze the effects of effluent contaminants in the atmosphere.

wrinkled bark and raised pockets of pitch on the bole accompany these symptoms. Extensive dying of feeder roots also occurs. The malady does not seem to have soil or tree-age preferences. Plantations and naturally occurring stands are equally affected. Varying degrees of tipburn among susceptible trees and the absence of symptoms on neighboring stems indicate resistance may be genetically inherited.[21]

Halogen effluents affect some species. Fluorine and boron, for instance, damage silver maple. Ozone and SO2 injure white ash.

Destruction of the forests of the Copper Basin in Tennessee and Georgia, the result of a century of smelting copper sulfate ores in the area, was discussed earlier. As yet, no silvicultural treatment can be suggested for protecting forests from airborne chemical toxins. The remedy, if any, must be reduction of effluents that carry these compounds to the forests.[22]

Mistletoe—Many species of broadleaf trees are subject to invasion by the flowering partial parasite mistletoe. Oak species are infested by *Phoradendro flavescens*. Christmas mistletoe (*P. serotium*) appears to be especially prevalent on river birch, the tree referred to by Prince Maximilian, who would become emperor of Mexico, as "the most beautiful of American trees."[23]

With some understanding of the problems encountered in endeavoring to protect the forests of the South, we now consider the means by which to improve the established forest. The forces of nature are always at work. Silvicultural efforts in some ways attempt to imitate nature; in others, they try to beat her at her own game. The multitude of natural phenomena from which the forest needs protecting often forces managers to go on the offensive to maintain vigorous stands of timber for supplying society's requirements.

7 Improving the Forest

Improving the forest involves intermediate management, procedures that take place between establishment of a stand and its final harvest at the end of a rotation. Intermediate management for the southern forest includes thinning, pruning, sanitation harvest, plant and animal pest control, and salvage. While salvage removes recently dead or presently dying trees, and sanitation harvests those that are disease- or insect-infested, thinning has as its proper role the release of some trees from the competition of others for soil moisture, plant nutrients, and sunlight.

Improving the forest also involves utilization of inherited characteristics for enhancing the value of individual trees. Called "tree improvement," foresters establish seed orchards and seed-production areas to provide an abundance of seeds for the so-called supertrees of subsequent generations.

THINNING

Thinning a forest provides landowners with the money to continue to manage their timber. Thinnings are also by-products of the forest that enable landowner to make a profit. Without this income, the bottom line may bring neither joy to the owner nor coin to his purse.

Thinnings, often mistakenly called selection cuttings, must be distinguished from regeneration harvests. The purpose of a selection regeneration harvest is to establish a new stand of trees of the same species on the same site. Thinning, in contrast, has another purpose: to enable the residual stems to grow more vigorously. Thinning removes some competition, thereby providing more soil moisture, nutrients, and light for the trees that are left to grow.

In addition to enhancing the growth of residual stems, thinning avoids the waste of stems that would be normal mortality if not removed in a harvest. This intermediate management practice also precludes the waste of wood, that is, the wood not growing on the stems that would have been retained had the stand not been thinned. Increased increment is not produced where a stand is not thinned.

Thinning in the South usually combines salvage and sanitation with release. Thus, poor-risk trees such as diseased stems and leaning trees are removed along with those that are suppressed and would shortly die. The southern pine beetle would not have been as destructive as it has been in recent years if thinning had regularly occurred. Too much food and too many weakened trees are available to the insect in unthinned and crowded forests.

Lumbermen favor thinning, because it enables trees to maintain a constant growth rate, and be less likely to produce lumber that warps and twists. For the southern pines, steady growth of six to eight rings per inch of radial growth is recommended. For pulpwood, two to four rings for each radial inch of growth is typical. (Trees frequently grew only an inch in radius every 20 or 30 years in the primeval southern pine forest.)

Too-rapid growth hazards the usefulness of southern pine for lumber. Excessive taper of a bole, development of many branches with their residual knots, and wood of low density and strength frequently result. When converted into lumber, fast-grown southern pine may also shrink excessively longitudinally and, therefore, warp. For pulpwood production, rapid growth is discouraged only if it is so rapid that specific gravity of the wood diminishes to a greater degree than the increase in increment provides for total cellulose yields. Rate of growth is maintained by regulating stand density and by controlling undesirable vegetation, including trees that are unmerchantable

Figure 7.1 A loblolly pine stand marked for thinning. Excessive *Cronartium fusiforme* rust damage and retarded growth were caused by the delay in timely removal of a third of the stand.

and species that have no economic value. Wide spacing, in addition to speeding growth, exposes trees to bending stresses that enhance windfirmness. (A tree's cambial cells so stimulated grow somewhat like those of a girdled stem: a tree girdled or bound with wire may put on 20 percent more wood the year after injury occurs, but it may die soon thereafter.) However, dense stands should not be suddenly opened, as this encourages windthrow, especially on shallow soils.

Thinning only slightly improves growth for young loblolly pine. While annual mortality of unthinned stands is less than 0.1 cord per acre to that age, mortality then rapidly increases to between 0.3 and 0.7 cord. Thus, thinning should begin early, taking one-half of the volume in a pulpwood-size stand. Thinning as soon as a merchantable harvest can be obtained is recommended, while precommercial thinning has also been found to be profitable.[1]

Suppressed southern pines, especially loblolly, that will die within a few years if not released have sparse and droopy foliage. As tree growth is a direct function of photosynthesis in foliage, when air temperature rises to 77˚F, fully exposed loblolly pine needles reach a maximum rate of photosynthesis at one third of full sunlight. However, even for open-grown trees, many needles

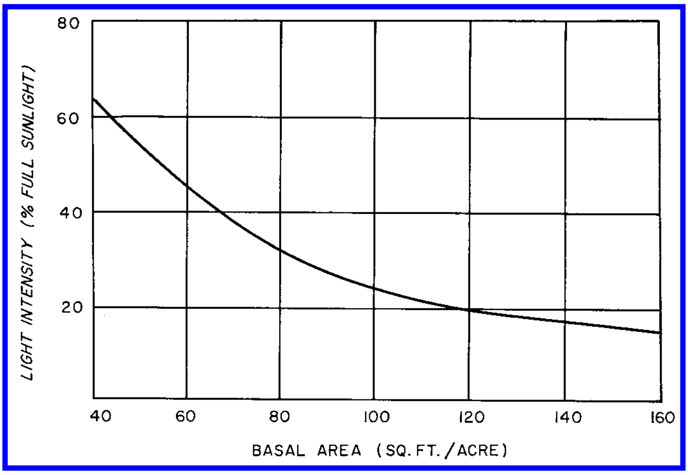

Figure 7.2 Relationship of basal area to sunlight. As stands of shortleaf pines increase in density, the percent of full sunlight that reaches trees diminishes exponentially. So, then, does the growth of all of the trees in the stand. (after Jackson and Harper in *Ecology*)

are shaded by foliage on the same tree and within the same cluster. It is this mutual shading, in contrast to that for broadleaf trees, that may account for the greater sensitivity of southern yellow pines to shading.[2]

Economic Maturity

Stands left unthinned grow until crowding causes stagnation of the stems. Adding only minimal growth to too many trees keeps southern pines in the low-value pulpwood class. Higher-priced sawlogs develop when growth is distributed among fewer trees. Stems in the 8-inch diameter class (up to 8.9 inches) marked for cutting go for pulpwood at low prices. Left to grow another year or two they would be in the 10-inch class (perhaps only 9.1 inches). But even small sawlogs bring, in a normal market, five or more times the price of pulpwood.

Thinning necessitates an understanding of economic maturity, sometimes called financial maturity. With interest rates above 10%, almost every southern forest is economically mature as soon as seedlings are put into the ground. Few stands of trees grow at a rate equal to an interest rate that high. Thus, economic maturity is the point at which a tree's growth rate is less than the value of that tree if it were harvested and the money received from the sale deposited in a savings institution at the current interest rate.

To overcome the limitation of economic maturity attributed to a tree's rate of growth, thinning aims to increase quality of the residual trees in a stand. Increasing both quality and volume of the residual stems then make thinning financially worthwhile. The 8-inch tree in an unthinned stand is pulpwood; the 14-inch bole of the same age in a thinned stand may be marketable as a high-value pole or several plywood bolts. Thinnings shorten the rotation age for quality products like the latter. For yellow-poplar, for which especially high prices are paid for grade-one logs, thinning may be highly profitable.[3]

High and Low Thinning

Two principal styles of thinning are utilized in the South. Low thinning (sometimes called German) caters to trees in the upper canopy. Low thinning removes suppressed, intermediate, and perhaps a few codominant trees, the latter to "sweeten the crop," thus encouraging timber buyers to bid on the logging chance. High thinning (also called French or crown) favors the lesser trees,

Figure 7.3 Low thinning of a white pine stand in the southern Appalachians. Thinning provides some income for the owner; but, more important, improves the vigor of the residual stems by reducing competition for soil moisture, nutrients, and light. Logging slash, a temporary fire hazard, remains on the ground after thinning. Often it is lopped or scattered, the organic matter thereby more quickly incorporated into the mineral soil. (authors' collection)

releasing them from overhead competition by removing mostly those in the dominant and codominant classes. Generally, foresters scrap both methods (along with the ambiguous term "selective thinning") and simply "thin," individually choosing each stem to be removed. Their choices depend on such things as the desired stand's basal area, site quality, and the condition of individual stems.

In deciding how much of a stand to remove, foresters depend on measurements of volume (in cords or board feet), number of stems per acre, or basal area. Basal area, a convenient measure of stand density, utilizes calculus to combine the number of trees with the size of the trees on a particular area to tell the manager if the land has too many, too few, or an appropriate number of stems per acre. Originally determined, the dbh of each tree is measured and that reading converted in inches to square feet in a circle of that diameter, and the breast height areas on a determined area then totaled. Now it is usually calculated by employing a simple coin-size glass prism. A typical plantation of southern pines in the western Gulf South may have at age 15 about 400 stems per acre. If these average 7.5 inches dbh, basal area will be about 123 square feet per acre. The volume of this forest might average 30 cords per acre. Removing one-third of the trees in such a woodland is a typical thinning recommendation. Thus, about 130 trees, having a volume of about 10 cords and a basal area of perhaps 35 to 40 square feet, would be marked for harvest.

Another stand, a 30-year-old managed plantation, may have about 150 stems, averaging 12 inches dbh, on an acre. Basal area amounts to around 120 square feet per acre. Again, removing one-third of these trees leaves a few more than 100 trees and 80 square feet per acre of basal area.

Rules of Thumb

A good standard, or rule of thumb, for a southern pine plantation is to permit and encourage stands to reach 120 square feet per acre basal area and then thin to 80 square feet. This treatment could occur several times during a rotation, the life of the stand.

Here are other rules of thumb for thinning guides:

- When loblolly pine stands average 6 inches dbh: 2 x dbh, leaves 300 trees per acre
- Dbh + 6, leaves 300 trees per acre
- Dbh + 4, leaves 450 trees per acre
- Dbh + 2 leaves 700 trees per acre

As multiples of dbh form divergent straight lines, the larger the multiplier, the steeper the line. In contrast, the plus rules, parallel lines form: the larger the constant, the higher the line on the axis of a graph. Thus, at 8 inches dbh, D + 6 crosses the 80 square-feet-per-acre basal area line while D + 2 is at 150 square feet, and thus a fully stocked stand.[4]

As economic models consider biological and physical rules as well as financial interests for thinning, one is reminded that reasons for thinning are to:

- Harvest poor risk trees (those that are diseased, leaning, more than 1 foot in the lower 6 feet of the bole, deformed, or crowded)
- Stimulate growth of residual stems
- Avoid mortality of some trees
- Maintain constant diameter growth throughout the life of the trees in the stand for high-quality lumber

Methods for determining how many trees and how much wood to remove may involve mechanical selection of trees, in contrast to the decision-making noted above. Mechanical thinning resorts to formulae or arbitrary decisions. A popular formula is D + 6. The timber marker first measures the diameter of the trees in the stand and then computes the average. If, for example, the average is 8 inches, the marker simply calls it 8; and to that 8 adds 6, giving the number 14. Fourteen feet is the average distance the trees are to be spaced after the thinning. Trees in between are marked for harvest.

Still another formula is D x 1.75. Again, a theoretical average diameter of 8 inches is arbitrarily called 8 feet and multiplied by 1.75. This, too, gives 14 feet as the suggested distance between residual stems in the hypothetical plantation. These formulas do not always give the same answer.

Row thinning, another form of mechanical thinning, calls for removing every third or fourth row of planted trees. In the case of dense stands of seedlings, rows are simply whacked out by laborers using sharp hoes. Precommercial thinning of saplings may be done by crushing young trees with heavy machinery. Harvesting equipment is used with larger stems.

Before the days of computer modeling, a forester in the Arkansas Coastal Plain developed 5-year cutting cycles. A 1934 guide assumed that 500,000-board-feet (MBM)-per-year harvests are necessary for a practical enterprise. The actual area on the graph occupied by any stand or group of stands represents the volume in the trees in the forest. Thus, 1 inch on the vertical scale equals 1 MBM per acre and 1 inch on the horizontal scale equals 100 acres. Then, 1 square inch equals 100 MBM for an area of *x* acres. In the case presented in the guide, growth after thinning must be at a rate equal to that made by stands with 3,500 board feet per acre, or about 400 board feet per year, to warrant another harvest at the designated time.[5]

Silvicultural Judgment

The chief advantage of mechanical thinning is that it can be used for most species on most sites by people with relatively little knowledge of timber values. This is also its disadvantage: the lack of silvicultural knowledge may result in quality trees'—those that should be saved for the final crop—being harvested prematurely, while some stems of low value, because of quality or location in the stand, are being retained. Formula marking and row thinning remove the need for judgment, and it is judgment that makes timber-marking fascinating silviculture for the forester. Indeed, silviculture (from the Latin *silvi*, meaning trees, and culture, meaning art) is the art of growing trees in managed stands. Thinning utilizes this art.

Although rules for thinning are employed, the trees themselves are the best guides. As a general rule, when live crowns of dominant and codominant stems are less than 40% of the total height, diameter growth diminishes appreciably. That is the time to thin. To wait until live crowns shorten to less than 30% is too late; trees then recover too slowly. Live crown foliage is unable to produce the carbohydrate necessary for recovery.

As yellow-poplar trees are sensitive to suppression, for example, foresters should thin from below. By so doing, stems likely to be lost by competition mortality may be salvaged. Crown increases of 20 to 50% of their height and diameter growth of two inches in 10 years have been recorded following thinning of small-crowned stems. Trees of this species must overtop their associates to maintain vigor. Thinning sprout clumps is advantageous. All but one should be removed, allowing the residual stem to increase in growth.[6]

Where dense stands of Atlantic white-cedar occur, the sites are often of poor quality, making thinning difficult to justify. For some situations, neither diameter nor height growth of crop trees may be appreciably improved by their release from competition for soil moisture, nutrients, or light. Yet, in vigorous stands on better sites, such as those well-drained and close to water courses, removing suppressed stems in the understory has caused appreciable diameter growth response for the residual stems. Thinning stands in mid-age by reducing stocking by one-half has diminished mortality from about 40% to a negligible amount. The trees that would shortly die were cut before they succumbed. Thinning dense understories often encourages windthrow, damage that can be avoided when thinning from above or by leaving unthinned strips of timber on the windward sides of white-cedar stands.[7]

Some competition among stems is good; it encourages self-pruning. However, when trees have less than one third of their total height in live crowns, stagnation sets in and fools even experienced foresters. A plantation of 500 stems per acre may appear homogeneous. In checking growth of the largest 100 stems per acre, however, a forester often finds that a woodland in which all trees appear to be growing slowly actually includes vigorous dominant stems.

Thinning slash pine stands infected with *Fomes annosus*, the causal agent for a root rot, may be inappropriate. Root grafts connecting the stumps of removed and residual stems serve as conduits for the infectious mycelia, the originating spores germinating on the freshly cut stumps. As the mycelia grow down and through the stump, root, and graft, the minute strands exude toxins that kill the nearby residual stems.

Growth-ring widths sometimes mislead the observer in planning a thinning. False rings occur, suggesting that less growth took place in a particular year than actually did. Baldcypress, for instance, lays down false rings as responses to soil moisture and aeration. The number of rings per inch in increment cores taken from opposite sides of a tree may vary by 10%. Cores taken from this species above the butt swell show, when magnified, true summerwood as narrow bands of small thick-walled cells. The false rings fade as the stain that colors them in their formation becomes indistinct with magnification of the cross-section.

Thinnings provide some control over soil moisture. In hot, dry weather, reducing basal area enables sustained growth of pole-size plantations, whereas temporary stagnation otherwise occurs. Radial growth continues for thinned residuals, while moisture stress limits growth of unthinned stems. Thinning further reduces losses associated with insect infestation, and mortality occurs in dense clumps of pines where partial cuttings would have conserved soil moisture during dry spells.

Abruptly changing growing space could alter specific gravity of the wood for many species. The change is dependent on the conifer earlywood-to-latewood ratio, latewood being denser. As latewood is influenced to a greater degree by available soil moisture than is earlywood, thinning that releases soil moisture for use by residual stems during periods of moisture stress stimulates latewood accretion and, thereby, increases specific gravity. On the other hand, the proportion of earlywood may increase with enlarging crowns, as greater sunlight, water, and nutrients become available following thinning. In this case, specific gravity diminishes.[8]

The forestry profession that supports the wood-using industries, and those industries that employ foresters have a contemporary problem. It involves getting a logger to thin when so much more money can be made by clean-sweeping (not clearcutting, a legitimate regeneration system). The answer may be a subsidy to loggers to encourage them to harvest these partial logging chances. It could be a better business gamble than the incentive programs now being financed by the taxpayers and the entrepreneurs of America's forests.[9]

Fraud in Thinning

Those with a historical interest may be fascinated by the use of dated nails in the first decade of this century for marking trees on national forest land. Similar to the galvanized nails used today to date the placement of railroad ties and utility poles, thinning nails were driven an inch into the bark at the base of the tree to be removed. When the tree was felled, the logger withdrew the nail and drove it all the way into the top of the stump. In the absence of inspecting foresters, tree thieves removed the nails from low-grade stems and drove them into stumps of illegally cut high-quality trees.

Later, marking axes replaced the nails. The axes were also challenged by the unscrupulous. Blacksmiths could duplicate the axe, and a common fence staple was shaped almost identically to the U in the US of a 1940s federal marking ax. The bent staple was then simply pounded into the butt of a tree and promptly removed for reuse. Inspectors casually glancing at the brand naively assumed the timber marker did not do a good job in designating the tree to be harvested.

Paint, squirted from oil-can guns, subsequently took over where axes left off. The dishonest logger simply purchases the same color paint to mark the trees he prefers for removal.

Red-Cockaded Woodpecker Problem

Silviculturally, proper thinning alters biological potential for wildlife throughout the southern forest. Instructions once given to timber markers included the removal of trees infected with *Fomes pini*, the causal agent of red heartrot. This was done so effectively that forest pathology professors could not locate disease conks to show their students.

Not only were the conk and the oval scar on the tree trunks that provided evidence of the disease's entry into pine boles scarce, so too was the red-cockaded woodpecker. Finally, the reason for the bird's disappearance from these woods was determined: It makes its nests in trees with red heartrot. Thinning prescriptions were changed; a limited number of diseased stems are now left in the forest.[10] (See Chapter 9)

Pruning

In the 1930s and 1940s, when labor was abundant at reasonable wages, even stands of low-value species were pruned to improve quality of wood. Perhaps 50 well-formed, fast-growing "crop trees" per acre were selected for treatment, if lumber was to be the end product. Persistent branches produce knots that degrade the value of boards sawn from the trees. Low return on this intermediate management investment now discourages this practice. Yet, failure to prune reduces the proportion

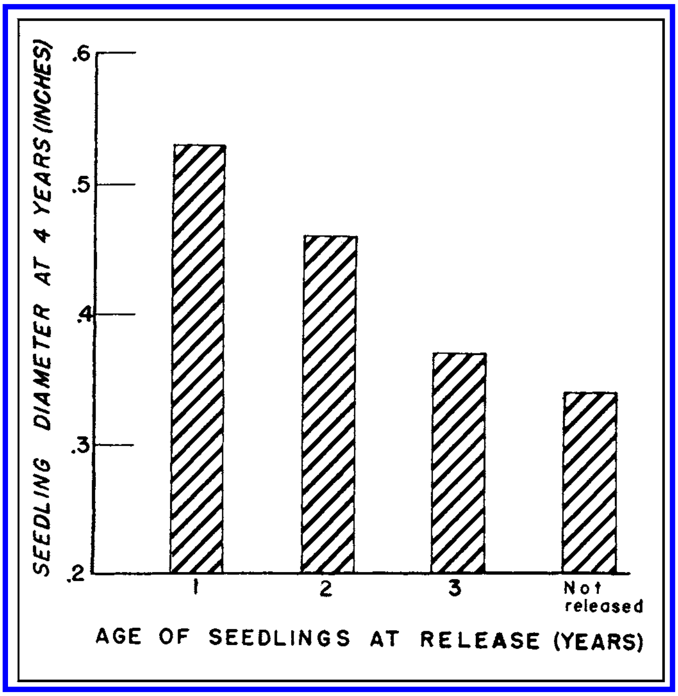

Figure 7.4 The importance of early release of longleaf pine seedlings in the grass stage. Seedlings retain the nanism characteristic until reaching 1 inch in diameter at the ground-line root collar. They then emerge from the grass. Thus, release from competing seedlings by thinning and removal of overtopping scrub oaks growing in the relatively sterile soil is important.

of the bole of the tree that is usable for sawtimber and adds slightly to harvesting costs. Studies now under way appear to show that the economics of "sudden sawlogs" could return the pruning saw to the southern woodlands.[11]

Trees selected and pruned for the final crop should be free of defects, in the dominant and codominant classes, and spaced about 20 feet apart. Pruning up to 80% of the live crown has little effect on height growth. For pine trees, diameter growth is significantly reduced when more than one-half of the live crown, with its carbohydrate-producing foliage, is removed.[12] A rule of thumb is to prune the first log to a height of 17 feet in three steps, yet not remove branches above a height of more than one-half of the total height of the stems. Pruning effectively aids recovery of ice-bent stems. If, for instance, a leader is pruned within one month of a storm, trees bent at angles of 30 to 90° straighten to less than a 10° lean. Slash pine trees bent less than 60° straighten relatively well without pruning.

Pruning is advisable for branches on which fusiform rust galls occur. To avoid spread of the *Cronartium* mycelia, the cankers should be removed if within 15 inches of the main stem.[13]

Natural retention of branches is related to both inheritance and environment. Although close-growing trees usually develop clear stems without manual pruning, some do not. While most open-grown stems retain lower branches, those that do not may exhibit an inherited ability to naturally self-prune.

Pruning scars on southern pines heal rapidly. Clear wood starts to form 4 or 5 years after small branches are removed from trees growing at least 3 inches in diameter in 10 years. While wounds from live branch pruning are not an important source of fungi entry, jagged stubs result in bark pockets that degrade lumber later cut from logs of such trees.

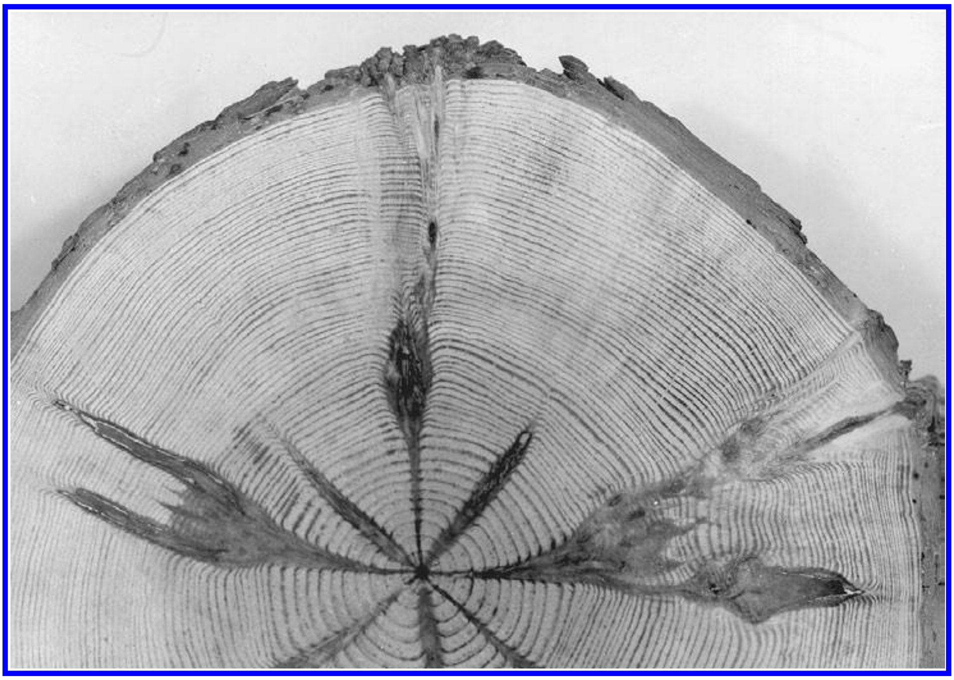

Figure 7.5 Knots reduce lumber and wood quality. This cross-section at the place on the bole where a whorl of branches radiates from the trunk shows the effect. Once the tree is pruned, whether manually or naturally, wood later laid down on the trunk is free of the defect. (USDA Forest Service photo)

Red heartrot infection can totally destroy the merchantable value of a tree. Hence, pruning of live branches denies fungi spores of rotting branch stubs of long-dead limbs access to the heartwood. Infection, however, may be through natural root grafts, as the disease appears to occur in clumps of stems. Whether pruning epicormic branches is beneficial in controlling heartrot remains to be determined.

Bud-Pruning

European bud-pruning, removing all lateral buds around the terminal bud from small trees after each growth flush, encourages production of knot-free lumber for some species. However, it appears ineffective for southern pines. Diameter growth diminishes after such treatment of 2- and 3-year-old stems. As each year's needles on the retained branches close to the ground are longer than those of the preceding year, this indicates that, during the early life of bud-pruned trees, the food-producing capacity of lower branches is supplemented by needles along the main stem. Flecks on lumber later cut from such trees appear where each needle had persisted on the living bole, much like that occurring for "foxtail" slash pines in tropical plantations.[14]

Nutrient Fertilization

Until the 1973 oil embargo by the Organization of Petroleum Exporting Countries, fertilization of southern forests was an anticipated treatment for hastening the growth and improving the vigor of southern forests. The great weight of commercial fertilizer, and thus the high cost of shipping and application to the soil, along with the manufacture of nitrogen salts from natural gas, discouraged much further effort to test the validity of theorized favorable economic responses to forest stands.

Figure 7.6 Callus tissue rapidly begins to heal pruning wounds. Here, on an upland hardwood trunk, incisions are closing after 2 years. However, water sprouts, depending on the amount of light received at the site of the wound, often appear just below the injury. (USDA Forest Service photo by F.B. Clark)

Economics

Fertilization as an intermediate management practice, rather than application at time of stand establishment, reduces the period the investment is tied up. At 10% interest, a \$100 fertilizer treatment at planting time will cost \$11,739 for a 50-year rotation. If the same degree of improved growth can be obtained by fertilizing 10 years before harvest, the cost is \$259. These computations utilize the compound interest formula: $V_n = V_o(1.0p)^n$.

On the whole, the low cost and improved vigor obtained with phosphate alone, in contrast to other elements and their mixtures with phosphate, makes this element the most effective nutrient supplement for slash pines. Applications of colloidal phosphate result in significant diameter increases over a 15-year period for slash pine on acidic flatwoods soils. Disking-in the phosphate stimulates growth. Phosphate is the element in short supply even on lands near phosphate beds in Florida; the element is readily tied up in soils. An abundance may be present but unavailable to plants because of soil pH or other chemical interactive characteristics.

Colloidal phosphate contains 2 to 4% acid-soluble P_2O_5 and up to 24% total phosphoric acid. This form of phosphate is applied in plantations in alternate 4-foot strips, the rows of trees centering the strips. Disking at time of planting tends to improve growth, but this could be attributed to the weed-control effect of soil disturbance.

Slash pines commonly display symptoms of nitrogen deficiency in sandy soils, especially in the lower Coastal Plain. Appreciable diameter growth occurs with nitrogenous applications, but height growth is not always stimulated.

Foliar and soil analyses indicate nutrient cycling is generally ineffective for sustaining growth stimulation following fertilization, even though phosphorus in soil and in the litter layer analyzes higher on fertilized than nonfertilized plots 19 years after adding nutrients. While diameter growth,

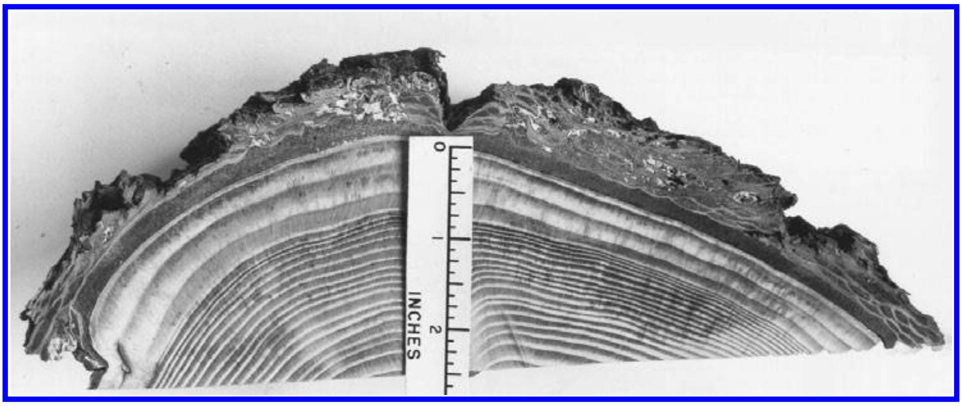

Figure 7.7 Radial growth response to nutrient fertilization. Because wood volume growth is subject to capital-gains-income taxing, allocating funds for such practices is encouraged. The outer tree rings of this cross-section show the dramatic influence of the treatment. (authors' collection)

and therefore tree volume, improves, specific gravity of the wood diminishes as volume growth increases.[15]

Inadequate soil nitrogen and phosphorus retard Virginia pine growth. The trees do well when soil nitrogen is between 25 and 100 parts per million and phosphorus 1 ppm. When needles have less than 1.7 and 0.14% of nitrogen and phosphorus, respectively, nutrition is considered unsatisfactory.[16]

Nutrient Requirements

Foresters aware of Liebig's Law of the Minimum (a reference to the fact that growth proceeds only to the limit allowed by the element most deficient in the soil) recognize interactions among nutrients. For example, potassium additions without nitrogen, and nitrogen supplements without potash, have retarded growth in loamy sands in Georgia.[17]

Growth-chamber studies, where the kind and amount of light, day length, humidity, and simulated rainfall were controlled, showed that trees vary in their ability to absorb nutrients according to the source of the seeds. Searching the slash pine range for the zone of maximum growth (and thus greatest vigor), the senior author was satisfied the sought-after strain was indeed in the center of the species' range. Seed from the crosses of the apparently "best" trees in the forest were germinated in a growth chamber and treated with nutrient amendments along with controlled crosses from other zones of the species' range. The inherently more vigorous trees most efficiently utilized the nutrients applied to the soil in which they grew.[18]

In other trials, the author added commercial fertilizer formulations of nitrogen, phosphorus, potassium, and trace elements to seedlings planted on both drained and inundated land. When excessive water is drained to 4 inches below ground level in a highly reduced (oxygen-starved), bluish-gray soil in the Atlantic Tidewater, a single application of fertilizer appreciably improved growth for at least 2 years. In contrast, where not drained, supplemental nutrients in the clay soil increased mortality, probably because of toxic salt absorption of the soluble elements. Longer needles of a darker green color occurred under the optimum fertilizer and water-level combination. Slash pine is more responsive to these water and nutrient treatments than loblolly pine, a species early recognized for its capacity to thrive well in the soupy soils of the eastern seaboard.

Littleleaf Malady and Other Shortleaf Pine Trials

This book has alerted the reader to the littleleaf disease on shortleaf pine trees in the southern Piedmont province. Many nutritional studies attempted to correct or to prevent the malady. In carrying out these trials, researchers learned healthy trees of the species exhibit diameter growth responses to various forms of nitrogen. For malady-free stands, leaf mold amounting to 40 tons per acre did not increase nitrogen in foliage, nor was growth improved. Over a rotation, however, this treatment would be highly beneficial to sites with a history of littleleaf disease.[19]

Shortleaf pines in southern Illinois and other northern extremities of the species' range have also responded to nutrient applications. Fertilizers are beneficial where decreases in growth have been observed, as when litter had been removed annually down to the mineral soil over a 12-year period. This procedure took essential elements from the site more rapidly than they could be replenished by the weathering of the soil parent material. On the other hand, foliar nitrogen is higher in thinned than in unthinned stands. The difference, greatest on the better sites, may be due to the more rapid breakdown of litter as increasing sunlight reaches the forest floor in the openings made by the thinning. The additional nitrogen is then available for absorption by the residual stems. Decaying plant residues after harvests also add nitrogen-containing humus to the soil.

Root-burning and Liming

Root-burning by fertilizer salts results in diminished growth. This may occur when nutrients are applied in mattock holes at the time of planting. High soil calcium levels, especially prevalent in abandoned agricultural fields and recognized by high pH, prevents establishment of both natural pine reproduction and plantation seedlings. Germinating seeds and young seedlings tolerate soluble calcium levels up to 500 ppm. As a generality, such lime levels equate to a pH of 6.5. (While the base chemical character of much blackland soil indeed diminishes survival and restricts the growth of southern pines, mortality and poor vigor are also due to the destruction of roots when these tight clays dry out and shrink and crack. Upon rewetting, hardwood roots, in contrast to the conifers, sprout prolifically, enabling broadleaf trees to survive. The pines, even the stump-sprouting shortleaf pine, fail to do so, for trees in these soils of rapidly changing moisture conditions succumb to the loss of water- and nutrient-absorbing roots.)

Seed Production

One must also consider seed production and vitality as responses to soil nutrient levels. Applications of commercial fertilizers, especially phosphorus and potassium, increase the quantity of sound seeds on shortleaf pine stems. Doses of nitrogen alone give smaller increases.[20]

Cone production for longleaf pines in Florida has been greatly stimulated by complete fertilization (along with irrigation). But for this species, typically producing cones with abundant seed crops at intervals of 10 years, relatively few cones were involved. For the sandhill-loving longleaf pine, too, hogs may be more likely to root out fertilized seedlings in the grass stage. The nutrient-enhanced root is a juicy carrot for the piney-woods rooter.

Pond Pines in Pocosins

With the exception of nitrogen in the nitrate form, soils of pocosin swamps are nutritionally sufficient for supporting good growth, providing drainage is adequate. The low level of nitrate relates to the high water tables that prohibit oxygen from penetrating the soil and, thereby, keeping nitrogen as well as organic matter in a chemically reduced state. These wet soils also have low levels of phosphorus, potassium, and the trace elements (manganese, zinc, copper, and boron) necessary for plant growth. Occasionally, total nitrogen and calcium analyze high. In spite of the high calcium level, acidity of pocosin peat and muck is around pH3. Soil pH controls the availability of phosphorus, iron, and other important nutrient ions; in turn, acidity and alkalinity are influenced by the accumulated organic matter. Acidity also affects the fungi that infect these fibrous soils. Some spore-producing plants, as well as other flora, fauna, and bacteria may also be excluded by low soil pH. Limiting bacteria in soil, in turn, limits nitrification.

Ammonium nitrogen, rather than the nitrate form, is produced by "mineralization" of the decaying organic matter. Deficiencies of nitrogen can be acute even when sites are drained and, with drainage, leaching of phosphorous and potassium to lower aquafers occurs. Undrained pocosins, in contrast, accumulate nutrients moved from higher ground. In these hydric situations, the reduced nitric form of nitrogen may be the reason loblolly pines seem not to intrude on these sites.

Salt toxicity in coastal soils does not appear to appreciably influence pond pine growth. The pH of sea water exceeds neutrality, and even a little intrusion into pocosin islands increases the highly buffered pH of organic sites. Pocosin soils, however, analyze low in sodium and other salts.

Eastern White Pine

Nutrition of eastern white pine has received much study in the northern reaches of the species' range. For trees growing in deep sands originating from glacial outwash plains—lakes that drained following the Pleistocene periods—potassium often is deficient. Trees exhibit the deficiency by their chlorotic needles, foliage that does not last the normal period, abnormally short needles, and poor terminal leader growth. A bright yellow discoloration of the current season's needle tips, appearing in the fall and affecting upper parts of trees most strongly, is symptomatic of magnesium deficiency in the coarse soils of low cation exchange in the North.[21]

Neither potash deficiency nor magnesium shortages have been detected in white pines of the South, even where planted far off-site in sandy clays of the lower Coastal Plain. In the North, 200 pounds per acre (approximating 200 kilograms per hectare) of muriate of potash (KCl) and 25 pounds per acre of magnesium sulfate (Epsom salts), respectively, correct the nutrient deficiencies.

Eastern Redcedar

Throughout its range, eastern redcedar exhibits an affinity for alkaline soils. On limestone-derived soils, trees of the species grow in pure stands. At the same time, the presence of this juniper influences pH, increasing alkalinity even on very acid soils in which single individuals occur within a stand dominated by other species. Thus redcedar prevails on calcareous sites, but endures sour soils. Indeed, it is frequently the earliest invader on acidic old fields, occurring on soils with pH as low as 4.7. This *Juniperus* grows well where limestone and alkaline shales compose the soil parent material as well as where thin surface layers are especially acidic due to leaching of carbonates. Yet, here the roots also grow in direct contact with underlying alkaline deposits.[22]

Managers of lands of low pH should consider encouraging regeneration or afforestation with this species. In the Ozarks, surface soil pH under redcedar canopies is about one unit higher than in the open. The higher pH is due to the leaching of calcium ions from the *Juniperus* litter, having accumulated in the foliage as a result of "foraging" for the element in the rooting zone some distance beyond the tree's crown and concentrating the element in the foliage. The same withdrawal of soluble substances at lower zones under the canopy likely occurs. The relative acid-neutralizing power of redcedar litter is twice that of the organic debris remaining from the decomposition of bluestem grass.

The species is encouraged where fires perennially consume organic matter and on eroded sites suffering from inadequate fibrous material in the surface soil. The high calcium level in the foliage hastens the development of new A horizons, the surface soil now having pores for rainwater infiltration and percolation. Organic matter measuring 5% of the soil's weight (in contrast to 2% under herbaceous ground cover) amounts to an increase of 3 tons of litter per acre.

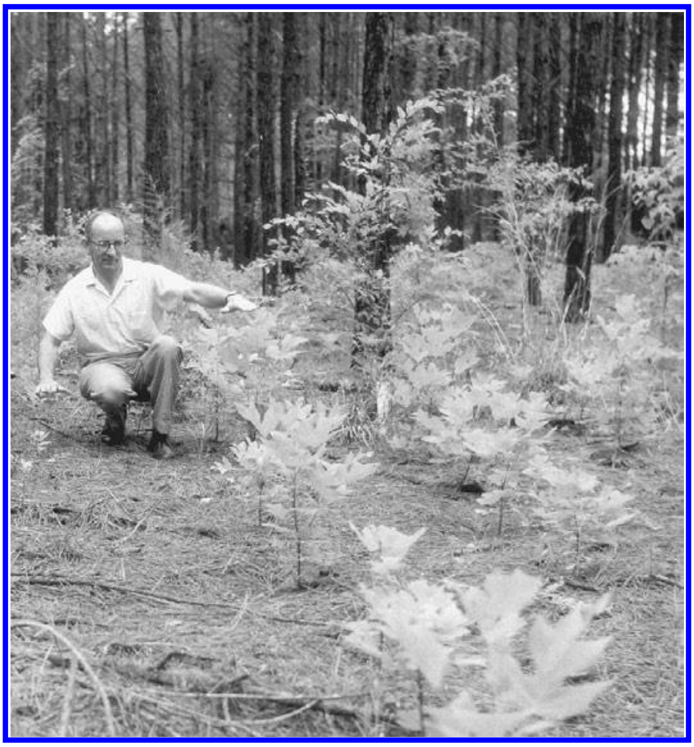

Figure 7.8 Yellow-poplar planted in a shortleaf pine stand that suffers from the littleleaf malady. The man's hands show the effect of a complete (N-P-K) fertilizer, placed in the planting holes, on height growth of seedlings planted a year earlier.

Improved soil volume-weight as well as porosity encourages use of eastern redcedar as cover on watersheds. On severely eroded loess soils, as in northwestern Mississippi, it will outgrow loblolly pine. On such sites and on less-damaged locales, the species responds well to fertilization with complete formulations and with mixtures of ammonium nitrate and limestone.[23]

Broadleaf Trees

Among the upland hardwoods of the South, two species stand out as effectively responding to fertilization. Lime and complete fertilizer applications improve survival and growth for black locust, especially if the hardy legume is planted on severely eroded sites or others requiring amelioration. As phosphorus alone stimulates growth for black locust, supplements in the form of the inexpensive colloidal phosphate may be appropriate.

Yellow-poplar responds well to fertilization, especially with nitrogen and phosphorus in mountain coves. The stimulated growth probably is important in enabling seedlings to grow above the critical height below which growing-season flooding is injurious.

Prescribed Fire

Prescribed burning as an intermediate management tool is used to control competing undesirable shrubs and trees, to improve wildlife habitat, to improve grazing for woods-ranging livestock, and for fire-hazard reduction. For weed-tree control, our principal concern here, the cost is often less

Figure 7.9 Igniting a prescribed fire. For 40 years, many in the forestry profession opposed the use of fire as a management tool. Then it became apparent, although already well-known by observant individuals, that fire provides an effective tool for (1) preventing fuel build-up that results in catastrophic wildfires, (2) controlling certain diseases, like brown spot needle blight of grass-stage longleaf pine seedlings, (3) improving browse for wildlife, (4) improving the quality of grasses and forbs for woods-roaming cattle, (5) preparing seedbeds to receive seeds for prompt germination, and (6) controlling weed trees and brush that compete with valuable stems for moisture, light, and nutrients. Here a drip torch lights a fire along a bulldozed fire line. (authors' collection)

than that required for the use of herbicides. Where smoke and its particulates may be an environmental insult, chemicals utilized for these purposes are the alternative.

The ability for pole-size and larger southern pines to endure hot fires arises from the insulation capacity of the bark. While outside bark temperatures subjected to fire might reach 1000˚F, the cambium layer heats only to 150˚F. The growing tissue, however, maintains this temperature 8 to 10 minutes after the outer bark has returned to normal. Roots are about as resistant to fire damage as above-ground parts of trees. Heat tolerance of seedlings (apart from longleaf pine in the grass stage), on the other hand, is minimal, as the bark is too thin to insulate the cambium.[24]

Mortality for trees increases as the amount of crown burned, expressed as the percentage of crown length, increases. With equal crown burning, mortality decreases linearly with increasing diameter. Slash pines more than 5 feet tall seldom die unless more than 70% of the crown is burned. Thus, the intent of a prescribed fire to control undesirable broadleaf weed trees, shrubs, and vines must be to minimize needle kill. Technique is important.

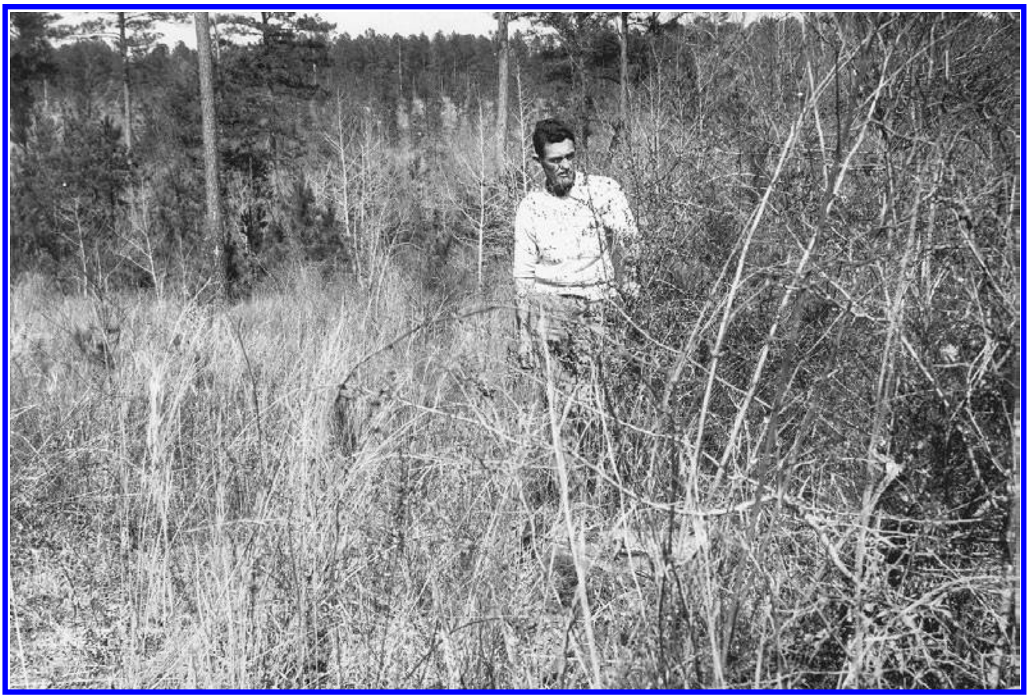

Figure 7.10 A prescribed fire controls brush prior to planting loblolly pine. One year after the fire (left) in this Piedmont site, trees were planted. The seedlings remained free of overtopping vegetation. To the right, seedlings did not survive the competition of the brush.

Prescribed burning for hardwood control is undertaken as soon as pines can endure the heat, because undesirable trees of nuisance species are well established by the time the pines are 10 to 20 years of age. Beyond that, broadleaf stems are too large for control with an initial prescribed fire.

Where prescribed fire is often used in loblolly pine stands for controlling brush and overtopping broadleaf trees, the prescriptions may seem like this one for East Texas: Ignite fuel 4 to 13 days after a rain of at least 1 inch, relative humidity of 26 to 64%, fuel moisture of 1 to 10%, and a south wind of 1 to 4 miles per hour.[25]

In the South Carolina flatwoods, consecutive summer fires for 3 and 4 years may be necessary to kill weed-tree root stock. Even then, only half the small hardwood stems are eliminated. On areas long protected from fire, fuel builds to the degree that damage to pine trees is inevitable.[26]

Strip headfires in 100-foot-wide bands are utilized for thinned pine—hardwood stands with basal areas less than 70 square feet per acre and where there is no fresh logging slash. Fire is set in the strips when fuel moisture is 3 to 8%, relative humidity 20 to 40%, and the wind low and steady. Such a fire may be set in the fall, winter, or spring. For some zones of the region, such prescriptions may be carried out on no more than 30 days a year.

Plantations of slash pine require more-moist conditions for safe prescriptions. Where foliage is draped and heavy, backfires alone are employed. While backfires do not run as swiftly as headfires, the increased heat arising from the slowly moving fire may be more damaging than a cool winter fire running with the wind out of the north.

Flames are kept less than 3 feet high by avoiding prescriptions that allow burning if air temperature rises above 50˚F. The southern pines tolerate fire of greater intensity when temperatures are just above freezing than on warm summer days. Conversely, fires to control deciduous weed trees are more effective on hot summer days. And there's the rub; unskilled writers of burning

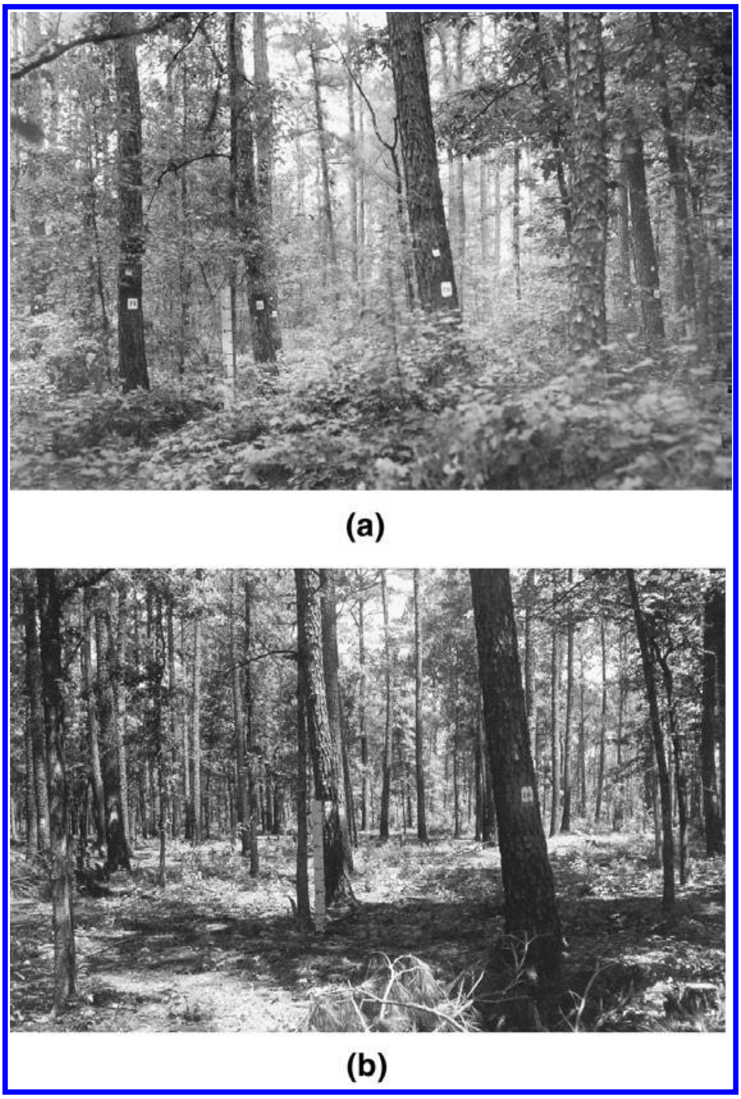

Figure 7.11 Weed-tree control with prescribed burning. Two hot summer fires 2 years apart (the delay to allow fuel to build up) controlled the broadleaf understory vegetation in a South Carolina Coastal Plain forest. Before (a) and after (b) the second fire. (USDA Forest Service photo)

prescriptions may provide for controlling brush while also defoliating and injuring the very trees whose vigor they set out to enhance.

Pitch pine, a serotinous species, lends itself to prescribed fire in upland sites where climax oaks and hickories push for dominance. The shallowness of ridge soils, and hence their xeric nature, is also conducive to pitch pine success over hardwoods following fire. Such fire prescriptions, especially periodic burning when crop trees are large enough to escape appreciable injury, are attempts to imitate naturally occurring fire. After new stands are established in mountain forests of this species, prescribed fires continues to be a useful tool. At periodic intervals after crop trees are large enough to escape injury, fire keeps down the brush that competes for soil moisture and nutrients.

Figure 7.12 Diked and ditched plot to determine optimum water levels for slash pine and loblolly pine seedling growth in the Southeastern Tidewater flatwoods. Free groundwater maintained at 4 inches below the soil surface provides for optimum tree growth.

For pitch pines in the New Jersey Barrens, dense understories of shrubs like leatherleaf and sheep laurel contribute to high fire intensity. There is but little difference in burning conditions for fires that effectively control plants competing with the pitch pines while not damaging the pines, and those that crown or scorch overstory pine foliage. Thinning the smaller stems prior to burning reduces losses, provided logging slash left behind is not itself a fire hazard that increases heat intensity. To reduce the hazard, foresters often prescribe periodic winter burns, which reduce fuel, making subsequent fires—wild and controlled—less destructive. Prescribed burning affects the soil, though usually minimally. Burning once every 4 years reduces the volume of organic matter and, thereby, diminishes the amount of nitrogen available to plants.

Drainage

Drainage as an intermediate management tool for southern forests is principally limited to pond pine, Atlantic white-cedar, and southern baldcypress woodlands. Draining the organic soils in which these trees grow, although desirable for improving growth, is seldom economically feasible. As a result of the treatment, less-desirable species often invade.

Draining wetlands, whether to improve tree growth or for other reasons, seems to be a practice of the past. When a president declares "no net loss of wetlands," one expects the federal government's Fish and Wildlife Service, the Environmental Protection Agency, and other regulatory bodies to be especially alert to this concern. The public echoes the chief executive's sentiments.

Measurable effects of drainage extend for some 300 yards from ditches, providing for an appreciable draw-down rate for water tables in a rain-free summer period. Draw-down depends on density and composition of vegetation and the proximity of the water table to horizons of root concentrations in the soil profile. Drainage ditches along the North Carolina coast that led water from a swamp doubled the site index of the former swamp from 20 to 40 for pond pine.[27]

Drainage changes the flora and fauna that inhabit the site. Hollies and wax myrtle increase in abundance, while swamp ironwood diminishes. However, little change in vegetation takes place in grass-sedge bogs in which pond pines grow. Following drainage there in the shade of closed canopies, the surface soil horizon generally develops from the thick needle-leaf litter inhabited by ants and rodents. Complete oxidation to the mineral soil of the peat or muck layer, as a consequence of drainage, enables satisfactory growth of loblolly pine, to which such sites were often converted.

Removing water from the land reduces surface elevations as organic matter exposed to the atmosphere rapidly oxidizes, especially so in warm climates. Water tables of slightly higher elevations nearby are also lowered as water moves laterally from higher to lower elevations. Then, during periods of drought, when lack of soil water limits tree growth, severe mortality might result on those undrained, higher-elevation neighboring sites. This kind of situation could lead to litigation if trees on undrained sites of one ownership die as the result of water losses to lower, drained land of an adjacent property.

In coastal pocosins, the flow of water in the layer of fine mineral matter lying buried under peat is as important to tree growth as moisture nearer the surface. To access this water or to drain this zone, deep ditches are cut through the organic matter, and shallow lateral ditches excavated at 50-yard intervals.

Slash pine replaces baldcypress in areas where surface water is drained from ponds. Drainage is essential for conversion, even where seed sources are present and vegetative competition absent, since excess water prevents establishment of slash pine.

In the coastal area of North Carolina, a ditch affecting the water table laterally for 1000 feet improves height growth of slash pine for over 500 feet, and a definite association between height growth and depth to water table occurs. Response of slash pine to deep-water drainage was less than that of loblolly pine, but the former holds its growth rate better in areas farthest away from the ditch.[28]

Good growth for slash and loblolly pines is best in moist depressions at pond margins that are temporarily flooded almost every year, but excess water removed by drainage to 4 inches below ground level provides optimum growth. Inundation, as frequent as once in 3 weeks to a depth of 3 inches is too severe for sustaining growth.[29]

Here we must say something about the wetlands controversy. In order not to lose wetlands, so necessary for wildlife habitat, the U.S. Environmental Protection Agency in 1992 changed the rules for defining such sites. Under the Clean Water Act of 1989, pine plantations in areas not inundated were earlier sometimes so classified. Making the definition more restricted also lessened the threat to private property rights for those owning these hydric biomes.

CONTROLLING WEED TREES WITH CHEMICALS[30]

The Second World War ushered in the use of chemicals in forest management. While DDT had been discovered as the insecticide that supposedly would forever rid foxhole soldiers and prison inhabitants of the fleas that carry the dreaded typhus germ, chemists synthesized herbicides like 2,4-D, that were intended to destroy the foe's rice fields in the Orient and thereby encourage hungry enemy soldiers and their political commanders to surrender. And inventive techniques for making fertilizer from cheap natural gas at the government's former ammunition plant in Alabama were accompanied by the development of fire suppressants, fungicides, and animal repellents. Later, however, the U.S. Congress enacted legislation that would control manufacture and use of essentially all chemicals introduced by man into the environment.

Herbicides were first used in forestry to any appreciable degree in the late 1940s. Intent was to control the broadleaf weed trees, mostly of sprout origin. Ammate, the trade name for ammonium sulfamate and one of the first herbicides, effectively controls undesirable broadleaf trees and shrubs when a tablespoon of the yellowish salt crystals is scooped from a wooden pail and poured by hand into cuts, called cups, made at about 6-inch intervals at the bases of trees. Workers wear gloves because, discarding the clumsy wooden spoons for ladling the chemical, they often use their hands. Ammate salt burns like table salt when in contact with skin that has been cut or scratched. Wildlife often find the chemical in the cup an inviting salt lick. No detrimental effect to humans or wildlife has been reported.

Ammate's corrosiveness prevents its use in metallic equipment. Water solutions are not necessary, however, because, within a few days, moisture in the air serves to dissolve the crystals

Figure 7.13 The honeysuckle–kudzu problem in the South. Considerable acreages, perhaps 1 in 25, in the Piedmont province of Georgia and South Carolina have been taken over by these exotic vines to the exclusion of forests. Control is essential, requiring chemicals, fires, and mechanical attempts at eradication

poured into the cups. Labor-intensive application methods required for ammate applications brought about the transition from this nonselective (kills all species) herbicide to other species-selective substances and methods requiring less labor.

Among the first of the selective synthetic growth regulators for forestry use was 2,4-D. For a while it was poured into frills made with axes through the bark and around the trees at waist height. Then 2, 4,5-T and combinations of the two herbicides were employed in frill applications or sprayed on tree bases.

The first injector for herbicides, the invention of an Oklahoma lawyer named Little, was followed by other so-called "Paul Bunyan needles." Little knew nothing of forestry's need for the equipment; he was simply tired of fighting scrub oaks that invaded his rangelands. Injectors enable workers to place chemical solutions into the growing inner bark at tree bases; from there the chemical moves by translocation to growing regions of the plant. These instruments obviously require much less effort than do the cutting of cups and the frilling of trees with axes.

By the 1950s, landowners controlled brush or small hardwood trees in dense stands by using foliage sprays applied from mist blowers mounted on trucks or trailers or released from helicopters or fixed-wing aircraft. When selective herbicides like 2,4-D; 2,4,5-T; and 2,4,5-TP (if the latter two should again be manufactured for sale in the U.S.) are applied as foliage sprays, pines usually are not harmed. Another popular material for foliar application is glyphosate (trade-named Roundup™).

Herbicides may also be broadcast applied as pellets and as soil sterilants. The hypo-hatchet, among the later tools to arrive on the scene, distributes concentrated chemical to the inner bark through a hose connected to a small tank harnessed to a worker's belt.

Figure 7.14 Tree-improvement studies often require aging sapling-size stems. For the multinodal southern pines, the last internode of the year is the shortest, the first of the season the longest. Here, white paint marks each year's first whorl of branches. As many as six or more may occur, depending on the quality of the site and the longitude. (USDA Forest Service photo)

Volatility of chemicals varies. The heavier the formulation is, the less the danger of particle drift or vapor movement to nearby desirable vegetation. Some ester forms may be of relatively low volatility; amine salts are generally even less volatile. Invert emulsions (mayonnaise is an example) find use in aerial sprays because little drift occurs. Constant stirring of non-inert mixtures is necessary, as these compounds often form unstable emulsions when diluted with oil or water.

Growth regulator herbicides are marketed in pounds of acid-equivalent per gallon of chemical. Hence, a 1-gallon container holding 4 pounds of acid-equivalent provides twice as much herbicide as a 1-gallon container with 2 pounds of acid-equivalent. The word "acid" refers to the chemical description, not the common conception of acid properties such as burning and dissolving.

2,4,5-T is alleged to have caused human fetus problems in Vietnam and to soldiers fighting there, jungle areas having been saturated with the herbicide to clear vegetation and thus protect American soldiers from ambush. Similar claims of human injury occurred in Oregon, where the

Figure 7.15 Provenance influences a regenerated forest. Here, stem cuttings from Mississippi Delta cottonwood trees planted in a Piedmont cove produced these trees in 6 years. (authors' collection)

chemicals were used to release valuable conifers from weed-tree competition. The federal Environmental Protection Agency's dispute-resolution conference of 1979 did not indict the herbicide. The courts have indicated they would not have suspended the product on the basis of evidence available to the EPA. Whether this chemical may harm future users is now a moot question: It is no longer manufactured in the U.S.

With the reduction in timber production on public lands across the South, industry is moving to more intensive management. The use of herbicides, sometimes in conjunction with fertilization, has increased as a site preparation tool, as well as for use in intermediate treatments.[31]

TREE IMPROVEMENT

Tree improvement, most advanced in America with the southern pines, involves the use of progeny from trees with superior characteristics. Thus, tree quality is improved through genetic inheritance.

Figure 7.16 Slash pine in a progeny test plantation. In this case, controlled pollination was utilized for selecting trees with high oleoresin yields. With the present low demand for gum naval stores, this would no longer be an appropriate concern. (USDA Forest Service photo by Dan Todd)

Selected from among individual trees in the forest are those with desirable phenotypic (visible) characteristics—slight stem taper, rapid growth, narrow crown, small-diameter limbs that grow perpendicular to the bole (hence producing smaller knots than those at acute angles), apparent insect and disease resistance, good strobili (flower) and hence seed production, optimum wood density and—if for naval stores production—favorable yields of gum.

Selection for some of these same characteristics by the loggers of earlier generations led to the low-grade forests now in need of improvement. With the first harvest of the virgin forest, lumbermen took the biggest and best trees and subsequently did so again and again, leaving the inferior stems behind as parent stock for the future forest. Foresters anticipated that the search for higher quality trees from which to procure progeny would eventually result in stems far superior to those logged by the pioneering lumbermen. Alas, researchers note little improvement beyond the third filial (F_3) generation, probably because other factors, notably soil fertility and moisture, are inadequate for supplying the requirements for the anticipated "super" trees.

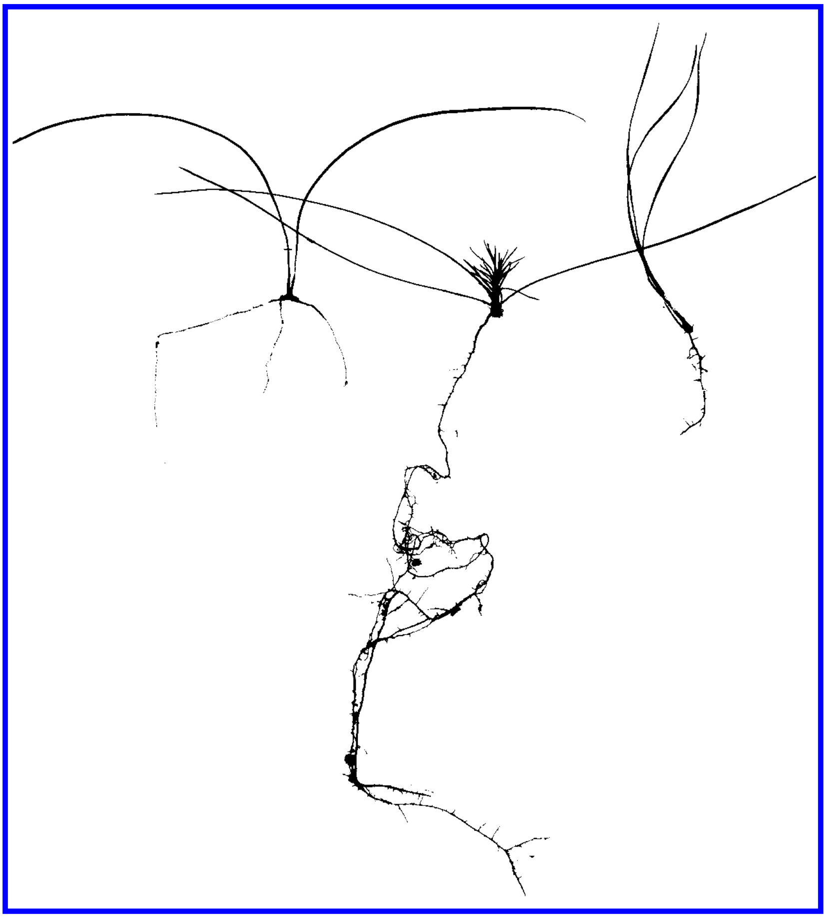

Figure 7.17 Rooted shortleaf pine needle bundles. From these tissues, treated with a growth regulator, new trees that are true clones of the parent develop. Thus, untold numbers of bundles can be collected from a superior tree without damaging it to provide regenerative material. (authors' collection)

Environment and Provenance

The role of environmental factors is easily confused with inheritance in the growth and form of forest trees. Environmental effects may be overruled by genetic composition. Thus, on a particular site, the trees may vary greatly in frost-, drought-, and disease-resistance. Branching habit may be attributed to either inheritance or environment. Branches that hug the ground on a tree in a dense stand and branches in an open-grown tree that self-prune suggest genetics; the opposite indicates environmental influence.

To aid in separating environmental and inherited interacting characteristics, foresters establish provenance tests. In other words, provenance tests enable discovery of trees that will produce the best seed for particular sites, not necessarily better combinations of genes. The best genetic composition for growth for a strain of a species originating in Maryland, for example, may not be better than the average growth in Texas for that strain because of the poor adaptation of Maryland trees to Texas temperature or day length. The same could be true for Texas strains of the species introduced into the more-northern, colder climate of Maryland. Hence, selections of parent trees to supply seeds of highest quality for the future forest must be carried out region by region.

Figure 7.18 A shortleaf pine tree selected for its superior quality for subsequent seed collection or controlled pollination. (authors' collection)

Eastern white pine, like shortleaf pine, develops roots when needle bunches are specifically treated. Needle rooting seems to be related to factors other than nutrition. Needles exposed to constant temperature of 78˚F and treated with the auxin indolebutyric acid develop roots. In a year or so, dominant radicles appear. Terminal shoot growth, however, is poorly correlated with root system morphology.[32]

Seed-Production Areas

Clonal seed orchards are not the only pathway to production of genetically improved seeds. Obtaining seedling progeny from controlled crosses of trees in the forest is an alternate approach.

Figure 7.19 Bagged slash pine female strobili, to protect the "flower" from "wild" pollen, are pollinated using a syringe that punctures the bag, releasing to its interior pollen collected from superior stems. A few weeks later, after the strobili scales have closed and the conelet is no longer receptive to pollen, the bag is removed. Inset: close up of bagged strobili. Note the five conelets and the cotton cushioning at the bag opening. (USDA Forest Service principal photo by Dan Todd)

With this method, however, 15-year-old seed-orchard grafts likely will not produce more seed than the same-age ungrafted trees under comparable conditions in the forest. In 10 years, cone production of planted cross-pollinated seed-producing trees should equal that of the grafted stems of the same age, provided the trees are grown widely spaced, cultivated, and fertilized. Seed orchards of grafted trees, however, provide a greater wealth of germ plasma from which to develop second- third- and fourth-generation progeny by recurrent selection where the pollen from the best progeny in each generation is mixed and applied to individual female strobili or flowers of chosen mother trees. The best of the individuals may be selected for making specific crosses.

Seed-production areas, utilizing naturally occurring trees in the forest, are less costly to develop than seed orchards for obtaining high-quality seeds. Here, phenotypically inferior stems are removed from these well-established stands, perhaps 30 to 50 years of age. Inferior trees are also cut from 500-foot-wide strips surrounding the area to eliminate pollen from outside the stand. Releasing the trees selected for seed production from their competition and fertilizing them with supplemental nutrients enables production of bumper seed crops in what might otherwise be "off" years. For example, a 44-year-old stand of about 60 trees per acre containing 14,000 board feet was reduced to 18 stems with 4,000 board feet to provide adequate light, moisture, and nutrients for the residual stems that then produced abundant quantities of seed of genetically high quality. Workers in seed-production areas have to decide if the cones high in the trees are worth climbing to collect, as the first branch in superior-quality stems could be 60 to 70 feet above the ground. Binoculars aid in estimating production, as the number of cones actually borne is about three times the count from

Figure 7.20 A genetically improved superior longleaf pine tree shown through 3 year's growth. The hand is at breast height. (authors' collection)

the ground. Counts of 170 cones per tree produce 15,000 to 50,000 seeds per pound, depending upon species, 75% of which likely will be viable.

Pollen

If land managers depend on seed released 18 months after pollen dissemination (the time lapse for most southern pines) for establishing new stands, they need to know the reliability of that dependency. Fresh pollen is not always viable. Freezing weather at the time of meiosis, when reproduction cells develop, kills germ plasma. To ascertain pollen viability at time of dissemination of the gold-colored dust-size grains, a small sample is placed in a vial of distilled water at 79˚F for 3 days. At that time, the germinated grains—those with tubes as long as the grains—are counted under a microscope.

Some idea of pollen counts is useful to those planning regeneration harvests. Colorless polyester tape, mounted on a thin aluminum plate through which holes have been punched, traps the pollen on its sticky surface. Pollen abundance, a clue to future seed production, is then measured.

Fusiform rust, caused by *Cronartium fusiforme*, damages seed orchards. Young leaves of oak trees, the alternate host, particularly water oak, exhibit yellow spots in mid-spring, brown telial hairs then developing on the undersides of the leaves prior to a period of high humidity. Spores released from these leaves soon infect pines. Consequently, foresters wait for forecasts of daytime rain or cloudy weather before spraying the pines with fungicide. Danger of infection passes when the fungal telia shrivel.

Other problems for seed orchards include the occurrence of late frosts that kill female strobili of conifers and flowers of broadleaf species, hot summers that bake the first-year cones as they begin to mature, birds that break cone- and fruit-bearing branches, and squirrels that prematurely harvest cones and cache seeds. Bird roosts placed beside each tree in a seed orchard reduce limb breakage, and 18-inch-wide metal bands around trunks prevent squirrels from climbing the trees and consuming the seed.

Seed certification for forest trees began to be implemented by the States in the 1950s. Georgia was the first, designating seeds by several categories, depending on whether they are collected from seed orchards before or after acceptable progeny testing. Certification also classifies seeds from so-called plus trees in seed-production areas. For certification, if from orchards, at least 15 clones must be included in the orchard to permit adequate cross-pollination. Both orchards and seed-production areas must have extensive isolation strips to exclude trees that would pollinate the elite stems from which seeds are sought. Eventually, seeds for planting in nurseries and for direct seeding in reforestation projects will come entirely from orchards or from elite trees that have had acceptable progeny tests.

8 Regenerating the Forest

As new laws are enacted, landowners become more aware of the need to regenerate forests, whether naturally or artificially. While Louisiana was the first southern state to require the retention of seed trees following a harvest, the legislation was not effective because it did not specify the species and the quality of the trees to be retained. Virginia, having a more favorable law for the purpose of assuring a new forest, requires that at least 10% of the trees 6 inches or larger in diameter be retained for at least 3 years or, during that period, a plantation must be established. Natural regeneration procedures save the high cost of planting.

Forest Trees in Ecological Succession

Important timber species normally occur in ecological associations that foresters catalog as forest-cover types. Some species are important in several types. While certain kinds of trees grow successfully when introduced outside of their native range, the use of exotics can be ecologically disruptive. Thus, we might prefer to rely on natural regeneration to replenish the site with locally indigenous species. Understanding succession is fundamental to comprehending natural regeneration.

Large trees are often old by human standards, although southern pines seldom exceed 130 years, even if 4 feet in diameter. (The 130-year figure derives from a 1950s study of all known uncut forests in the three southeastern states—Georgia, Florida, and Alabama. However, pathological or biological maturity of southern pines on some sites may exceed 200 years.)[1] One should not, however, assume that they are permanent or invulnerable to death and decay. All timber stands reflect stages in a sequence of ecological succession that could be interrupted at any time by natural catastrophes such as windstorm, insect epidemic, disease, fire, or logging. To produce the stable, or climax, forest, ecological succession might require centuries without natural or human disturbance. Most virgin forests of lumbering history in the South were at sub-climax or even earlier stages when harvested for building materials. For example, white and southern yellow pines seed-in abundantly only on denuded sites. Yet these species were ready for harvest in the U.S. in the 18th, l9th, and 20th centuries because of earlier interruptions in ecological succession. Native Americans, then European settlers, burned the forest, and lightning fires, tornadoes, and hurricanes laid bare the land.

The key to forest succession is the relative tolerance of trees to competing demands by their neighbors for light, moisture, and nutrients. Certain species, in contrast to the southern pines, thus persist under dense shade. Regenerating under their own canopies, these kinds of trees dominate the climax forest.

Tolerant species that form climax types are represented in the South by American beech, river birch, sugar maple, red spruce, Fraser fir, eastern hemlock, and a number of oaks. Harvesting by the selection system of individual trees in these forests provides space for new stems and assures perpetuation of the type. While the single-tree selection system is often effective in complex broadleaf types, such as those of southern river bottomlands, encroachment of weed species in the openings might preclude the method.

At the other extreme are species intolerant of shade, including most pines and many hardwoods (especially cherry species and white ash). Others intolerant of shade in the formative years are cottonwood, willow, and yellow-poplar. Although these are prolific seed producers, they compete poorly with established vegetation and rarely occur in understories. The seeds of these pioneer trees germinate readily on exposed mineral soil, as their seedlings grow rapidly if light is abundant, and “capture” growing space to exclude competitors. Stands of these species usually result from logging, abandonment of cultivated fields, or deposition of new river alluvia in stream bottoms.

Species' success in ecological competition is also affected by morphologic and physiologic traits. Trees of some species sprout from roots or stumps, using an established root system for nourishment to outgrow adjacent seedlings. Others produce many small seeds that are scattered widely, while seedlings of species that produce few—but large—seeds, with much food stored therein, may outgrow competing plants not so endowed.

Seeds of most plants appearing in ecological succession are usually available at appropriate times in the sequential evolution of the vegetative cover. Thus, a disturbed site may be dominated initially by annual weeds or grasses, followed successively by biennial and perennial herbs and shrubs. On fertile sites, some of the initial annual invaders grow so rank as to inhibit establishment of pioneer tree species, delaying the development of a tree cover until a new catastrophe scarifies the soil and exposes the site to full sunlight. Eventually, trees encroach.

Because seedlings and saplings of ecological pioneers do not compete well in a shaded environment, reproduction establishment for these species following selection harvests is undependable. To regenerate stands of intolerant trees, foresters clear sites, using a legitimate silvicultural system called clearcutting. As a system to develop a new stand of trees at the end of a rotation, clearcutting is not simply "whack and stack" and then abandon the site. Regeneration of commercially useful forests is clearly the intent. Clearcut areas may be in blocks or strips, depending on seeds from the surrounding walls of timber.

Between these extremes in silvicultural regeneration systems—selection and clearcutting—are shelterwood and seed-tree methods. Shelterwood harvests generally require three cuttings, the first to release the seed trees from competition for soil moisture and light to encourage seed production and, at the same time, to prepare the site to receive the seeds by scarifying the soil. The second harvest also provides for seed germination while protecting and releasing the new seedlings. The final cutting releases all of the seedlings, enabling them to grow freely in full sunlight.

Seed-tree harvests leave an adequate number of trees to produce seeds for the new stand. Timber markers select superior phenotypes for parent trees, thus encouraging the new forest to be favored with straight stems of slight taper that exhibit small branches extending at right angles from the trunks. There should also be evidence of seed productivity; old cones lying on the ground provide a clue. Seed trees should be evenly spaced, the number per acre depending on species and site quality.

SOUTHERN PINES

Ten species of southern pines produce essentially identical wood, marketed as a single material. More than half the nation's softwood comes from these trees. Four species are of primary importance. Loblolly pine, the most widespread and abundant, is a fast-growing tree of slightly more intermediate tolerance and highly regarded by timber growers. It now dominates much land formerly occupied by longleaf pine. Shortleaf pine extends farthest north, is intolerant, and out-produces its hardwood associates on many sites. Slash pine, fast-growing on both dry sandy and moist flatwoods sites is relatively tolerant of competition; genetically superior strains are available. Longleaf pine, the most intolerant, grows slowly in youth, but develops straight, clean stems of excellent quality. Longleaf and slash pines, occurring mainly on the Gulf and Atlantic coastal plains, produce commercial oleoresin as well as fiber.

These four principal species occur in pure stands, in mixtures with hardwoods, and with each other. None is climax (apart from longleaf pines' fire climax characteristic), their seedlings usually are unable to survive under their own shade or that of invading competitors.

The ecological climax for most southern pine sites is a hardwood type, with occasional relict pines. Such forests occurred widely in the Piedmont province in pioneer days, but less so in the Coastal Plain. In the Coastal Plain windstorms and forest fires more frequently interrupted the ecological cycle to set back succession and to initiate extensive pine stands. Despite wasteful cutting and woods-burning, most existing natural pine stands originated by natural reseeding of cutover

Figure 8.1 Partial harvests (seed-tree, shelterwood, selection) may not succeed in regenerating a stand of southern pine for a number of reasons—too many seed trees for competition; the soil is not scarified to receive the seed; and the brush competes with seedlings, if any germinate. (authors' collection by R.D. Baker)

forest or abandoned farmland. Many dry sandy sites now growing pine would, if not disturbed, succeed to a forest of permanent climax cover types.

Management of southern pines requires maintenance of a sub-climax vegetative association. The alternative, allowing stands to revert to predominantly hardwood types, is incompatible with optimum production of structural lumber, plywood, and long-fiber pulp. Only when managed primarily for pine can the South's 100 million acres of potential pine land meet the nation's projected needs for these products. Managed southern pine forests, regenerated under systems that remove most or all of the existing stand, require control of established hardwoods by fire, chemicals, or mechanical means.

It is uncertain whether any of the worst enemies of the southern pines—littleleaf disease of shortleaf pine, annosus root rot in slash pine, or the southern pine beetle—are appreciably fostered by monoculture silviculture. Even-aged forest management in pure stands, however, need not be the cause. In this region, hardwoods occurring along streams reduce the size of even-aged, single-species blocks of southern pines.

Prompt establishment of herbaceous cover on regenerated areas limits accelerated erosion to a period of 4 to 6 months after each cutting. Proper reproduction procedures should hold the aesthetic insult to about two growing seasons. Since intervals between harvests are about 20 and 40 years for pulpwood and sawlogs, respectively, such exposure disturbance is not excessive for the moderate slopes of Coastal Plain and Piedmont sites. On mountainous terrain in Arkansas and the Appalachian chain, less-intensive clearing, more-limited cutting acreages, or special erosion control measures may be desirable.

Figure 8.2 A noble loblolly pine (straight, minimal crown, small branches at right angles from the bole, and growing in full sunlight) would make an excellent seed tree, but also a tempting tree for a sawmiller operating in the Gulf Coastal Plain. (USDA Forest Service photo by P. Carter 1935)

Foresters must consider game and other wildlife when deciding on regeneration methods. Pure pine stands dense enough to exclude understory plants are poor habitat for some animals. However, the edges of openings made in harvests, as well as thinned stands, produce wildlife food in the form of shrubby and herbaceous browse, seeds, and fruits. Regeneration areas, from the time of site preparation until crown closure of young trees, afford excellent white-tailed deer and bobwhite quail habitat. With small, well-distributed cutting areas, intensive pine management should also be compatible with large populations of doves and turkeys. Nearly as much game is produced as would be under intensive single-use wildlife management.

Some people consider managed southern pine forests in the Coastal Plain aesthetically monotonous. Only where the gentle, flat terrain is broken by farmlands and harvests do the forests not obscure the view more than a few rods distant from roads. Allowing ecological succession to proceed to the broadleaf climax reduces the monotony, but at appreciable cost in fiber production.

Figure 8.3 The seed tree in the right of center background provided the seeds for this longleaf pine sapling stand of about 300 trees per acre. Some seedlings remain hidden in the "rough," others have recently emerged from the nanism stage—fire preceded stand establishment. (USDA Forest Service photo by J. Cassady)

Prescribed burning exposes mineral soil and controls shade-producing canopy. A typical prescription for a summer fire in Virginia to prepare the site to receive seeds calls for a burning index of 4 to 5, relative humidity of about 50%, air temperature between 84˚F and 92˚F, fuel moisture between 5 and 7%, and winds at 2 to 3 miles per hour 8 feet above the ground. Sometimes, as in poorly drained coastal sites where standing water slows litter decomposition, fire cannot be used to expose the mineral soil.[2]

The site having been made ready and the seeds available, germination now depends principally on water availability. Seeds must contact a continuously moist medium, as the water serves to stimulate cell growth and rupture seed coats.

Puddled soil, caused by repeated passage of heavy machinery in logging operations, reduces growth for young seedlings, because fine roots are unable to readily penetrate compacted soil. Similarly, survival and growth suffer on heavy soils of silt and clay texture that have been baked hard by the rays of the sun.

Numerous seed and seedling pests take a toll. Ants destroy seeds and cut seedlings, birds pick coats from seeds just after emergence of cotyledon leaves, and mice travel appreciable distances to get seeds where abundant on cutover areas. Mice use the protective cover of logging slash for tunnels on their long excursions of a mile or more. Fungi account for some10% of seedling mortality, while even cockroaches get their share. Trampling by grazing cattle possibly also reduces survival rates of seedlings.

As noted, southern pines are typically managed in even-aged stands, where foresters occasionally prescribe shelterwood, seed-tree, or clearcutting methods. All of these methods require an

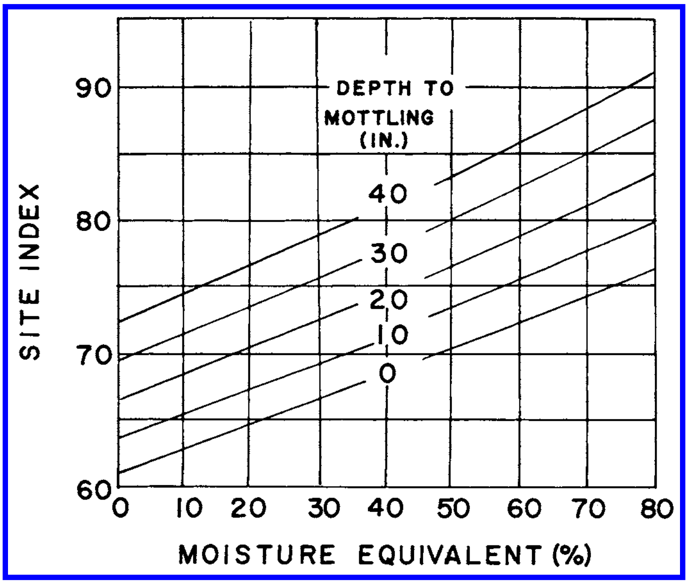

Figure 8.4 Success of natural regeneration may depend on the quality of the site. Where no trees are available for determining site index, depth to mottling is a dependable method: site index for longleaf pine growing in imperfectly and poorly drained soils in the coastal plain is affected by both moisture equivalent (a laboratory reproducible measure of soil water) and depth to mottling. (after Ralston, 1951)

adequate seed source, exposed mineral soil for the seedbed, and adequate sunlight to enable the seedlings to survive beyond a few years. The need for the latter two requirements relegates shelterwood harvests to the most productive sites, where fertile soil and favorable water relations compensate to some degree for the lack of sunlight reaching the foliage of seedlings. Group selection, when utilized in uneven-aged management, results in the establishment or maintenance of uneven-aged stands.

While even-aged management, including shelterwood harvesting, is typical for loblolly and shortleaf pines, these species may be regenerated and managed on better sites using single-tree selection to produce uneven-aged stands. Yet, herbaceous and woody competition on high-quality sites makes the selection system difficult to practice.

Seed-Tree Harvests—Seed-tree regeneration, retaining five to 10 high-quality trees and releasing them from competition several years before the anticipated harvest, usually provides for adequate stocking of the new stand. Ten feet of open space all around the crown enables sufficient light and soil moisture and nutrients to supply the tree's requirements for producing seeds.

Seed trees should be among the largest of those in the stand bearing cones. Dominant and co-dominant stems with a history of producing at least 30 cones each year and appearing healthy are sought. Some seed trees will be lost to lightning strikes and other agents, yet their net growth almost always exceeds mortality. These trees should be harvested as soon as reproduction is established, for some may bear the ill effects of logging damage—butt scarring and soil puddling.

Some seed production tallies may amount to more than two million seeds per acre in stands of loblolly pine. Even seed crops in poor years amount to 25,000 sound seeds per acre. Foresters determine these statistics by randomly placing seed traps in the woods. The trap openings, into which seeds fall through a rodent protection screen, of 1/4 milacre (1/4000 acre) provide convenient conversion data to an acre basis.[3]

Selection Harvests—The aesthetically preferred selection system for regenerating forests is often relied on throughout much of the range of loblolly and shortleaf pines. The southern Arkansas–northern Louisiana area appears to be especially adaptable. With this system, cutting cycles of 10 years or longer, depending on site quality, make openings at least 15 to 30 feet in diameter as each tree is harvested. Smaller holes in the canopy provide inadequate space for reproduction survival and development. Fire must be excluded from these stands, for some stems subject to heat injury will be present throughout the rotation. Selection harvests find their greatest usefulness where broadleaf species encroachment is not serious or where well-stocked stands of pine hold in check the few small hardwood trees present. Otherwise, the deciduous species take over the openings before pine seeds have had a chance to germinate and the resulting seedlings become established. Logging damage to residual stems during subsequent harvests is unavoidable.[4]

With group selection, openings are sufficiently large to also encourage weed trees to encroach, the pines barely surviving in the shade of overtopping canopies of broadleaf species. Overtopped pine trees as old as 20 years, however, may recover vigor when released from competition. To maintain seedling vigor, basal area of the balance of the merchantable trees in the stand should not exceed about 50 square feet per acre. To reduce a forest to that degree is to practically make a seed-tree harvest. Group selection in the mixed pine–hardwood forests of Arkansas has produced excellent regeneration of both hardwoods and pines.[5]

Tree vigor is a direct response of foliage area and the consequent production of carbohydrate. Hence the number of branches on a tree and the length of the stem with green needles appreciably increase with increasing size of openings in the forest. Annual diameter growth for southern pines in the Piedmont was shown to dramatically increase from about 0.5 inch for openings under 35 feet to about 1.2 inches for those greater than 45 feet. One might then suggest minimum openings of this latter distance to support favorable growth of newly regenerated forests. In that event, group selection harvests seem practical.[6]

Even where openings are adequate and the ground scarified to receive the seed for prompt germination, loblolly pine seed loss may be so severe as to impede regeneration. As much as 98% of viable seeds may be consumed by predators or destroyed by fungi. On the other hand, even where a site is not prepared by burning, as few as 10,000 well-spaced seeds per acre assures a well-stocked seedling stand.[7]

Clearcutting Controversy—Lay readers should realize that stands of southern pine that appear to be uneven-aged or many-aged probably are not. Stems within a stand ranging in diameter from 3 to 30 inches and in height from 30 to 130 feet likely are of the same age, seeding-in simultaneously. Sensitive to competition for light, moisture, and nutrients and to release brought about by natural catastrophe, some stems grow faster than others. Some seem to be genetically destined to assume dominance; while seeds that produced some stems may have fallen on the droppings or the carcass of a long dead animal, the seedling benefiting from the isolated favorable nutrition of that locale. Most of the second-growth unmanaged pine forests of the South appear many-aged because of these influences. When then subjected to thinning (though often erroneously referred to as selection harvesting), the stands appear even more of an uneven-aged character.

Attempts in the early days of acquisition of national forests of the region to regenerate loblolly and shortleaf pines by the selection system resulted in failure. Jungles of broadleaf trees and brush captured the openings. Costly herbicide applications failed to adequately release the pines. Directives then instructed district rangers to utilize clearcutting and other even-aged systems to reproduce these forests.

That the national forests of the region were purchased for as little as $2.80 an acre suggests the poor condition of these lands. Yet, these lands, were purchased to grow trees in order to avoid a future timber famine. For the next 50 years, foresters—with the assistance of providence—went about rehabilitating these abused lands. By the end of this period, the appearance of the forests to many was that of virgin old-growth. Meanwhile, the Forest Service, in the U.S. Department of Agriculture, following its congressional mandate to provide wood for the country's consumption, moved from thinning and selection regeneration harvests to clearcutting as the most efficient way to produce the fiber and to regenerate the forest with species desirable for paper and lumber.

Figure 8.5 Preparing for the second cut of a shelterwood regeneration cut in a shortleaf pine stand along the Georgia Fall Line sandhills. Stumps from the first harvest 5 years earlier are visible. The second harvest is to release seedlings that germinated from seeds following the first cutting. A third cutting will follow, removing the remnant overstory. Prior to the 1960s, loggers often worked without regard to today's safety standards. (authors' collection).

Forest Service adversaries in the 1980s attempted to halt the process by lobbying Congress for new laws and budget restraints. They called attention to the effects of clearcutting on soil erosion, wildlife habitat depletion (especially for the endangered red-cockaded woodpecker), and the ugliness of the logged sites. During a much-publicized "walk in the woods" in a national forest, the Forest Service chief promised a U.S. Senator that no more clearcutting would take place on that forest.

Forest Service antagonists also object to other even-aged management systems (seed-tree and shelterwood), insisting that only selection harvests be permitted. On many biomes, however, forests of southern pines do not reproduce with this system. Rather, with the mineral soil unscarified to receive seeds and inadequate sunlight reaching the forest floor to nurture the newly germinated seedlings, broadleaf weed trees capture the site.

Private landowners fear that if national forest managers are prohibited from utilizing clearcutting, they, too, will lose the right to use this economically efficient regeneration method, that states will be charged by environmental laws and agencies to restrict the practice, and another privilege of land ownership will be surrendered.

An alternative to clearcutting, used in Europe, at first resembles a seed-tree harvest, but the residual stems are left to the end of the rotation rather than harvested when the new stand is established. Windthrow, epicormic branching, and economic loss detract from the method.[8]

Shelterwood—The ugly appearance of clearcut forests, the loss of full financial return attributed to seed-tree harvests, and the ecological problems associated with selection harvests call attention to the possibility of using the shelterwood system for southern pine types. Though not used extensively in the South, the method has possibilities where a dense story of advanced reproduction occurs under an immature overstory. In this event, a management plan may call for removing one-third of the stand volume in three harvests at 5- to 10-year intervals. The amount removed must be carefully gauged, for heavy residual stands restrict height growth of reproduction. Modifications of the shelterwood system include scarifying or burning the site to assure adequate distribution of seedlings. As is the case for seed-tree harvests, returning loggers and equipment to felling sites adds considerably to the cost of a logging chance. And each return with heavy machinery to harvest some of the timber risks damage to residual trees and to reproduction. Soil compaction and erosion may also increase.

In various parts of the South, there exists for natural regeneration in shelterwood harvests a fragile relationship between seed production and precipitation. In the lower Piedmont, the favorable combination of seed availability and favorable soil moisture may occur only once in a decade. There, new stands appear beneath an overwood of loblolly pines, giving rise to a two-aged relatively pure stand. Only when the overstory density is under 60 square feet per acre basal area, however, can advance reproduction be assured. Increasing shade may be as detrimental to seedling survival as the greater competition for soil moisture of higher stand density. Longleaf pine lends itself to a modified shelterwood harvest in second-growth, leaving 15 to 20 trees per acre following the initial harvest.[9]

Clearcutting—Clearcutting, modeled after the German regeneration system, is appropriate for southern pines. Areas of up to 20 acres in size will allow for seeds coming from the walls of trees surrounding the openings. Sites should be prepared by burning, disking, or herbicides, the whole operation scheduled for the anticipated ripening of cones and dissemination of seeds.

Flowering of Southern Pines—A knowledge of flowering and fruiting cycles is essential for employment of cultural methods requiring natural seeding. Female strobili initiation, several weeks behind male, begins between late August and mid-September. The flowers are visible in December and continue to grow during the winter. Staminate flowers, recognized by clusters of up to eight aments arranged spirally around the axis of a branch, are up to two inches long at the time pollen is shed in early spring. Pistillate flowers, in groups of one to six, are receptive to pollen for a period of from several hours to a week, depending on the weather. They are one inch long and flesh colored at pollination time. Cones mature in the fall, about 20 months after pollination.

As a generalization for pine species, female flowers occur mostly in the upper branches near the tip of the current year's growth, close to the terminal bud. Male flowers, usually absent in the upper crown, occur most abundantly at the basal portion of current year's growth and on lower branches. Pollen on male flowers is carried by wind to fertilize female flowers of neighboring trees. This precludes self-fertilization and the resulting hollow seeds that would follow if staminate strobili were high on the trees, gravity then encouraging fertilization of pistillate strobili below. When on the same branch, male and female flowers are separated by more than 5 inches. Conelets become visible to the naked eye in middle to late October; growth ceases during winter. If large crops of male and female flowers do not appear simultaneously, as often occurs, few seeds develop. This is especially true for longleaf pine.

Figure 8.6 This open-grown loblolly pine, while a good seed producer, will likely produce progeny of inferior quality: low form class (much taper), poor self-pruning, and many branches, therefore knots. (USFS photo by F. Helm)

Seed Production for Southern Pines - Apart from the coppice system of regeneration, adequate seed supplies are essential for natural regeneration of a forest by any of the silvicultural systems just discussed. By adequate is meant that hundreds of thousands of seeds may need to fall on an acre to produce a seedling stand of several thousand young trees. Birds, rodents, and insects consume, and fungi infect, many seeds. Drought, rain, heat, and cold kill others, and vegetative competition reduces vigor. Soon after germination, many seedlings, still in the cotyledon stage, die from other pests and weather conditions. Seedbed preparation and prescribed burning further expose seeds to nature's vandals. To guarantee a thousand well-distributed seedlings per acre of cutover land could require at least 200,000 seeds. Half that many may be required for seedbed-prepared sites.

Fair to good slash pine reproduction requires at least 800 to 1,500 cones per acre, and a fair to good seed year provides 50,000 to 100,000 seeds per acre. Releasing seed trees 19 to 22 months before the crop matures enhances production.[10]

Figure 8.7 Child-mother pine. A longleaf pine seedling, barely out of the grass stage, bore two cones, according to this 1939 photo taken in Mississippi. (Courtesy USFS photo by W. H. Morin).

Pine seeds are produced almost every year, except for longleaf pine, but abundant crops occur less frequently. Production on three-year cycles appears typical. In the Piedmont, crops of 50,000 shortleaf pine seeds per acre fall only once in 5 years. Usually about 60% of the seeds are fertile. Although trees as young as 12 years produce cones with viable seeds, the best yields come from trees about 35 years old.

Seed crop size depends on density of the stand, weather, time since seed-tree release, and provenance. In the Virginia Coastal Plain, for instance, a large seed crop may be followed for the next two years by a small crop and vice versa, giving a one-good-year, two-poor-year pattern. Piedmont productivity runs less than for the Coastal Plain. The pattern for mature undisturbed stands appears dependent on physiological factors responsible for storable bud formation during the growing season, strobili blossoming the following spring, and cone maturation two years later in the fall.

Soil moisture influences nutrient absorption and carbohydrate production, shown by the direct relationship of seed abundance to early summer rainfall of the second previous year. Releasing trees selected for seed production compensates for low early summer rainfall: liberation, if done before June, reduces competition and thus increases seed production three years later.[11]

Not all trees respond to release by increasing flower, cone, and seed crops. Inadequate nitrogen reserves or carbohydrate shortages could be responsible. About five% less reserve carbohydrate was found in one- and two-year-old twigs of released trees than in unreleased stems, the reduction attributed to the drain from the twigs for seed formation. Yet nitrogen in those same twigs was 22% higher in released than in unreleased stems. This suggests, as noted elsewhere, the importance of altering the C:N ratio in the growing tissues in order to stimulate flowering.[12]

Early and abundant flowering of 6-year-old slash pines on sandy soils in northern Florida was stimulated through an application of complete fertilizer (nitrogen, phosphorus, and potassium). Nitrogen probably plays the most important role in strobili stimulation.[13]

Heavy rains during pollen shedding in the spring affect seed crops two years later, as great quantities of the golden yellow dust wash to the ground and hence are not available for sexual fertilization of the eggs in female strobili. Cold fronts, too, kill flowers, and a sudden drop in temperature inhibits pollen release.

Injury to trees may stimulate flowering and subsequent seed production. For some species, strangling tree trunks with steel wire and ringing them with knife-cut girdles alters the carbon:nitrogen ratio which, in turn, stimulates flower development. Nutrient applications may more effectively disturb the carbon:nitrogen ratio, resulting in greater seed production two or three years after treatment. Nitrogen alone should be used, for a complete fertilizer stimulates vegetative growth rather than triggering growth of flower primordia. Pruning may increase flowering: removing upper limbs stimulates strobili production low in tree crowns, where pollen-producing male flowers form. Low branch pruning, conversely, may stimulate female flower production, these strobili usually occurring in the upper crowns.

Seed Viability—The number of viable seeds is greater on branches high in the trees exposed to light than on lower ones. Large-crowned trees produce more viable seed percentages than small-crowned ones, the crowns of the former being free of competition for light and thus able to more efficiently produce carbohydrate necessary for development of healthy seeds.

Viability for loblolly pine ranges from 30 to 60% over the years, greatest in good crop years. It is optimum at seed ripening time in early November throughout most of the species' range. Viability decreases as the period for seedfall progresses, so that in January less than 30% of those seeds disseminated the previous fall remain viable. This suggests the profitability of seedbed preparation prior to initiation of seedfall in order to take advantage of the seeds of highest viability.

For any season, seed crop size and percentage of sound seeds are logarithmically related, the number rising steeply with increasing total seedfall beyond 100,000 per acre. Viability of seeds may relate to the distance seeds are found from parents—hollow seeds, being lighter, travel farthest.

Some viability may be retained for a year following autumn seedfall, although germination usually occurs the spring following seedfall. Some seeds not consumed by foraging animals lie dormant deep in the duff to germinate later. Some may be preserved even when humus layers are burned and on sites in which fire has not been sufficiently hot to kill them.

Viability can be ascertained by simply cutting samples of seeds to learn if they are hollow and therefore worthless. Yields of full seeds, exposed by slicing cones in half longitudinally, can be estimated by the formula:

$Y = 4.93 + 7.49X$, where Y = total number of sound seeds per cone, and X = average number of seeds per cone exposed in slicing.[14]

Seed Dispersal—Foresters use information gleaned from observing flower, cone, and seed production in order to plan harvests. They first watch for strobili formation in these gymnosperm (naked seeds) species, then for the appearance of conelets, and finally for mature cones. To plan for harvests, foresters make binocular counts, standing with the sun behind, so that the observer sees all of one side of a tree's crown. All cones of the current crop are counted, even though they may appear to be on the far side of the tree. Then the number counted is doubled. Some will be

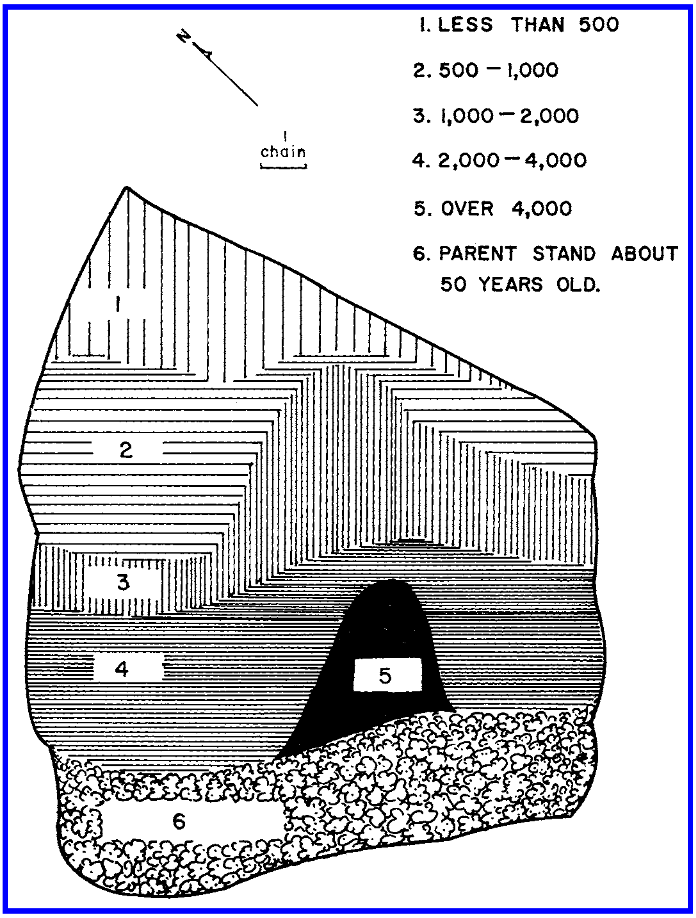

Figure 8.8 Shortleaf pine–loblolly pine winged seeds in the Piedmont fill canopy openings as great as 500 feet wide with 50 seedlings per acre. (after W. E. McQuilkin in *Ecology* 1940, 21, 137)

missed; a few actually on the far side of the tally will satisfy the missed ones in the calculation. While counts among observers vary by over 100%, they usually tally lower than the actual number. The most precise counting is done in late summer when current cones are brighter in color, the scales closed, and the cones nesting among the needles near branch terminals. The actual number is then computed from the regression equation:

Y = 2.244X, where Y = actual number of cones and X = the count when 7x50 binoculars are held by hand. The number of conelets also can be determined, using a constant of 2.719 x number of cones counted.[16]

Another technique for determining seedfall potential is to count cones that ripen over a three-year period on sample branches from felled trees. During late May in the Virginia Coastal Plain, for example, strobili presently observed will ripen the fall after next, yearlings will ripen next year, fully mature cones on trees will ripen later in the present year, and cones that matured and opened the previous year remain on the trees. The recorded trend in sizes of cone crops indicates changes to be expected in the immediate future for a tree, a stand, or for the region.

New conelets arise at the ends of new shoots, one-year-old immature cones occurring with the last year's needles. Those that will open late in the current year hang below the needle growth, while mature and open cones are lower yet on the branches or lie on the ground.

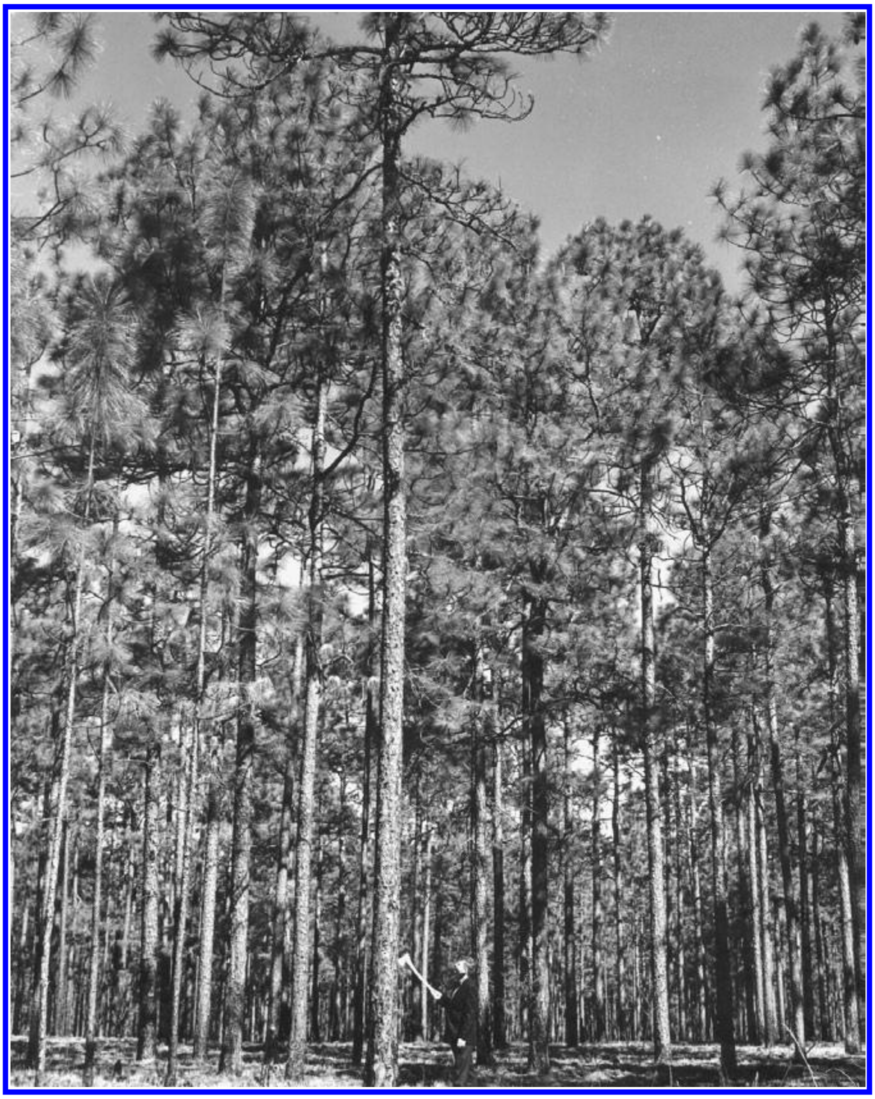

Figure 8.9 This superior longleaf pine has been chosen as a seed tree for a seed-tree regeneration cut. Note its straightness, high form class (minimum taper), self-pruning character, small branches (hence small knots), branches at right angles (also smaller knots). (authors' collection)

Gulf coast forests, in contrast to the Atlantic seaboard, have less frequent seed crops. Inland Texas, for instance, has gone a decade without adequate sources of loblolly pine seeds. Central Alabama trees once went 15 years without a good crop. For that area, prediction of future cone crops based on tree diameter and age is about as good as any method: larger, older trees with the densest crowns bear the most cones.[17]

Seed dissemination depends on wind direction, wind speed, air temperature, and humidity. Greater freedom of air movement in openings, such as cleared fields, encourages flight of winged seeds. Wind eddies just to the leeward side of a stand account for heavy caches near walls of trees on the windward side of a cleared strip. Most seeds, however, fall in and adjacent to stands, only about 40% escaping from a wooded tract to a distance of 100 feet. Good distribution may on occasion occur up to 400 feet from a seed source for most winged-seed species. A rule of thumb for dispersal is that seeds fly 2 to 3 times the heights of trees and up to 1000 feet in strong winds.

Abundant seedfall generally follows or coincides with sharp drops in temperature preceding rain. These thermal lows, resulting from cold fronts, are accompanied by low humidity and high winds from the north and west which may be more important than rain and temperature in seed dispersal.[18]

Seedfall in the Piedmont for loblolly pine begins in late October, peaks in November, and is virtually complete by January. As many as 2 million seeds per acre may fall. Warm, dry, windy periods favor seed dispersal. Cones of many species close slightly on wetting, temporarily restricting seedfall.

Seedfall occurs perhaps 10 days earlier in the southern and eastern coastal zones of the range of loblolly pine than in the cooler more northern climate of the Piedmont. As a general rule, seeds begin to drop by mid-October, peak in early November, and four-fifths will be released by early January. Some await June for dissemination.

A test for cone ripeness for southern pines is their ability to float in oil of a specific weight. Similarly, full and empty seeds are separated by flotation: full seeds of longleaf pine sink when poured into vats of n-pentane.

By way of summary and as rules of thumb for loblolly pine in the northern rolling Coastal Plain: ovulate buds form in September, influenced by nutrition and environment; flowers (strobili) of both sexes develop the following March, though frost may have an inhibiting effect; and pollination takes place the next month. Here prolonged rain may be a major obstacle to successful pollen distribution. Growth of conelets takes place between May and October, a period in which insects take a heavy toll. The organs lie dormant until the following March when fertilization of the eggs by the microspores in the pollen grains disseminated a year earlier occurs. On spore germination the male element passes through the pollen tube en route to the ovule. In spite of the abundance of sperm grains, some ovules will not be reached.

Coppice—While some pines, like pitch, shortleaf and Virginia, produce sprouts from seedling bases, especially when injured, vegetatively reproduced “seedlings” seldom arise from the root collars of other pines. For species which sprout, dormant buds located in the axils of a lower primary needle and the stem elongate to form shoots. The meristematic tissue at this juncture may produce needle fascicles of secondary foliage as well as a dormant bud from which a shoot arises. In the latter case, dwarf shoots first appear, growing slowly, but not forming branches. Dormant buds near the tree base, protected by thick bark, are not likely to be triggered by heat or injury to elongate into branches. Sprouting species do not have a crook just below the ground level. Sprouts arise from this zone, tissues covered with a smooth brownish layer of cork cells, similar to the covering of roots. Phloem layers of these buried stems contain a higher concentration of starch than does the exposed stem.

Loblolly pines, which do not exhibit a crook, may sprout after being clipped by rabbits, the animals leaving a substantial portion of the stem from which shoots may arise. This occurs most often where soil has washed in around seedlings, the root collar lies buried well below ground level, and the epicotyl (the part of the seedling above the cotyledon node) exposed. Severing the epicotyl does not result in sprout formation; nor does sprouting occur when trees are beyond the young seedling stage. Mortality of sprouts increases with seedling age, seldom surviving if seedlings are more than two years old. Southern pines do not produce root sprouts.[19]

The origin of shortleaf pine sprouts has been described earlier (Chapter 2). Here we note the use of sprouting to regenerate these conifer forests, especially in the Barrens of South Jersey. Second generation sprouts are common, coppice colonies breaking up after a few years, and leaving a single stem. Often these stems give rise to forked trees, although this may be a genetically inherited characteristic.

Figure 8.10 These grass-stage seedlings arose simultaneously from seeds from a wall of pole-size trees surrounding a clearcut. Here the seedlings are readily distinguished from grass because of a recent prescribed burn to control brown spot needle blight, a soil-borne disease caused by *Scirrhia acicola*, that attacks succulent needles. The foliage promptly resprouts from the terminal buds which have been protected from the fire by the tufts of needles. (authors' collection)

Virginia pine also sprouts prolifically, but only shoots from seedlings and saplings develop into trees. The resulting trees are often short-lived and of low quality. Foresters reluctantly recommend the method for regenerating stands of this species.

Longleaf Pine: The Tree[20]

Understanding the ecology of longleaf pine is necessary to the latter discussion of its natural regeneration. Among the finest stands of southern pines found by early European explorers were those of longleaf, the hard pine that, for over a century and until the mid-twentieth century, enjoyed a world-wide reputation. Strong, even grained and durable, the straight, clear stems could be hewn into square cants that were oxen-logged to water and floated down rivers to every Gulf and southern Atlantic port for shipment to destinations throughout Europe. Exporting all-heart timbers 12"x12"x80' to ports as far away as Greece for shipmasts, many Gulf Coast producers could boldly proclaim on their letterheads: "Longleaf pine structural timbers for the world market." Although little of this strong, hard, stiff wood is now going abroad, today's silvicultural knowledge makes possible regenerating forests that, in a decade or two, could recapture the status of longleaf pine. The effort is underway.

The species' prevalence on the high and dry sandy hills gave rise to "hill pine" as one of its thirty or so common names. It's on these hills—perhaps just a foot or so above the surrounding flats—that quality longleaf pine can be grown. No other tree in the southern forest has the majestic form, the tall gently tapering stem, the long graceful needles at the ends of twigs dancing lightly to the cadence of the slightest breeze, and the open park-like canopy that is home to quail and turkey.

As sawmills replaced the broadax and the manual pit saw, longleaf pine became a lumberman's choice wood. Laying railroad tracks as it moved, the industry marched across the South to harvest every stand of longleaf pine. Although other pines were utilized when longleaf became scarce, the

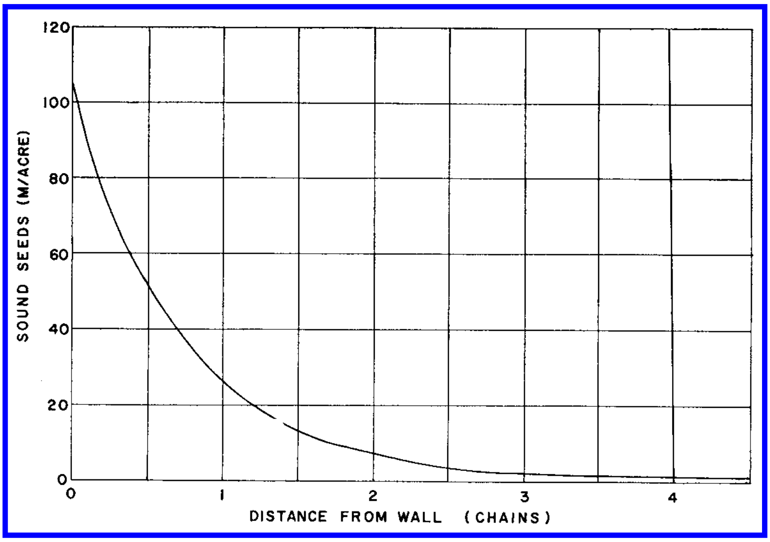

Figure 8.11 Longleaf pine seed dispersal from the walls of trees adjacent to clearcut openings. The short distance suggests limiting the size of clearcuts when depending on natural regeneration. (from Boyer, 1958)

virgin forests of this species continued to produce lumber and timbers that set standards of excellence without equal among the world's tree species. But by 1940, the original longleaf pine forests existed only in memory. Why had natural regeneration not occurred? Why had other pines filled its niche in the biome?

Among the unique characteristics of this tree is a temporary nanism, or dwarfing, in a grass-like stage. So like grass are these ground-hugging tufts of needles surrounding the bud at the soil surface that the inexperienced mistake the seedlings for a stiff-bladed bunch grass. Environment as well as genetics influences the amount of time seedlings remain "in the grass." It may be three years or less, where soil moisture is adequate and plant competition negligible, to 25 years on dry, xeric sites covered with dense overtopping crowns of scrub oaks and the competing ground cover of wire grass.

Taproots reach moist soil horizons early. The roots may be a foot deep, and lateral roots may number fifty, within the first year of life—both in the presence and absence of vegetative competition. Controlling competition by hoeing out excess seedlings and killing weedy brush encourages height growth. Seedlings usually begin height growth when the dwarfed stem has grown to an inch in diameter at the root-collar. When that ground-line size is attained, height growth often exceeds 3 or 4 feet a year.

In a region where forest floors are frequently swept by fire, longleaf pine clings to the ground in this grass stage when other vegetation, including seedlings of other species, is vulnerable to fire damage. Well-rooted and with ample food reserves, longleaf pine seedlings eventually spurt upward, not as a slender, thin-barked shoot, but as a thick stem surrounded by bark and a dense, continuous array of long needles. Although not completely fireproof, seedlings survive fires during the first few years of height growth. Past the grass-stage, seedlings and small saplings succumb to the heat of a fire. After the stems are 10 to 15 feet tall, they become the nearest thing in nature to an "asbestos tree," surviving all but the hottest fires.

As young longleaf pine trees rarely survive beneath the shade of their parents, seedling and sapling stands are often pocked with openings where the competition for moisture and perhaps nutrients by seed trees excluded their offspring. Advantage lies with the tallest trees: most of those that do not keep pace die from suppression. An efficient producer of cellulose in pure stands, this pine's intolerance of competition accounts for much of its excellent form: leaving the grass-stage with a rush, the strongly phototropic main shoots grow straight toward the zenith in their vital struggle to keep a place in the sun.

A disease, too, keeps longleaf pine in the grass stage. Brownspot needle blight, caused by a fungus present in most soils, infects needles near the ground. The straw-yellow spots of diseased tissue, turning brown and running together, eventually kill the infected needle, subsequently defoliating seedlings. Three successive annual defoliations kill seedlings, but infection of half of the needles severely retards growth. Although effective fungicides are available, cost prohibits their use. So foresters prescribe fire as the management tool of choice.[21]

With protection from fire, the disease spreads, seedlings stagnate, and many die. Prescribed fires, however, have salutary effects, destroying spores along with infected foliage, and freeing the new needle growth for a couple of years from major infection.

A fire prescription may call for ignition at 3 o'clock on a winter afternoon when the temperature is about 50˚F, the relative humidity above 50%, no more than two days have lapsed since a rain of 1 inch or more, the wind steady and out of the north at 6 to 10 miles per hour, and the fuel moisture about 10%. Cool fires, running rapidly with the wind, are needed. Slowly moving fires, those pushed against the wind, remain so stationary that they build up temperatures lethal to bud and cambium as well as to needles. So precise is a properly prescribed fire that a Bull Durham cigarette paper wrapped around the bud of a grass-stage seedling is not charred, yet all the needles are consumed to within a couple of inches of the bud. The ring of needle stubs around the bud provides protective insulation; the needles are expendable. From the bud, new needles promptly sprout to form lush-appearing vigorous foliage to manufacture carbohydrates by photosynthesis. Those sugars provide the vigor that leads to height growth.

There is a paradox: prescribed burning lays bare the soil, allowing reinoculation with spores carried from the ground by rain splash. Sometimes two fires to reduce the disease may be necessary to assure that a healthy, well-stocked longleaf pine forest emerges from the grass.

Animals also retard establishment of quality stands. Town ants clip needles, dragging them to their underground colonies, there to form "town" nests where the needles are chewed into bits and inoculated with a fungus that lives on the needles. The fungus "garden," a pure culture, provides food for the ant. Subsoil, excavated in forming these galleries, is deposited around the entrance holes in crater-like mounds. Rain flattens these "hills," the first conspicuous evidence of a colony locale. Gassing with methyl bromide piped through a long tube inserted in a passageway to the throne room of the colony eliminates the town.

Piney-woods' rooters, progeny of feral pigs, may consume seedling roots in their quest for concentrations of starch. The food reserves of grass-stage seedlings, stored mainly as starch in the thickened taproot, can provide the diet for these razorback hogs when acorns are scarce. Lean and long-snouted, they visit these conifer stands only after oak mast is gone from the lowlands.[22]

Other animals also affect regeneration success. Cattle must be properly managed lest trampling while grazing destroys small seedlings. A family of pocket gophers has "thrown out" over 200 seedlings on an acre in a single year. Rabbits bite off terminal shoots, cotton rats clip stems at the ground line, and pine mice work from below the soil surface in holes in the ground. Non-toxic rodent repellents for the control of these small mammals have the approval of the Environmental Protection Agency.

Renewing a Longleaf Pine Forest— About once every 10 years longleaf pines produce an abundant seed crop. The weather must be just right to adjust the carbon:nitrogen ratio of primordial tissues to stimulate formation of flower buds. Then male flowers disseminate pollen as female flowers receive it. Fertilization of eggs in the conelets occurs a year later. If pollen dispersal and reception are not synchronized, empty seeds, or cones lacking seeds, result.

Synchronization is jeopardized because different trees within the stand are involved. Male flowers—properly called strobili for the conifers—are usually found on the lower branches and females on the upper. Thus, wind currents transport the fine, yellow powder-like pollen to neigh-

Figure 8.12 An excellent naturally regenerated stand of pole-size longleaf pines in the lower Coastal Plain. Prescribed burning has controlled brush and seedling needle blight. Note the abundance of cones on the ground, but a total lack of seedlings due to lack of full sunlight and competition from parent trees for soil moisture and nutrients. The candelabra-stage seedlings are the same age as the overstory. (authors' collection)

boring trees, rather than to branches and strobili immediately above the same tree. Self-pollination, like poor synchronization, leads to hollow seeds.

To increase the number of seeds produced in those infrequent crop years, foresters employ a modified shelterwood harvest system. Releasing selected seed trees—those that are straight, healthy, and with a history of prolific cone production—further enhances vigor and absorption of soil nitrogen and water and allows more sunlight to penetrate the crowns. This first harvest in the shelterwood series adjusts the ratio of carbon and nitrogen in the tree's living tissues, thus improving the chances for flowering. After the seed crop is assured, all but the five or six seed trees per acre are removed in the second harvest of the series. These are retained after seed germination for insurance in the event of stand failure. Leaving them longer than for stand establishment and insurance causes stagnation and loss of the new seedlings within a "magic circle." That circle has a radius of at least 55 feet. Thus, seedlings and seed trees of longleaf pine are mutually exclusive.[23] Loggers harvest those seed trees not claimed by lightning, wind, or insects after the new forest is assured, milacre stocking by then amounting to perhaps 75%. Modified seed-tree harvests also serve well under some conditions, loggers at first taking all but the seed trees and, in the process, scarifying the soil to receive the seeds that subsequently fall from those selected stems.

Mourning doves and rodents eat seeds. So also do hordes of migratory birds—among them robins, flickers, blackbirds, and grackles. (A vast clearcut longleaf pine tract remained idle for decades, for no matter how seeds were disguised in attempts to reseed the land by man, the birds always found them. Not until seeds were treated with bird and rodent repellents were these lands regenerated.)

Logging scarifies the soil, tearing up the “rough” (the ground cover of wire grass and broom sedge in longleaf pine forests). Such scarification is essential because seeds must be in contact with mineral soil in order to germinate. Disking, scraping, or prescribed burning also removes grass and herbaceous plants to expose mineral soil.

Artificial regeneration of this species has increased over the last few years, with demand for seedlings often greater than supplies. While basic questions concerning the development of quality seedlings have been answered, questions regarding topics such as the proper planting date are just beginning to be addressed.

Virginia Pine

Regeneration of Virginia pine usually succeeds when carried out by clearcutting in strips or blocks and by seed-tree harvests. While most seeds fall close to parent trees, whether seed trees or walls of timber, adequate seed dispersal occurs as far as one-fourth mile from seed sources. Leaving more than 10 seed trees per acre does not improve the catch. However, windthrow of mature stems in sparse stands of this shallow-rooted species discourages the use of the seed-tree method. This loss diminishes seed production. So, too, do prevailing winds coming from clearcut openings to be regenerated: seeds then fall on the lee sides of the trees and within the uncut stands.

Releasing seed trees from competing neighbors in crowded stands of small trees encourages seed production. Past production of cones provides a likely guide to future cone potential: trees black with old persistent cones long after seeds have been dispersed should produce favorable crops in the future. Seed viability percentages, ranging from 20 to 80%, improve with seed crop size.

Virginia pine has a natural proclivity to sprout (although at least one account reports otherwise), resulting in vast stands regenerated by the coppice method. Only shoots from seedlings and saplings, however, develop into trees. Stumps of larger trees deteriorate before sprouts establish adequate root systems. Coppice often results in short-lived, forked trees of low value, called “school-marms.”

Not always does Virginia pine occur in pure stands. Natural regeneration of this species occurs simultaneously with shortleaf pine, the former usually exhibiting better growth. Where Virginia pine precedes white oak in ecological succession, the pine volume may be twice that of the oak. Harvest plans should take such long-range matters into account.[24]

Growth potential of this species increases as latitude decreases, a fact foresters need to consider in utilizing natural regeneration. Thus, other components of the site being similar, stands on land with a SI 65 in Maryland and Virginia would measure about SI 77 in South Carolina. Greatest variation of site productivity occurs in the Piedmont province: there SI ranges from 50 to 83, and averages 65.[25]

Quality of light affects seed germination. Red irradiation favors the breaking of dormancy, this light sensitivity likely playing a role in the success or failure of regeneration.

Sand Pine

While clearcutting is the silvicultural method of choice for sand pine, foresters also consider shelterwood harvests, removing one half to two thirds of the stand in the first cutting and the remainder ten years later. The shelterwood system in this case admits sufficient sunlight to heat and open cones held on logging slash while residual stems provide suitable shade to protect succulent, young seedlings from the searing heat of the light reflected from the brightly colored sands of the species’ habitat. Seedlings will also arise from seeds released from cones that open when residual stems are later harvested. The seedlings produced following the first harvest afford some protection for those germinating from seed following the second cutting. A two-age stand results. (The serotinous nature of the Ocala race of sand pine may preclude the use of seed-tree and shelterwood regeneration methods.)

Seed-tree harvests of these small short-lived serotinous stems, leaving as many as thirty trees per acre (contrary to what has been noted for other species), enable satisfactory reproduction without first prescribing fire. Log-skidding scarifies the site and cones begin to open within three days of being exposed to full sunlight, provided logging slash containing cones lies on white sandy ground. Seed release and germination may be delayed several years following a harvest before encountering heat sufficient for opening the cones. However, most seeds in cones remain viable that long.

Timing is important in establishing reproduction. Although seed germination occurs throughout the year, drought and heat kill seedlings still in the cotyledon needle stage in late winter and early spring. Heat becomes critical in summer, but rainfall in that season in peninsular Florida usually maintains adequate soil moisture to sustain the race of sand pine growing there.

Slowly moving backfires in autumn seem to be the most effective way in the Big Scrub, in the center of the Florida peninsula, to prepare the site to receive seed in preparation for regeneration. The explosive nature of the resinous trees and the accompanying vegetation restricts the use of headfires. Fires that crown (and head fires running with the wind often do) consume cones, causing delays of many years in securing a new stand of trees. During the interim, brush and scrub oaks encroach.

Fires sufficiently hot to open cones sometimes kill parent trees. While the merchantable timber may not be salvageable, great quantities of seeds will fall from these dead trees within a few weeks of a fire, germinating—usually in the winter—within a couple of months. (Frosts damage seedlings that arise from seeds in winter.) If salvage is feasible, the logging effort injures many seedlings. Prescribed burning might best be utilized only where stands are poorly stocked and otherwise not worth retaining for a harvest following establishment of a new stand of seedlings.

Seed release, by fire or sunlight, probably provides enough seeds for rodents (especially white-footed deer mice), large and red harvester ants (even though the insects produce no more than two hills per acre), and birds (like the chewinks and mourning doves) as well as for stand regeneration. Damping-off and rootrot fungi and nematodes injure freshly germinated stock. Heat intolerance also injures seedlings, noted when roots have been washed with hot water for nematode control and then planted; yet surface soil temperatures of 160˚F frequently occur in sand pine sites.[26]

A scarifier-seeding machine used following harvest of stands of the Ocala race makes a pit-and-mound microsite, the seeds dropped on the mound. The method improves spacing, saves seed, eliminates precommercial thinning, and minimizes site disturbance.[27]

Pitch Pine

All of the classical even-aged regeneration methods have been recommended for the serotinous pitch pine. Clearcutting finds adherents if advance reproduction is present; seed-tree harvests, retaining 5 to 10 trees per acre, providing prevailing wind direction and wind speed are appropriate; and shelterwood, where site desiccation from drying winds and exposure to the sun's rays would occur with more drastic openings. Natural regeneration often requires prescribed fire in order to favor the pines over the encroaching shade-tolerant broadleaf species. Such burning usually precedes the first harvest of a three-cut shelterwood, preparing the seedbed and yet providing some protection from the wind and sunlight. Where overstory hardwoods are so old that sprouting is not much of a problem, fire may aid in altering a broadleaf forest of cull stems to a productive pine stand. By manipulating harvests and fire to take advantage of good seed crops, conversion of an oak - pine woodland to a pure pine forest might be accomplished.

Sometimes insistence on maintaining, or conversion to, pitch pine on these inherently climax hardwood sites is not desirable. Let nature have her way: an abundance of oaks, hickories, and other deciduous species will capture the site. From these woodlands, lumbermen may harvest acceptable broadleaf trees 50 years hence.

Pond Pine

Pond pine, a serotinous species subjected to periodic wildfires, readily reproduces new stands with clearcutting and seed-tree systems. Even where managed, poorly drained sites, typical of this species, produce trees only about 30 feet tall in their first 20 years. At 50 years, heights are about 50 feet, boles having no more than two small-diameter merchantable logs. From that time on, growth rate declines, stem mortality increases, and the stands deteriorate.[28]

Trees produce seeds when young, cones borne on stems only 10 years old. For trees up to 30 years old, cone production relates directly to age. By that time, a single tree periodically produces 200 cones with 75 seeds in a cone, half of which are viable.[29]

Some cones open without the assistance of heat, especially following years of insect depredations or during periods of unusual warmth, either in summer or winter. While fires encourage cone opening to release seeds, they also stimulate sprouting of this conifer.

Height growth for pond pines appears unaffected by soil moisture or stand density. For most sites in which this species predominates, soil moisture is virtually always adequate and, if not, the number of stems per acre diminishes in order that the surviving trees will have sufficient moisture to sustain their growth.

OTHER CONIFERS

The phenology of eastern hemlock, red spruce, and Fraser fir contrasts with that of *Pinus:* cones of the *Tsuga, Picea,* and *Abies* genera ripen in the fall of the year of spring flower production and pollination

Eastern White Pine

Eastern white pine, long the most valuable timber of northeastern America, was found as large, high-quality trees in many of the virgin forests of New England, the Lake States, and into the Southern Appalachian mountains. It is not, however, a climax species, being less tolerant than most of its associates and unable to regenerate under their shade. This pioneer tree seeds in on burned over, cut-over, or abandoned farm lands. Long-lived individual stems have stood in undisturbed situations until ecological succession has surrounded them with climax species such as eastern hemlock.

Because of its intermediate tolerance, white pine can be regenerated by silvicultural systems ranging from individual tree selection to clearcutting. Clearcutting that simulates nature's hurricanes and lightning-caused fires remove enough tree cover and sufficiently scarify the soil surface for pine seeds to germinate and for seedlings to thrive.

Shelterwood cuttings are designed to achieve regeneration gradually, removing the old forests in several harvests over periods of 10 to 30 years. The first cutting stimulates seed production on the trees left standing. A few years later, a second harvest further scarifies the soil to enable seed germination as it removes 60% or more of the remaining trees. Part of the parent stand is left for shade to protect from sunscald the seedlings arising from the seed produced after the first harvest and germinating on the scarified soil. A final cut, after regeneration is established and seedlings are no longer subject to sunscald, removes the rest of the old stand.

Regeneration of white pine by the selection system, favored by some environmentalists because it is less disturbing to soil, watersheds, and aesthetic values, is feasible primarily where associated species have sparse foliage and are generally less tolerant than these pines. Costly manual or chemical release from this broadleaf competition is often essential, making selection cutting uneconomical. Single-tree selection also tends toward site domination by species with more tolerance, but less economic utility, than white pine.

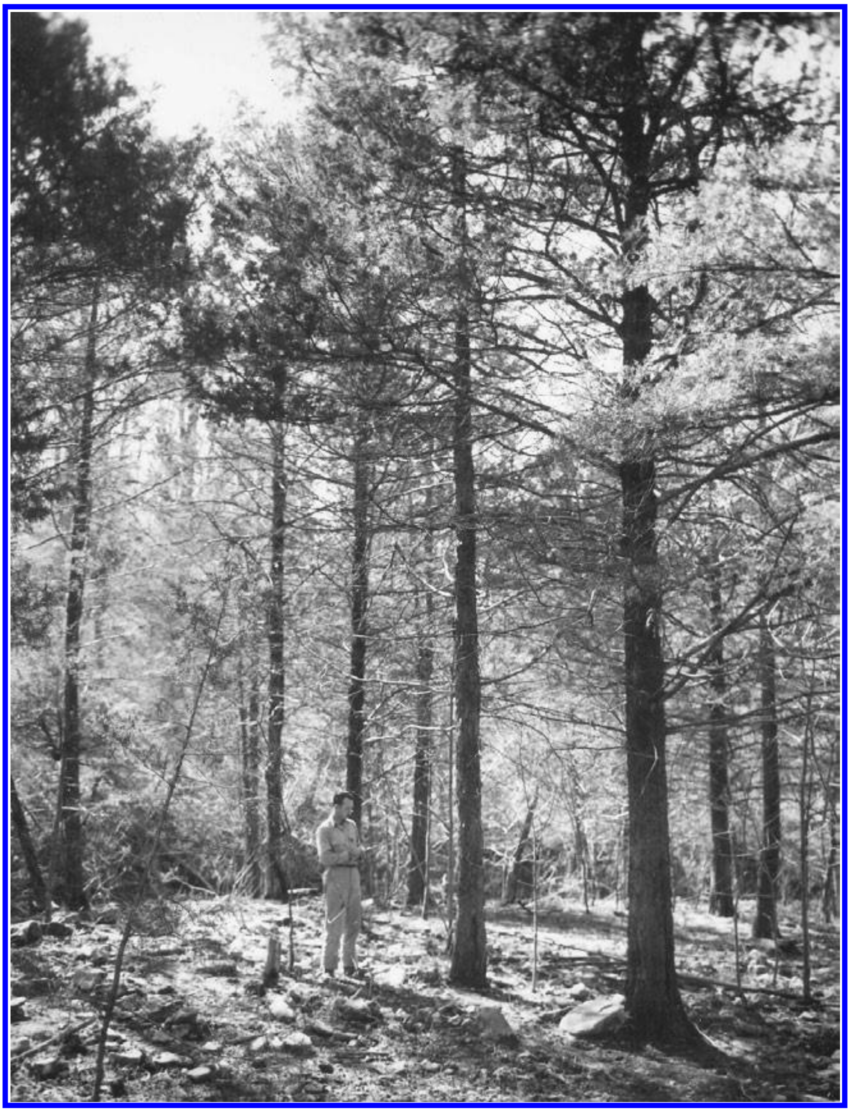

Figure 8.13 Southern mountain rocky sites must depend on natural regeneration. Improving such stands is difficult. Here low-grade limby white pine, a species growing in even-aged stands is relatively pure. (authors' collection)

Clearcutting in strips or blocks combines the ecological characteristics of the species with economic considerations for least-cost continuation of the type. Other advantages with clearcutting include its adaptability to heavy logging machinery, a timber-edge beneficial to wildlife, and ease for replanting by machine if natural regeneration fails. Size of harvest areas is limited by the distance to which adequate numbers of seeds can be supplied from the adjacent stand. This prevents harvest openings so large as to be unacceptable for watershed protection and aesthetic appreciation.

Eastern Hemlock

For successful regeneration of eastern hemlock stands, foresters watch for the occurrence of seed crops, likely to occur every two or three years. Cones of hemlock release their winged seeds gradually, the scales opening and closing with changes in humidity. Dissemination is in all directions, as the wind within the species' range frequently shifts direction. Harvests by clearcutting follow seedfall. With other even-aged systems or uneven-aged selection regeneration, harvests take place either shortly before or after seedfall. If prior to seedfall, a sufficient number of cones, and therefore seeds, remain available on the residual trees to supply the requirements. Soil scarification is not essential, as seeds of the shade-tolerant species germinate and put down roots through litter, and seedlings survive under canopies of parent trees. One tally noted eight million seeds disseminating over a two-year period and germinating from March to May. However, seeds do more readily germinate in scarified soil: breaking through the litter layer usually satisfies the requirement. Grazing by livestock serves the purpose, the animals also grazing or browsing competing vegetation. Two- and three-cut shelterwood harvests promote germination and early seedling development.[30]

Although hemlock stands survive when regenerated in full sunlight, the trees prefer partial shade. Sunscald can be serious, especially to advance reproduction, when stands are suddenly and drastically opened. Thus on south- and west-facing slopes, canopy shade should not be reduced below 50%. The thin bark also makes even the mildest prescribed fire an unsound silvicultural practice.

Because this species does well in uneven-aged stands regenerated by selection harvests, the method should be encouraged, perhaps to aesthetically compensate the public for the ecological requirements of other species that necessitate even-aged management and large openings for seedling establishment.

Symbiotic mycorrhizae fungi, the mycelia sometimes completely encapsulating rootlets, are important for survival of hemlock seedlings. This is especially so on acidic soils. Damping-off fungi, however, detrimentally affect hemlock seedling survival and growth.

After establishment, the conifer grows more slowly than its competing broadleaf species, making cleanings of the latter necessary as often as several times during a rotation. Trees respond well to release, probably partly because of the availability of additional soil moisture for the residual stems.

Wind causes radial stress checks (cracks across the rings of annual growth) and wind-shake (lengthwise separation of the wood between the rings of annual growth), both degrading lumber, the more so where stands have been opened. Windfall, however, is minimal, even for stands that have been heavily thinned: extensive tap and lateral roots provide windfirmness.

Spruce and Fir

Because of the shade-tolerance of the high-elevation red spruce and Fraser fir, selection regeneration is appropriate. The first harvest (cutting cycle) must be delayed until the trees are at least forty years old, as the spruce trees will not bear adequate numbers of seeds until then. Mice and voles reject fir seeds but relish those of spruce, possibly accounting for the relative composition of the two species in these stands. The shallow-rooted nature of the spruce, in contrast to the fir, may also contribute to the prevalence of fir over spruce: strong winds rage through these summit stands, throwing the spruce. And wind-related desiccation kills the lateral feeding roots of the spruce, just under the surface of the soil, as the uppermost horizon of peat and moss dries out. This occurs mostly where harvests have allowed the sun's direct rays to reach the ground.

The long periods, perhaps 20 years, between selection harvests suggests the shelterwood method as an alternative system, especially if no advance reproduction is present. With this technique, eventually resulting in an even-aged forest, half of the stand volume would be removed with the initial harvest, the balance removed after the new stand is firmly established. Clearcutting has been used in the Southern Appalachians when an abundance of seedlings are already established and where the costs of road construction into inaccessible areas prohibits the use of systems that call for harvests of lesser volumes.

Seeds released from cones at a height of 50 feet sail with a 5-mile-per-hour wind as much as a quarter of a mile. However, beyond 600 feet the number may be inadequate to restock a stand, necessitating supplementary planting in order to obtain full stocking.[31] Protecting young seedlings from the drying effects of wind with roof shakes or similar barriers may be desirable. Difficulties in regenerating spruce and fir trees in the South's high ridges suggests replacement with pitch pine on the poorest sites and on lands being reforested at lower elevations. Moss covering the forest floor indicates sufficient soil moisture for seed germination; yet moss dries out if a stand is opened by harvest or fire. Red spruce seeds germinate on most any seedbed except sod. Even rotten wood and duff suffice.

Atlantic White-cedar

Natural regeneration of Atlantic white-cedar is readily obtained with clearcutting in blocks or strips, each opening covering five to ten acres. Two reasons for the singular use of this system: partial cutting results in windthrow of residual stems due to the shallow-rooted nature of the species growing in the fibrous soils of its preferred habitat; and hardwood encroachment makes weed-tree control necessary where even minimal light is admitted through openings made in the crowns. Control of the inevitable dense jungles of brush that follow harvests is facilitated in large openings.

As many as 1700 stems per acre occur in stands 60 years old. Volumes at maturity of 30,000 board feet per acre have been reported. This volume is in many small trees. Maturity occurs on most sites at 80 years, when long, straight, clear boles with little taper provide high-quality lumber or poles. Height growth remains steady until mid-age, then gradually declines until it ceases. Diameter growth continues longer.

White-cedar cone production is increased by releasing seed trees. In one instance almost 3 times as many seeds (7,000 versus 20,000 per tree) and cones (20 versus 55) were produced after release. In unthinned stands, where cone production may be light but constant, new openings increase flower fertilization the first growing season after a partial harvest. Substantial increases in cone numbers occur the third season after cutting—from 5 to 50 cones per tree. For maximum seedling establishment, release should precede final harvest by 2 to 3 years, assuming ground cover conditions are satisfactory for germination after seeds fall.[32]

The seed-producing capacity of Atlantic white-cedar is noteworthy. (1) Seedlings germinated at the rate of 2.5 million per acre from seed stored in the top inch of peat under one mature stand; another 1-1/2 million seeds were found in the 1- to 2-inch horizon. (2) Over 8 million seeds per acre per year were disseminated for two consecutive years from a mature stand, giving rise to 2 million cotyledon-stage seedlings on an acre. (3) Stems above 5 inches dbh produce more than 4000 cones per tree and those between 3 and 4 inches dbh 1000 to 3000. (4) As many as 64 cones have been produced by 3-year-old seedlings only 1 foot tall. (5) Ordinarily seeds are produced every year. (6) Viability varies greatly: at least from 8 to 90%. (7) Apparently birds and rodents consume few seeds of this species.[33]

Seed release occurs in the fall and winter (mostly by mid-December) from cones which open when dry; dissemination ceases when cones wetted by rain of a half an inch or more close again. Wind, of course, aids dissemination: at 5 miles per hour, seeds fly from a 50-foot height 600 feet into an opening. Seeds land to the lee of a wall of trees and, in dense woods, likely not 50 feet from the tree which produced them.[34]

Favorable moisture relations sometimes requires drainage for successful regeneration, ditches excavated for the purpose and provided with controls enable maintenance of proper water levels over a vast system. Uncontrolled drainage in peaty soils may raise or lower water levels critically, mortality of seedlings attributed both to flooding and to air pockets that develop around roots when water subsides in drained locales. On hummocks of drained peat, trees die during droughts of short duration.

Whether prescribed fires may be helpful silviculturally is not well established. To control broadleaf weed trees requires fires sufficiently hot to burn into the peaty surface soil to kill dormant buds from which the broadleaf sprouts arise. Such heat also consumes white-cedar seeds stored in the peat. If protected from fire beyond the rotation age, a bog ecological climax follows Atlantic white-cedar. This wet-site vegetation consists of broadleaf plants: swamp bay, sweet bay, myrtle, swamp ironwood, red maple, and blackgum.[35] This species readily regenerates by layering; branches in contact with the ground take root.

Baldcypress

Baldcypress and its pondcypress variety, ecological pioneers, become established when water is low in one or more extremely dry seasons following periods of sufficient moisture for soaking the soil for one to three months. A saturated, but not inundated, seedbed is essential for seed germination. Natural regeneration occurs after drainage of open cypress stands. Both bald- and pondcypress occur in pure, even-aged stands, or they are associated with a few water-loving broadleaf species. Few mature forests remain to be naturally regenerated, work has begun on artificially regenerating this species: Little is known about how best to do it.

Usual sites for regeneration are the bases and knees of old trees on which typical bay shrubs and trees encroach to form "islands." These islands of shrubby vegetation in the water expand, unite, and—aided by vast root systems of bay shrubs along a shoreline—form a solid organic surface covering ponded areas.

While baldcypress may sprout, the shoots usually make unsatisfactory trees. The sapwood of stump sprouts quickly rots: basal sprouts are more lasting. Shoots seldom occur on trees more than ninety years old, nor on stumps injured in logging. Healthy sprouts for a while, however, (as for many species) grow faster than seedlings arising from seeds.[36]

Intolerant of overhead shade for long periods, some release of reproduction may be essential in order to assure establishment of seedlings and saplings. Conversion of poorly stocked baldcypress stands to hardwood forests where regeneration is not readily established may be a viable alternative. On heavy cutting, broadleaf species capture baldcypress sites.

Pests affecting regeneration success include nutria that uproot seedlings and eat bark, roots, and stems; swamp rabbits that clip stems; a leaf-chewing beetle that gouges minute cavities in both leaf surfaces; and *Fomes geotropus*, a fungus that leaves an antiseptic brown powder in pockets of rot (though this malady usually occurs on older trees). Lumbermen market pecky cypress, the result of the pathogen's activity, as a desirable trait.

BROADLEAF SPECIES

Hardwoods compose about one third of the U.S.' wood harvest. About 50 important species provide this fiber for lumber, plywood, and paper. Despite major acreage losses to agricultural clearings, water control impoundments, and urban sprawl, the nation looks to the South's mixed deciduous forests for the bulk of its quality hardwoods.

Broadleaf trees of the region range widely in ecological characteristics and tend to grow in associations of many species, making complex the regeneration for many cover types. One of the simpler types (maple–beech–birch) is discussed as a classic example of tolerant tree species. Highly intolerant hardwoods—black willow, eastern cottonwood, and yellow-poplar—are at the other end of the scale. Like the intolerant softwoods, these pioneer species require exposed soil and full sunlight for regeneration. They grow in pure, even-aged stands. Cottonwood and black willow, especially fast-growing species, are commercially important where seeded in on new sand deposits along rivers and other alluvial sites. Their value has encouraged intensive management, even though several cultivations to control weeds may be required.[37]

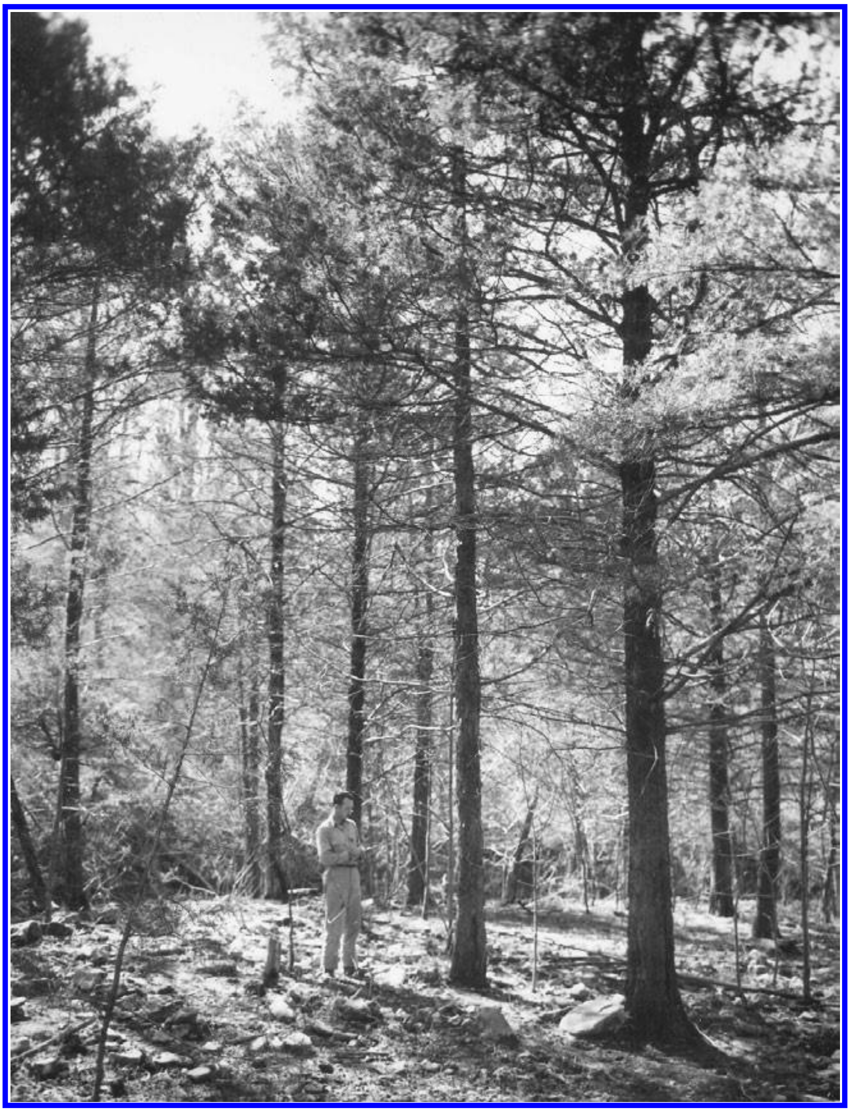

Figure 8.13 Southern mountain rocky sites must depend on natural regeneration. Improving such stands is difficult. Here low-grade limby white pine, a species growing in even-aged stands is relatively pure. (authors' collection)

The every-decade federal forest survey tallies thousands of acres of upland and bottomland broadleaf trees across the South in overcut, high-graded, and silviculturally mismanaged tracts. Under present stand conditions, costs, and expected growth responses, foresters treat these by (1) clearcutting and planting, (2) clearcutting and allowing to coppice, or (3) partially cutting to remove the most inferior stems in order to encourage species and form of potential merchantability. Natural regeneration provides for the latter two methods.

Stands of shade-tolerant species tend to include trees of all sizes, if not all ages, and lend themselves to the selection system. This method does not differ greatly from customary commercial logging of broadleaf forests, which has long selectively removed trees on the basis of value, a procedure called "high-grading." The tolerance of many species permits them to occupy small openings, even those created by removal of single trees. The selection system, however, is handicapped by the appetite of deer, which destroy the palatable seedlings of preferred tree species.

SELECTION

Forty years using the selection regeneration system in a mixed broadleaf stand in the Southern Appalachians fails to provide adequate reproduction. Rather, tolerant undesirable species take over openings made by removal of the larger trees in periodic harvests. Killing these stems with herbicides improves survival and growth of commercially useful saplings, although poorly formed trees and those of no economic potential continue to outnumber useful stems.

Figure 8.14 With the harvest of high-quality old growth broadleaf species from uplands across the South, pines—as pioneer species—inherited most of the sites via natural regeneration. (SFASU Steen Library archives)

Harvest methods resembling natural disturbances such as group selection, along with precommercial thinning and fire prevention, provide for the most favorable regeneration. Advance reproduction from root sprouts and, shortly after felling, from stump sprouts usually plays the principal role in species composition, even where seed trees of high quality and vigor of a preferred species have been selected for parenting the next rotation.

Selection harvests are recommended for stands with a high proportion of good trees of at least pole size. Where desirable growing stock of larger stems is scarce, but saplings of favored species are abundant, heavy cutting should be done. Desirable species generally retain their vigor and position in the stand after harvests.[39]

Shelterwood—Only for intolerant pioneer species, such as yellow-poplar, eastern cottonwood, upland oaks, and sycamore—is a shelterwood cutting appropriate for broadleaf woodlands. If the first or second cuttings, to encourage seeding and release of seedlings is too heavy, many weed successional species capture the site. The stand then becomes mixed and eventually uneven-aged as the even-aged pioneer species pass from the site.

Seed-tree—The transition noted above for a shelterwood cut in broadleaf forests is even more pronounced in seed-tree cuts designed to regenerate pure-even-aged stands. Even where preferred species are retained as seed trees, species composition of a new broadleaf forest is uncertain.

Clearcutting—Clearcutting systems are feasible for bottomland hardwoods, as seedlings of tolerant species are usually present in the understory before a harvest begins. Light-seeded species, like ash and maple, have advantages over heavy-seeded mast producers, such as the oaks and hickories, because of the ability of the former to disseminate their winged seeds great distances. Competition among the young trees and vigorous growth of brush and vines further alter the mixture, releasing selected crop trees then becoming necessary. Costly hand labor may be required. Clearcutting that is not followed by cultural treatments results in invasion of wild plum, hawthorn, staghorn sumac, and a score of other weed plants.

Oak-Hickory—Selection by groups is recommended for mixed oak stands in the Southern Appalachians which are relatively devoid of other species. Here, as elsewhere, the oak–hickory type may be climax and the trees intolerant of shade. About 1/3 of the basal area is harvested initially, with less volume removed at subsequent 15–25-year cycles. Quantity of composition is improved as the best of the larger stems are retained along with inferior trees among the smaller stems. The cut may also be designed to favor quality trees in the understory over those in the overstory.

For hydric sites not susceptible to drainage, regeneration is especially difficult to obtain, for reproduction often occurs in dense patches in temporary shallow pools of water beneath closed canopies. Harvesting trees by any system raises the ground-water level, submerging seeds and seedlings. If land is submerged during the growing season, seeds do not germinate; if inundated at other times seedlings remain dormant until water recedes.

Figure 8.15 In selecting stems for seed-tree regeneration, in the case of yellow-poplar, one looks for evidence of vigor. On the left is the bark of a tree of low vigor; on the right higher vigor. The more rapidly sloughing bark indicates faster growth (as it does in all species). (USDA FS photos by D. Todd, 1951)

Maple-beech-birch

The maple–beech–birch type is usually climax, all three species here being tolerant of shade. On moist sites, however, even the more shade-tolerant species, like eastern hemlock within its range, invade and become dominant. Birch, of the three preferred species commercially, is less tolerant than its associates. Its light seeds, widely distributed by wind, and its poor deer browse encourage seedling establishment. Beech, least desirable of the components of this southern angiosperm forest because of fungus infections that cause rot, is the most tolerant. Animals mainly distribute its heavy seeds. Maple is intermediate to its two associates in both tolerance and seed dispersal.

On most sites, selection harvests perpetuate the maple-beech-birch type. This management system, recommended where stands include trees of many ages, causes minimal disturbance to soil, watershed, and aesthetic values, while providing small openings for wildlife browse. The method favors the more tolerant beech, affording a greater number of hollow (because of rot) den trees and an abundance of beech nuts, a key wildlife food. A chief drawback of the selection system is the lower economic value of the beech in contrast to the preferred birch and maple. Also, logging is costly, heavy equipment must be transported to the site for each of the periodic (perhaps every 10 years) harvests. Skidders damage trees, scarring their buttresses and thereby encouraging disease infection. Selection, however, affords opportunities to correct undesirable ecological trends by harvesting less-desirable stems at frequent intervals.

Widespread clearcuts were made in the past to regenerate overmature stands of these broadleaf species. Where the seed supply is limited on overly large cutover areas, pioneer plants (such as blackberry) or light-seeded trees (red maple) invade and capture the site. While this drastic, though usually temporary, disturbance to watersheds and aesthetic values is an adverse consequence of clearcutting, temporary abundance of browse for wildlife occurs.

Yellow-Poplar

Yellow-poplar in the Southeast prefers mesic conditions. These trees appear as pioneer species following clearcutting or other denuding of the land. Clearcutting, an effective regeneration method, calls for openings of at least an acre and for seed-bearing trees at the periphery of the stand. On fertile, permeable soil with high nitrogen content, these trees outgrow other hardwoods and most conifers. Harvests of up to 50 acres are effective if seedfall is adequate and the soil is scarified to receive the seed. Prescribed burning, exposing mineral soil, also enhances seed germination. In areas where deer populations are high, large seed-tree harvest areas or shelterwood cuttings in blocks may be appropriate. In these, deer are less likely to damage young trees: they tend to congregate in small openings to feed on palatable yellow-poplar seedlings.

Tracts larger than 10 acres are well suited for the seed-tree system, retaining about five trees per acre for seeds. The shelterwood system finds use when initial openings are large enough to allow full sunlight to reach the forest floor for a third of each day, harvesting after reproduction is established removes the balance of the stand.

Foresters manage this tree of economic potential for wood quality. (Old-growth yellow-poplar has been prized since colonial times as a soft, easily worked wood for cabinets, pattern-making, and interior finish.) The wood is rather light (specific gravity: 0.3-0.4), that of younger trees likely to be heavier than older stems. To produce light-weight, soft wood, older stems, the growth of which has been retarded through competition for sunlight, are selected. (This contrasts to the situation for the conifers, where fast growth produces lighter wood.)

As defects in wood include discoloration associated with mechanical logging injuries and the consequent oxidation of chemical compounds in exposed tissues, logging must be done carefully. Blemishes caused by epicormic branch stubs probably degrade yellow-poplar more than do insects or diseases. The small knots, although sound, left by repeated sprouting from the bole discolor the wood and lower its grade. Unfortunately, thinning encourages formation of these water sprouts.

Water sprouts on released trees which had previously been suppressed may aid in restoring vigor. After crowns shorten, as by natural pruning, sprouts tend to arise to restore the photosynthetic losses of lower crowns. Most sprouts appear on the warmer south or southwest sides of trees, assuming the crown is symmetrical all the way around the stem. Few sprouts occur within the crown.

The species' seedlings and saplings respond well to fertilization with nitrogen and phosphorus, especially on well-drained bottomlands. Growth stimulation by nutrient amendments enables seedlings to rise above a critical height below which growing season flooding becomes injurious.

TUPELO GUM

Slight, temporary drainage, if possible to control, aids in regenerating this cover type (also called water tupelo) as well as baldcypress-swamp tupelo stands. Seed-tree harvest and 2-cut modified shelterwood cuttings, anticipating even-aged stands, are appropriate. For the latter method, the initial harvest provides for seed production, seedbed preparation and seed germination. Final harvest awaits establishment of a satisfactory stand.[40]

Water tupelo captures sites to the exclusion of baldcypress because of the ability of the seeds of the former species to retain viability when under water for an entire year. Thus the water tupelo seeds germinate but those of other trees, especially the silvical associate baldcypress, are killed by inundation. Sites flooded briefly are therefore necessary for continuing cypress-tupelo types in southern swamps. (Seeds of the tupelo gum germinate and survive while afloat for significant periods.)[41]

SWEETGUM

Marketed as redgum, because of the color of the heartwood, when grown in river bottoms, this species often is found in pure, fully-stocked, even-aged, second- growth stands on alluvial soils. Such stands are regenerated by seed-tree harvests; leaving too many stems encourages encroachment of undesirable shade-tolerant species. Seed trees should be no further apart than 100 feet. Even with 25-mph winds, few seeds fall beyond 200 feet of a seed tree or wall of timber. Clearcutting is undependable as a means of regeneration.[42]

Coppice—Many broadleaf trees reproduce by coppice sprouts, especially for short rotations. An initial advantage in height growth over seedlings is attained, but this is usually lost in about 6 years. Most sprouts of desirable species outgrow those of weed trees if given an equal start. To provide this advantage for economically useful stems, weed-tree control may be necessary. Although a single prescribed fire after a harvest encourages sprouts of low origin to exhibit uniform reproduction, continued protection is then essential. Fires result in a high percentage of stool sprouts, so called because repeated burning kills shoots, the subsequent sprouts developing enlarged, distorted, callus-like structures at the ground line. Tap roots surmounted by such structures resemble one-legged milking stools.[43]

Stool shoots have been found to be superior to seedlings for Ozark Highland regeneration, as seedling height growth there is slow—usually one-half that of sprouts. Five sprout generations may appear from a single root system. In one cutover forest of the Southern Appalachian Mountains, sprouts accounted for much of the sapling-size reproduction. Unfortunately, perhaps a third of the coppice shoots are infected with butt rots of various pathogens transmitted from the parent stumps and originally inoculated through logging wounds, fire scars, and other injuries. Stems originating high on stumps and from larger stumps have the most decay.[44]

Factors having little, if any, influence on stump sprouting or the height growth of sprouts include stump height, season of harvest cutting, and the presence of butt rot when cut. Stumps up to 16 inches diameter and 100 years old in stands 50 to 150 years old sprout prolifically, while larger and older stumps sprout little. The breaking point for black oaks appears to be 22 inches in diameter, or 150 years of age: sprouting ability increases with size of parent trees up to about 6 inches dbh and then diminishes. While a stump occasionally will produce more than 20 sprouts, 6 to 8 is normal.[45]

Many broadleaf trees sprout from below ground. Such trees are distinguished from true seedlings with difficulty. Only by digging into the soil to discover a root origin can one ascertain

Figure 8.16 Oak sprouts from low stumps. Many quality trees in a mature forest derive from this form of vegetative reproduction.

whether young trees are either true seedlings or sprouts. To obtain favorable coppice reproduction, foresters favor stems for crop trees that arise from roots; otherwise preferred sprouts are those which originate from low, small stumps.

Rainfall patterns apparently do not influence height growth of sprouts, as height increment is usually completed in early spring when the water supply is adequate, even in drought years. Adequate soil moisture provides for uniformity of sprout height growth on many sites.

When sprout control is desirable, it may be partially obtained by piling logging slash on stumps. Some shoots may grow laterally along the ground surface to the edge of the slash pile and then turn upward. Trees cut after midsummer are not likely to sprout until the following growing season. For yellow-poplar stumps, decay is rapid; thus they provide little support for sprouts arising from them. This is especially important in areas subject to strong winds and sleet storms. Nevertheless coppice regeneration is utilized on short rotations and for young stands to quickly produce a new forest. Sprouts of this species push through dense blackberry jungles to overtop seedlings and sprouts of numerous other more shade-tolerant species. Even yellow-poplar seedlings cannot compete favorably with neighboring sprouts of the same species.

Sweetgum stands are also readily regenerated by coppice. Sprouts in the river bottoms reach breast height in a single year, about twice the height growth of seedlings. Though hill-grown sweetgum produces inferior wood, sprout growth there is equally vigorous.

Fire influences the initiation of coppice reproduction. Fine upland oaks occupy burned-over areas within a few years of a fire.[46] Smaller trees are most easily killed by fire because their bark is readily enveloped by flame-fed leaf litter and debris. These young trees then produce an abundance of sprouts, the ability to do so an inherited characteristic. For American beech, roots must be injured for root sprouting to occur, the coppice then arising from adventitious buds from within callus tissue associated with wounds.[47]

Fell-and-Burn—Pine-hardwood forests of the Southern Appalachian Mountains and the upper Piedmont province provide foresters with the opportunity to use fell-and-burn, an unique silvicultural regeneration practice. This procedure differs from regenerating monocultures in that timing of clearcutting and site preparation by prescribed fire is important and residual stems of all species above a few inches in diameter are cut and left following the final harvest. Heavy machinery is not utilized to prepare the site for pine planting. Rather, cutting residual trees in early spring provides time for foliage and twigs to cure before a summer fire is ignited. Then, about 400 loblolly or shortleaf pines per acre are planted in openings at about 10xl0-foot spacing. The hardwood sprouts that arise from roots, stumps, and logging slash in spring have low vigor, due to low carbohydrate reserves. These newly formed sprouts then are top-killed by burning, further reducing vigor and allowing the planted pines to become established. Variations of this basic methodology are also being tested and adopted.[48]

Reasons to commend the practice over conifer monoculture include maintaining biodiversity (both of vegetation and fauna), encouraging the new forest to be aesthetically pleasing, providing more habitat for a variety of wildlife (and added revenue from hunting leases), minimizing damage to watersheds (as heavy equipment is not employed to shear residual trees), reducing erosion, and greatly lessening the cost of regeneration. Increasing prices for stumpage of hardwood species of all grades—for (1) state-of-the-art pulp and paper manufacture, (2) chips for oriented strand board, (3) furniture and wall paneling, and (4) export—encourage this silvicultural method. Mills adjust to the raw material supply rather than foresters adjusting the forest to the mills' requirements.

Nonindustrial forest landowners will more likely use mixed-stand management, especially if aesthetics or recreation are motives for retaining ownership of woodlands. Foresters call it 3-D regeneration: biodiversity, market product diversity, and economic development. The value of the system is suggested because, across the South, 20 to 40% of the basal area of pine and hardwood mixtures growing under natural conditions is of broadleaf trees. Reasons to discourage the practice include (1) longer thinning cycles and delayed final harvests (as stems in the needleleaf-broadleaf mixture grow more slowly than do pure pine stands), (2) less total wood volume and income produced per acre, (3) exclusion of fire until hardwoods are old enough to be beyond heat damage (perhaps 6 inches dbh), and (4) a compromise habitat for wildlife and timber (in contrast to optimum wildlife in a pure hardwood stand and optimum wood production in a pure pine forest; here the vertical diversity of vegetation encourages more niches for a variety of wildlife.)

Silviculturists may restrict fell-and-burn to the more xeric sites where pines out-compete hardwoods; yet they must control the heat of prescribed fire lest the root mat in the F (fermentation) and H (true humus) humus layers be destroyed. In the Piedmont, the thin root mats in these soil horizons are especially susceptible to destruction and, when that takes place, soil erosion follows. Moisture stress, not shade nor poor nutrition, causes the pine mortality of low survival rates.

A variation fell-and-burn procedure utilizes winter felling. Burning that follows is less uniform than for later treatments, providing for more forage, more vegetative biodiversity, more slash for wildlife cover, and a thicker L (litter) humus layer for soil microflora and micro- and macrofauna.If fire is delayed until summer, the nesting season for game and song birds will have passed. Summer burning also increases herbaceous growth, hence enhancing habitat for insects feeding on the green leafy vegetation and the wildlife that feed on the insects. Burning when the humus is moist reduces nitrogen losses to the atmosphere.

Fell-and-burn regeneration may yet be used in the lower Piedmont, the Coastal Plain, and the Interior Highlands. Especially is this so for the lower Coastal Plain because of the importance of these forests for hunting. Turkeys, for instance, prefer planted pine and natural broadleaf mixtures. At this time, however, prescriptions for fire to accommodate the type are lacking. Eventually, the method may be employed for mixed-stand bottomlands of the region. Under any condition and for any site, this rule of thumb holds true: the species, pine or hardwood, that overtops its neighbors in the seedling stage will remain dominant throughout much of the life of the stand.

Some researchers believe the Southeast will warm measurably in the next 50 years. If that occurs, accompanied by expected erratic weather, tree diversity would offer protection from excessive storm damage and associated insect and disease problems. For any part of the South, successful fell-and-burn regeneration will depend on improved land classification, utilizing the four factors of site: edaphic, climatic, physiographic, and biotic.

Regeneration and Water Quality

We conclude this chapter with a note on the importance of maintaining water quality in any regeneration effort. Indeed, a forester does well to ask, before planning any silvicultural practice, what the results of that practice will be on the water of the area. Will clean water, free of harmful microbes, and clear water, free of sediment, be maintained?

Nonpoint source pollution may occur as a result of a silvicultural practice, especially logging for regeneration. States under the Water Quality Act of 1987 are charged with enforcement of the act. Most states rely on voluntary compliance with established Best Management Practices (BMPs) to control nonpoint source pollution.[49]

BMPs include seeding ground cover, fertilizing herbaceous plants, and mulching. Installing road dips, water bars, culverts, and road relocation may be involved. Mandatory BMPs may make regeneration harvesting unprofitable on marginal sites.[50]

9 Integrating Uses of the Forest

Society requires that the forests of the South be utilized for more than the production of fiber for solid wood products and paper pulp. Federal law mandates that the national forests of the region, covering 15 million acres in the South, be subject to the Multiple-Use Act, giving substantial, if not equal, weight to wildlife, water, herbaceous plants for livestock, and recreation—as well as to wood. The public's attitudes toward private ownership take on a similar hue, and the industries that control 20% of the forested acreage in the South often bow to this mandate. Industrial leaders choose this position as good neighbors and citizens. Pragmatically, it is wise to do so: Arsonists and vandals run loose in the world. Non-industrial forest landowners are not so readily pressured to integrate uses of their privately owned tracts, although it is often to their benefit to do so. In addition to the four non-timber uses mentioned above, southern forests are also managed for gum naval stores and as shelterbelts to protect the soil from blowing in the wind.

Recently introduced phrases—*new forestry*, *new forest perspectives*, and *ecosystem management*—attempt to describe forest practices of the future. Protecting esthetic values and maintaining biodiversity will receive greater emphasis, especially as accelerating human demands on natural systems cause the loss of biological diversity.[1] With this new importance, sustainability of a site as an ecosystem replaces sustained yield of forest products as the aim of forest management. Thus, environmental ethics and concern for the conservation of all resources, as well as integrating resource management among the many uses of America's forests, gain prominent attention.

Sustainable forestry has been defined as "management that uses and enhances the productive capacity of the land and its resources while conserving the integrity of the forest's ecological processes." A forest so managed has the capacity to respond to changing social needs as well as to changing levels of investment in the amelioration of abused resources.[2]

WILDLIFE

Broadleaf trees enhance wildlife and fish populations by providing vegetative protective cover, food, dens, and shade over streams. Silvicultural treatments of woodlands usually do not interfere appreciably with long-term game-management objectives. Changing vegetation during a rotation over the years provides a variety of habitats for many animals.

White-tail deer

In woodlands of loblolly pine and shortleaf pine, the predominant conifers of the South, considerable white-tailed deer forage is produced in well-stocked stands not encumbered with a dense mid-story of hardwoods too tall to be browsed. Sometimes, as in the pitch pine barrens of southern New Jersey, deer are so numerous that redistribution is essential to avoid herd starvation and severe browsing of planted pines, although the resinous conifer would not normally be a food preferred by white-tails. Transfer of deer from southeastern coastal islands to inland uplands has long been practiced to protect both the deer and the trees of the off-shore woodlands.

In the mountainous uplands, woods-workers cut browse on higher slopes and ridges to form dispersal patterns for deer. Placing salt-blocks sometimes alleviates overuse of coves near these ridges. Leaving zigzag boundaries maximizes the amount of border left in this vegetative manipulation for browse replenishment.

Figure 9.1 A healthy 8-point white-tailed deer. Southern pines and a mixture of hardwoods sustain carrying capacities of trophy animals, though many argue that management of the herd and site for trophies diminishes the total population and thus reduces the chance for hunter success. For white-tailed bucks, hunters count all of the tines on both antlers to determine the number of points. Judges of trophy quality couple the width of the antler spread with the number of points to determine winners. (USDA Forest Service photo)

For cover and feed, seeding of grass and clover on fertilized skid trails, log landings, and abandoned logging roads enhances deer vigor when foraged, although the animals do damage conifers planted or naturally seeded-in on these sites. Browse injury falls off when trees are about 4 years old. Deer repellents, like a thick lime paste placed on seedlings, reduce browsing appreciably.

To improve deer habitat while enhancing production of commercial timber in Appalachian upland hardwood stands, rhododendron and mountain laurel shrubs are removed by chemical or mechanical means. When cutting these ericaceous plants, which are not a preferred food, tops are partially severed so that they fall within reach of deer. With some cambium left intact, translocation of products of photosynthesis to root systems takes place for subsequent resprouting and leafing. Subsequently the shrubs die, as complete browsing removes foliage more rapidly than the rate at which leaves can manufacture carbohydrates for return to roots. Eventually, exhausted root reserves in this low-lying cover enable improved growth of commercial stands of timber, as competition for soil moisture, nutrients, and sunlight diminishes. Cutting strips about 20 feet wide through shrubby brush of a multitude of non-ericaceous plants also provides food for wildlife while enhancing water production.

Foresters establish game pastures within stands of timber. Plowing and planting such sites to clover for deer browse eventually crowds out grasses. Old house sites in the forest also make fine game pastures. These are especially desirable where cleared strips return to ericaceous shrubs rather than to more-palatable deer food. Corn is a popular deer food supplement for planting in these pastures. Bartram, the early-day botanist of the Appalachian region, reported that Native Americans—long before white settlers arrived in the South—developed meadows for game.[3]

Figure 9.2 Forage planted for deer browse in the southern Appalachians. Openings are made in the canopy prior to seeding orchard grass, Kentucky fescue, and ladino clover. Shown is a yellow-poplar stand growing in a cove. (USDA Forest Service photo)

Along with prescribed fire for improving timber stands in small, well-distributed units to benefit deer, thinning and other partial harvests enhance the quantity of forage and browse. Prescribed fires in longleaf pine stands set at least once every 3 years, and removing low-mast producers from mature stands of turkey oak also effectively improve the quality of browse food for deer.[4] For high populations of deer in pine woodlands, foresters maintain openings in which patches of mast-bearing hardwoods are encouraged, enabling a carrying capacity of one deer to 20 acres. Shearing and chopping prior to pine planting provides favorable broadleaf forage for the first few years. Placement of salt blocks and providing pelleted rations in feeders strategically placed in the pineries aid health and distribution of deer. Fast approaching in the region is the time when economic benefits, assured by the value of harvested bucks, will surpass that of stumpage.[5]

Foresters record about 80 woody species in longleaf pine forests utilized for browse by deer. Half of these are starvation diet food. Many evergreen or semi-evergreen hardwoods and vines are preferred forage. While a browse line in the angiosperm woodlands indicates an overstocked range, even the pine may be browsed, which suggests a severe dietary problem. Perhaps the best indicator of deer utilization is the *Smilax* greenbrier—where plants of the thorny vine remain small, over-browsing is severe.

Fires often alter browse forage, enabling French mulberry, viburnum, greenbrier, sweetgum, blackberry, grasses, and forbs to capture the site. While fire is detrimental to yaupon, a deer favorite, higher protein and phosphorus levels occur in other plants where this vegetation is burned.[6]

To support one deer on 40 acres of pine–hardwood forest, felling cycles must be no longer than 7 years. Crude protein levels in deer forage rapidly diminish after that. Twenty acres will adequately support one deer several years after a harvest when broadleaf tree forage is abundant.[7]

The diets of grazing cattle and deer often overlap. Deer diets, both in uncut pine–hardwood forests and those harvested less than 3 years earlier, are dominated by leafy browse throughout the year. In contrast, cattle diets in uncut woodlands consist mainly of grasses and forbs during summer and autumn and a mixture of these herbaceous plants and browse during winter and spring. In recently harvested tracts, bovines feed throughout the year on grasses and forbs.[8] Deer (and grouse) foods are altered by thinning, with total dry weights of forage in cove hardwood stands reaching a peak 2 years after stand density is reduced.

Squirrels

At least two broadleaf trees totaling 5 square feet of basal area per acre (two trees of 22 inches dbh) provide sufficient dens for an optimum eastern gray squirrel population. (The western fox squirrel also inhabits the western fringe of the southern forest.) Good den trees:

- Have crotches in crowns
- Have much durable heartwood
- Produce food as well as shelter
- Are currently in use (as indicated by cut bark and wood around the lip of the den entrance)
- Are at least 15 inches in diameter
- Are well distributed throughout the woodlands

Squirrels prefer cavities with volumes between 1 and 3 cubic feet. Seldom are entrance openings lower than 10 feet from the ground and more than 4 inches in diameter, as large entrances allow rain to wet nests and permit predators to enter. Large openings also provide shelter for raccoons. Favorable den cavities require 8 to 30 years to develop.

Seeds of species of the white oak group, maple, beech, black walnut, chestnut oak, sweetgum, blackgum, and basswood provide quality food. Some authorities consider red oak group acorns cathartic to squirrels, and thus the animals shun them unless suffering from a food shortage. As white oak mast germinates shortly after seedfall in autumn and acorns of the red oaks in the spring, the latter are available, in spite of the laxative characteristic, during the critical winter period.

Trees of little commercial value left for squirrel food in silvicultural operations include hawthorn, wild plum, and hazelnut. Trees of potential value for lumber and also for game food include several hickory species and black cherry. Fires that consume mast seriously affect the squirrel food supply and hence the population of these *Sciuridae* rodents.

Birds

No forests in eastern North America are managed for game production to the extent of longleaf pine, and none affords more harmonious management practices for timber and game together. For this forest, wildlife enthusiasts express concern about the effects of broadleaf weed-tree control on game, even though chemical and mechanical techniques now available to managers are inadequate for eliminating all of the shrubs and trees desirable for game. Of greater concern are the vast areas of unmerchantable dense pine and hardwood stands without understory plants that provide food or protection for wildlife. Where intensive site preparation over extensive areas is practiced, one fourth of the area may be left in untouched strips for wildlife conservation. Ordinarily, however, game food is adequate in longleaf pine forests, as much of the grassy area of these conifer woodlands is bisected by broadleaf species in swamps, ponds, and drainages.

Less conflict between avian life and silvicultural activities occurs with this species than with agriculture, because large-scale farming leaves little border area around cultivated fields and

Figure 9.3 The pileated woodpecker is the largest North American woodpecker (assuming the ivory-billed is extinct). The bird, driven from its former cavity by a screech owl, now carves a new nesting site in a dead hardwood tree. Bird books often refer to the pileated as having vacated the forest, never to return, following timber harvests and intrusion by people into its habitat. However, this bird, like many kinds of wildlife, acclimates to man's presence as long as suitably sized snags and some mature trees remain. (USDA Forest Service photo by R. Conner)

improved pastures. Such reduced border areas drive bobwhite quail from farmlands. These birds do well on both cutover and forested longleaf pine sites.

Bobwhite quail may be encouraged in southern pine stands by appropriate placement of cleared food lanes 25 feet wide. These swaths, covering some 12% of an area, meander to provide the

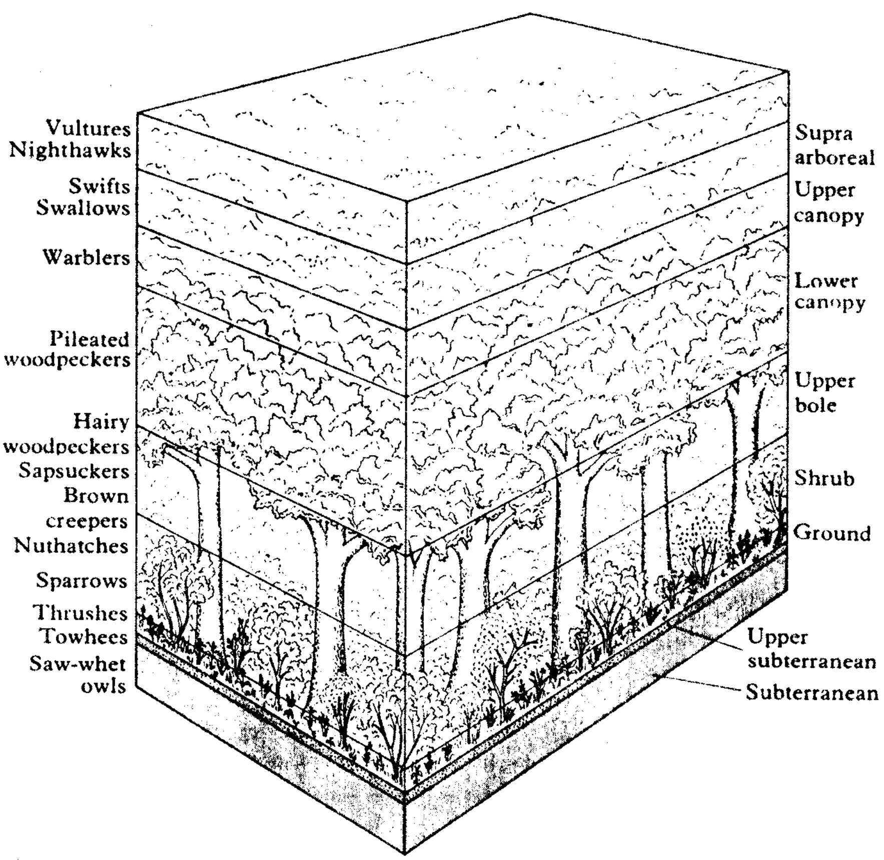

Figure 9.4 Avian habitats in a mature broadleaf forest. Note the birds that typically inhabit each of the nine layers. Some strata may be lost because of fire, grazing, or excessive browsing. (after R.H. Giles in *Wildlife Management*)

greatest perimeter of vegetation edge and also to avoid cutting valuable trees. Deciduous trees in the woods bordering the food lanes are thinned to increase interspersion of birds and, at the same time, to favor pines over oaks. Fire-prevention strips 100 feet wide, plowed along roads, protect food-production lanes planted in the woods.[9]

Oak, grass, legume, and shrub seeds, as well as those of longleaf pine, provide good quail food. On sites in the Southeast where pines and an assortment of hardwood species occur together, one bird for each 4 to 6 acres is considered good quail stocking. In the western fringes of the cover type, favorable carrying capacity amounts to one bird for 10 to 40 acres.

As longleaf pines are infrequent seed producers, providing cone crops, at 10-year intervals, on average, and as seeds from shrubs are insufficient in late winter to supply food for bobwhite quail, foresters prescribe fire to reduce the herbaceous ground cover and, thereby, encourage seed production by perennial legumes. For roosting, nesting, and feeding, quail require ground cover that is open below, but that furnishes some protection from winged enemies above. Late winter burning, before the seeds of legumes germinate, is recommended. Earlier burning that scorches the seeds of partridge pea may cause them to germinate (as they lie near the warm surface of the blackened earth) and later be killed by freezing temperatures. Night burning after a rain when the wind is low and the relative humidity high serves well in dense brush. Thinning dense stands encourages

Figure 9.5 A high-country ragged stand. Typically, low-grade trees like these are removed to temporarily increase water flow into streams and the sites are then planted to more economically valuable species. Left unmanaged for timber production, such woodlands provide habitat for many kinds of wildlife with minimal loss to the inventory of wood.

ground-cover vegetation, especially so since the best longleaf pine habitat for quail has about 30% less basal area than that advocated for maximizing timber production.[10]

Fire for quail management in loblolly and shortleaf pine forests aims to reduce to 4 feet understory vegetation (holly, yaupon, blackgum, waxmyrtle, and dogwood) that in the absence of fire would be 10 feet high. Plowing the soil and thinning the stand to open up the woods may be as effective as prescribed burning for improving quail habitat. Narrow uncut strips of trees left at stand edges provide shelter, as coveys of birds range between wooded areas. Quail move only about 20 feet into the timbered zones.

Prescribed fire in longleaf pineries every 3 or 4 years also improves wild-turkey habitat. Dwarf varieties of blueberries and huckleberries produce more fruit while the fire prunes branches to enhance berry production a year after the fire. As the optimum range for turkey contains a high population of oaks and hickories, wildlife managers maintain an adequate number of these mast-bearing trees of seed-bearing age. Wild turkeys find abundant insects in game pastures that have been established to enhance deer populations.

Concern for songbirds and other non-game birds is mandated in part by federal and state regulations pertaining to threatened and endangered species.

A mixed pine and hardwood forest of the western Gulf meets this mandate, providing 35 species of plants important for songbird food. Fifteen months after a clearcutting harvest, 28 of these plant species were found to be more abundant than on adjacent unharvested sites. Important among this vegetation are grasses, sunflowers, and legumes.[11] Prescribed burning is carried out in the grassy balds of the Southern Appalachians to enhance the winter habitat for golden eagles. Fires should be ignited at 5- to 10-year intervals to provide regrowth of the herb and shrub communities upon which this threatened species depends. Regrowth is adequate between 1 and 3 years after burning.[12]

Birds especially appreciate juniper seeds. The presence of these berry-like cones in winter, when other fruits and winged seeds are scarce, makes the species desirable in wildlife management. The fruit matures in the fall and clings to trees until late the following spring. Birds relish the whitish bloom on the deep purple fruit,which contains about 5% protein, 10 to 30% sugar, and about 15% starch. (Birds also often fall from their perches, inebriated after consuming fermented seeds of these species.)

Southern Appalachian forests show a decline in cavity-nesting birds due to the loss of large-diameter snags required by certain species. Salvage harvests and fires eliminate many of these trees. However, live stems with large dead limbs seem to compensate for the loss of the large snags. Rotations of 100 years may be required to maximize the number of snag-dependent animal species.[13]

Red-cockaded Woodpecker—Of particular concern today is the red-cockaded woodpecker, listed by the U.S. Fish and Wildlife Service in 1968 as an endangered species. Generally found in open, park-like stands of old pine trees that have been severely infected with the red heartrot pathogen, the birds nest in cavities readily carved from the soft tissue of the xylem core. A federal district court in Texas ruled in 1988 that the USDA Forest Service did not adequately protect the bird in the national forests in that state. While appeal of the case awaits a decision, the Forest Service has directed all national forests in the region to follow the district judge's mandate:

- Stands within 1,200 meters of a nesting colony site must be periodically thinned.
- Clearcutting is forbidden within that zone.
- Herbicides cannot be used to control the brush within the zone.
- Fire must be periodically prescribed at 3- to 5-year intervals to kill back the brush and thus maintain the stand in an open, park-like condition.[14]

The judge may have lacked good advice or have failed to heed it. Pine reproduction likely will be killed by subsequent prescribed fire; the periodic thinning will result in larger openings for hardwood trees and shrub growth, while enhancing the vigor of the residual pines so as to exclude the fungus. Without new conifer ingrowth, the stand will continue to age until finally overmaturity and death of the trees on the colony site occurs. Similarly, broadleaf trees could take over the site to the exclusion of the pines, certainly further threatening the bird. (Delaying tactics resulted in the loss of 3,500 acres of prime forest and five red-cockaded woodpecker colonies in an old stand.)[15]

If the court's decision stands, private and state forests across the region may in time be required to follow similar management procedures. Industrial and nonindustrial private landowners alike are subject to severe penalties for violation of the federal Endangered Species Act.

Meanwhile, the 1990 hurricane along the South Carolina coast destroyed much of the habitat of this woodpecker. Researchers quickly developed a technique to rescue the bird from near extinction in that area. At about 20 feet above the ground in residual trees, wildlife biologists carve out an opening in the periphery of the tree, then excavate an oblique cavity into the sapwood (or heartwood if the tree is old enough to have produced this interior core of nonliving wood), and into this opening place a box with an entry hole. Birds searching for a nesting site locate the ready-made cavity and use it for a home. Under normal conditions, it takes 3 or 4 years for the birds to excavate a nest tree, and several generations continue to lay eggs and rear young in a single nest.

Long rotation ages (60 to 120 years), provided basal area is adequate, maintain habitat for the bird (whose cavities at a glance often resemble those of the pileated woodpecker). Consequently, shelterwood harvests may be recommended. (Pine straw on the forest floor in unburned sites has been marketed while maintaining habitat for the woodpecker.)[16] Intensive management, including thinning, prescribed fire, and cleaning to maintain pines at wide spacing, provides favorable habitat for colony stands while reducing understory broadleaf vegetation.

Figure 9.6 Forests provide for Isaac Walton's "compleat angler." Habitats are restored and maintained, as by this water tupelo swamp of second growth surrounding a natural pond of variable water level.

Breeder couples of these birds have several young males as helpers to maintain the colony, where nest trees are readily identified by sack-shaped cavities surrounded by many bird pecks to release sap from the living pine. These woodpeckers forage for insects for up to 3/4 of a mile, flying under tree canopies for protection. Steel plates could be nailed around openings to keep other birds from widening and taking over a nest site.

Trout—From 1903 to 1935, logging old-growth forests without concern for regeneration in the Southern Appalachian Mountains significantly reduced the population of brook trout. The numbers of these fish likely would have risen with prompt regeneration of the forest that in turn would shade streams. Meanwhile, rainbow trout, first introduced in 1910, has become the predominant trout. After 1950, brown trout were introduced in the region.[17]

Streams in these mountains are the southern limits for natural schools of trout, a sport fish that requires shaded waters where temperatures remain below 75˚F. Where streamside timber is harvested, temperatures rise as much as 20˚F above that of shaded creeks. In midsummer, the temperature of such warm water meandering in a stream below a clearcut harvest area and through 400 feet of forest cover drops to about 66˚F, the optimum for brook trout. Streams flowing in the open have at midday an 18˚F rise in temperature for each unshaded 1000 feet. Therefore, harvests of timber on stream banks must be carefully controlled so that shade cover is not removed. Policies often require an uncut 50-foot-wide border adjacent to creeks.

Catalpa plantations should not be located near paths used by fishermen. Fishermen injure trees by clubbing trunks to dislodge catalpa worms, a favorite bait, that feeds on the leaves of these trees.

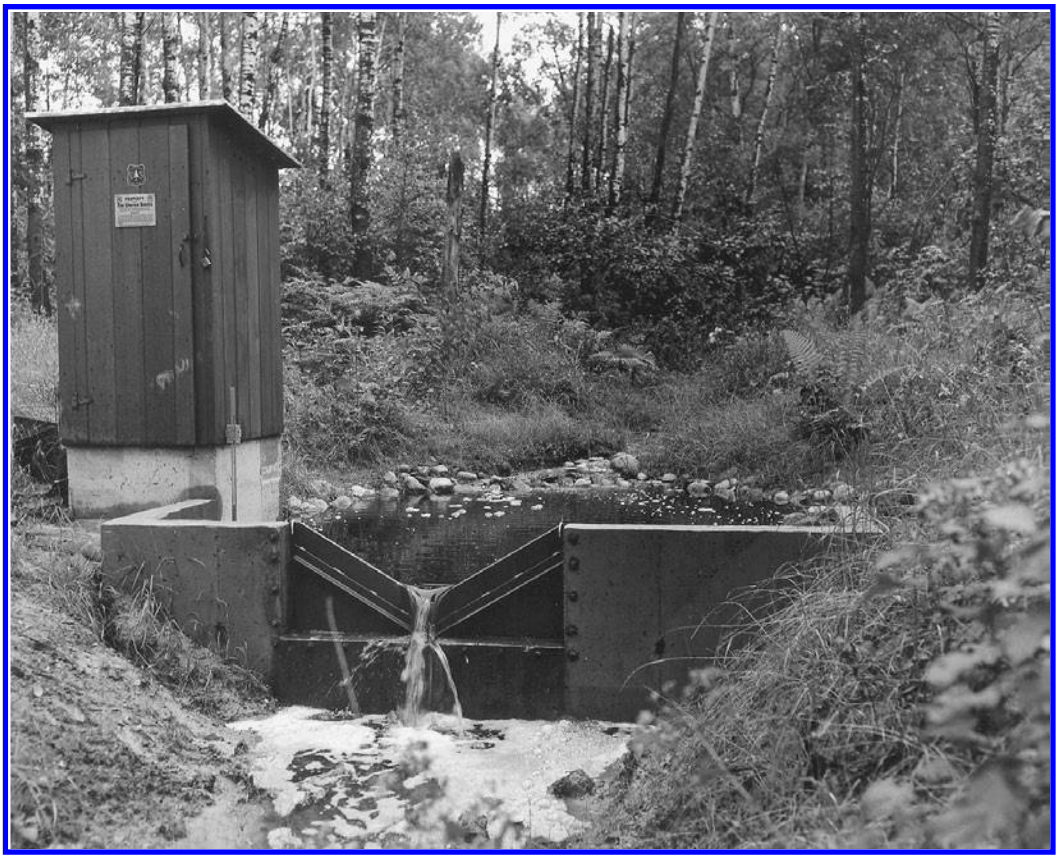

Figure 9.7 A V-notch weir. The flow of water in high-gradient creeks can be measured with 120-degree V-notch wiers. Shown is the flow from a small 30-acre watershed, tallying 0.3 cubic feet per second (cfs). The shelter houses an 8-day recording device. (USDA Forest Service photo)

WATERSHED MANAGEMENT

Foresters manage woodlands for water production as well as for fiber. This is especially so for the upland hardwood stands whose presence enhances the flow of clear, clean water for industry and human consumption. Manufacturing processes require water that is free of sediment; people need water free of dangerous microbes. The opportunity to integrate silvicultural procedures to increase waterflow and, at the same time, to grow fiber for the future, exists in these deciduous forests. In these woods cattle graze, wildlife make their homes, people hunt, and many folk find pleasure as temporary intruders, but watershed protection and water conservation remain the most important uses for the aesthetically pleasing mountain woodlands. Yet, aesthetic interests might allow slight damage to watershed capability. Picnic areas and campgrounds, for instance, unavoidably injure watersheds; but providing "public pleasuring grounds," the phrase of a Congressional act once given as a reason for establishing national parks, may be an appropriate use of the woodlands.

Hardwood foliage that each autumn covers the ground with nutrient-rich foliage entices fauna and flora to participate in its decomposition. The decayed organic matter provides pore space in which the soil holds water, much like a sponge, to maintain a high infiltration rate of rain water that, consequently, lowers surface runoff. Runoff of rain water deposits sediment in streams.

Figure 9.8 A San Dumas flume weir with recording device. Note the solid concrete walls to which the steel flume is attached. A special mortar mix assures that these dams are tightly connected to bedrock so that no leakage occurs. (USDA Forest Service photo by B. Muir)

Less significant, but no less important, are the needles in pine forests. A 2-inch layer of undecomposed needles, weighing over 4 tons per acre, after a rain holds—in the absence of an underlying humus layer—from 0.01 to 0.09 inch of water. Erosion is reduced by providing time for the rain to infiltrate slowly into the ground.[18] In contrast, destruction of underlying humus along with deciduous foliage exposes soil to the impact of raindrops, a force sufficient to seal pores and reduce infiltration to a negligible rate. Thus, prescribed burning must be used cautiously, for frequent burning retards the development of a humus layer, the surface zone of litter that would in the course of time be incorporated into the mineral soil now oxidized by the heat of the fire.

Charred organic matter seals soil pores, reducing the infiltration rate with diminished porosity. Surface fires alter the habitat of most fauna and flora that decompose organic matter, thereby reducing populations. These microbes, living in the unincorporated litter of the forest floor, are essential for the normal decomposition and mixing of the biomass with the mineral matter in the surface soil. Ground fires, those running under the soil surface or in organic soils, drastically alter microbial life, as the heat of the fire oxidizes the humic material and gives rise to an oxygen-reduced state. Fires above ground have a negligible effect on soil temperature.

Partial harvests are appropriate where large clearcutting operations threaten watershed values. With reduced harvests, animal logging with horses and mules returns to replace soil-compacting

Figure 9.9 A check dam for watershed protection. These log structures in the eroded Appalachian country hold the soil, thus encouraging healing of a site as trees encroach following land abandonment from agriculture. (Tennessee Valley Authority)

machinery to minimize runoff and maximize the production of clear, clean water. Animal skidding permits logging a site following rain without seriously puddling soil, in contrast to the detrimental effect of even rubber-tired skidders. Slight soil compaction appreciably reduces the movement of rainwater into the surface of the ground, as well as the growth of trees.

White pine forests, indigenous to the South's mountainous area, cover lands often dedicated to water production. The species serves well in maintaining favorable soil conditions for watershed protection. It is thus an effective replacement tree for planting in areas lacking favorable reproduction or seed sources of desirable species. Conversion increases water yields, as cutting prior to planting and periodic release of dense stands are both treatments that reduce transpiration demands and, thus, are appropriate for stimulating the output of water from forested watersheds. Cutting dense ericaceous shrubs in a white pine woodland both increases water yields and encourages natural regeneration of white pine and other light-seeded, relatively shade-intolerant species.

On the other hand, white pines growing on a site over several rotations without intervening broadleaf types covering the land could alter a porous crumb mull humus, found under an earlier climax deciduous forest, to less porous surface soils. The thick mat of needles under a stand on such a soil effectively absorbs water from light storms, holding much of it only until evaporated and, thus, neither allowing its use by plants nor its percolation to streams. In contrast, the greater amount of water held by decayed hardwood foliage incorporated in the soil is retained for plant use and for subsequent release in springs and streams. Some argue, however, that because pine needle depth remains rather constant throughout the year, not fluctuating between autumn leaf fall

Figure 9.10 Brush dams to hold soil. Put in place before planting pines in this highly erosive Mississippi loess soil, the trees will stabilize the soil in 5 to 15 years, thus protecting the watershed. (USDA Forest Service photo)

and late summer of the following year (unlike broadleaf foliage), conifer woodlands provide better continuous rainwater infiltration than does hardwood vegetation.[19]

Landowners have at times found it economically desirable to remove pine straw for plant bedding and mulching material. This should be practiced on a rotation system, as annual removal of pine litter over a decade significantly diminishes water infiltration rates. It also deters tree growth. In one case, raking litter from shortleaf pine stands annually for 12 years resulted in a loss for the period of 0.2 inches in diameter and almost 100 board feet per acre in volume growth.[20] Growth reduction may be attributed to the loss of nutrients stored in fallen foliage or to water lost to evaporation in exposed soils.

An old-field shortleaf pine–loblolly pine stand in West Tennessee 20 years after abandonment from agriculture still had not had the soil restored to a favorable condition for water infiltration.

Figure 9.11 Wide-track crawler tractor. While logging should cease during wet periods, the wide tracks disperse the weight of the machines, thereby reducing soil compaction and puddling of the soil. (Texas Forest Service photo by R. Billings)

The top 3 inches of mineral soil under the pines was twice as compact as under adjacent broadleaf trees, although the amount of organic matter in the soil was the same for these two conditions. Litter weight for the old field, from which at least half of the top soil had been lost to erosion, was 9 tons per acre. For hardwood forests, the weight was 18 tons. (For open pasture land, litter weight amounted to only 240 pounds per acre.) Conversion to white oak, dogwood, black locust, *Juniperus* species, and other mull-forming vegetation aids restoration of compact soils, thus promoting greater recharge of ground water aquifers.[21]

Hemlock Relations

Eastern hemlock, also an important cover in mountainous watersheds, and no longer needed for tannin, often shares the coves along streams at lower elevations with stands of yellow-poplar. Silviculturists suggest harvesting the commercially low-value conifer, thereby reducing transpiration losses and increasing stream flows. This treatment encourages the establishment of yellow-poplar, stems of which would otherwise be unable to penetrate the dense evergreen canopy. In the openings where logging scarifies the soil and thus improves the seedbed, yellow-poplar stands readily become established. With care in logging, such as skidding away from streams, creek-water turbidity should not be significantly increased.

Because the soils under hemlock forests have mull humus layers in which organic matter is incorporated, the sponge-like mantle is favorable for absorbing and storing rainwater. Soil animals, attracted by the high nutrient content of the foliage, also contribute to this porous condition. There are exceptions, exemplified by a stand growing on a sandy loam with a low pH and a notable absence of earthworms. The humus remained raw, unincorporated with the mineral soil, and with physical properties unfavorable for water absorption and retention. Adding lime to that site improved the availability of calcium for earthworm activity, increased the volume of pore space, and raised the infiltration rate of the rainwater.[22]

Rainwater flowing down hemlock needles and stems and passing into the soil carries with it potassium and calcium. The leachate of nutrients is greater in the fall than in the spring. Considerable losses of nutrient elements to drainage water during heavy winter rains, and before chemical elements can be utilized by plants making spring growth, probably occur.[23]

Aquifer Outcrops—Runoff during intense storms occurs because rainfall exceeds the volume of available pore space in the surface soil. On ridges and upper slopes, the depth of gully-making, trash-moving storm water sometimes exceeds the depth of the shallow surface soils.

When rainwater infiltration rates of a gravelly loam soil undergoing ecological transition over a long period were charted, the effect of vegetation succession was notable. One-half of the precipitation on the abandoned treeless old fields ran off with storms as light as 1 inch per hour. Under pioneer pine species, as much as 16% of the rainfall was lost as runoff; while runoff from later successional hardwood forest occurred regardless of rainfall intensity of as much as 3 inches an hour.[24]

Aquifer outcrops, into which rainwater infiltrates to be subsequently percolated downward, may properly be retained in broadleaf brush. Such sites should not be denuded to be regenerated to commercially valuable conifer species. Storage of water in the subterranean aquifers below the outcrops maintains an inventory of clear, clean water.

Infiltration and Water Value—Rules of thumb for assessing infiltration rates under various species and land use conditions suggest the importance of certain cover, even if of little timber merchantability. Using infiltrometers, one finds a liter of water passes into the surface soil (1) under a broadleaf canopy in 30 seconds, (2) under a pine canopy in 3 minutes, (3) in a freshly cultivated field in 30 minutes, and (4) in a heavily used recreation area with compacted soil in 30 hours.

Rules of thumb about water value also aid the forester in multiple-use decision-making. An acre-foot of water is worth about $3000 when used industrially. It is worth about S300 when used for recreation, about $30 when used in agriculture, and perhaps $3 in the growth of trees in a forest. Hence, the value of rainwater used by trees may be only about 1/1000 of that for the manufacture of products from those trees.

Site Preparation—Sheared and windrowed site preparation for plantation establishment produces more storm runoff than other silvicultural treatments, such as chopping or shearing alone, the runoff amounting to 10 times the volume on undisturbed watersheds. This severe treatment with soil-compacting heavy equipment exposes the mineral soil to four times the impact of the force of the raindrop than where cover remains on the land. Nutrient losses are also high. The impact of harvests, in the absence of site preparation, seldom exceeds 3 years.[25]

Figure 9.12 Helicopter logging. Four logs are cabled together for aerial skidding to salvage beetle-killed pines or to remove hurricane-downed, fire-hazard, windthrown trees without otherwise disturbing the site in a wilderness area. (Texas Forest Service photo by R. Billings)

Even rubber-tired skidders increase bulk density by their compaction and, thereby, reduce air and water pore space and infiltration rates of water movement into surface horizons. As long as 12 years might be required for soils so affected from tree-length logging with this heavy equipment to return to normal. Survival and growth of pines planted on such sites are probably affected for at least 5 years. Disking the soil greatly expedites restoration.[26]

Truck-mounted cranes used in thinnings and selection harvests minimize damage to the soil. The mobile single-drum yarder with a 30-foot swing boom doubles as a log loader after trees are grappled from the stand. To protect watersheds, these machines and animal skidders, though costly, may be desirable.

Streamside buffer zones that exclude logging are essential if water courses are to remain relatively free of sediment. Poor logging practices and the accelerated decomposition of the forest floor immediately adjacent to harvested stream banks encourage erosion and subsequent discharges of mineral soils into creeks.

Sediment predictions are possible, but not by the universal soil loss equation used by agronomists. Forest soils behave differently, principally because of the heterogeneous soil surface conditions left by harvesting, site preparation, planting practices, and survival. As with agricultural cropping, however, rainfall erosivity, soil erodability, and slope of the land affect sedimentation.[27] (The universal soil loss equation is $A = R\ K\ L\ S\ C\ P$, where A = total soil loss in tons per acre per year, R = rainfall index, K = erodability, L = length of slope, S = degree of slope, C = crop factor (kind of crop grown), and P = conservation practice.)

RANGE FOR DOMESTIC LIVESTOCK

CATTLE

Production of herbaceous plants for feeding domestic livestock has long been an established practice in southern forests, probably since the earliest days of Caucasian entry. The South's pineries and bottomlands are not the range forest of the West, where cattle vie with sheep for parcels of open park-like woodlands on which to graze for certain months of the year. As clearcutting and steam-donkey skidding of the South's virgin forest took all of the large trees and knocked down small

Figure 9.13 Integrating grazing, wildlife, gum naval stores production, and timber management. This stand of second-growth longleaf pine with a favorable grass cover provides herbage for cattle as well as habitat for wild turkey and bobwhite quail and trees for gum and fiber. This stand arose from seed following destruction of the earlier stand by cyclone-force winds. (USDA Forest Service photo)

ones so that second-growth stands did not develop, a cover of bluestem grasses resulted. Cattle, already ranging the Coastal Plain forests for over 300 years, naturally migrated to these cutover areas. Cattlemen encouraged continuation of the herbaceous cover by frequent and indiscriminate burning of the woods.

Most grazing in the southern woods is in forests of longleaf and slash pines. Prior to establishment of seedling stands, fire and grazing together maintain a prairie-like ecotype. Several species of bluestem grasses predominate, adequately sustaining a cow on as little as 13 acres, though twice that acreage is more typical. Burning these grasslands encourages cattle to congregate. As the vegetation is consumed by fire, nutrient minerals contained in the plant ash quickly leach into the soil with rainwater. There the roots of grasses absorb those mineral elements, providing nutritional forage for the grazing animals. As fire improves forage nutrition, cattle migrate to such sites, where they may then trample tree seedlings.

Herbaceous food plants grow best on sites that were burned prior to chopping of the logging slash and brush. These grasses, principally *Andropogon scoparius* and several species of *Panicum*, provide food for both cattle and deer. Herbage production is also encouraged by thinning and prescribed burning.[28]

After pine seedlings germinate from seed, grazing must be curtailed, lest animals trample young trees or, if forage is inadequate, eat or nibble them. Dipping seedlings at planting time in cattle repellents discourages browsing. After seedlings have been established beyond injury by trampling or browsing, the worst problem for the trees is "riding down" saplings as the animals rub and scratch their hides. A 3-inch diameter bole can be bent nearly to the ground.

Cattle may also girdle trees, the cloven hooves scraping off a portion of the bark from around the stems and thereby reducing vigor and growth.[29] Saplings may be denuded to a height of 8 feet. Terminal buds seem to be considered a delicacy.

Grazing may expose soil to raindrop compaction and erosion. Too-severe compaction results in stagheaded trees, the crowns resembling elk antlers. Trees so weakened become easy prey for insects and diseases. Too much compaction also restricts water and air movement into and through the soil profile, when the diminished moisture and air reduces tree vigor.

Heavy grazing seems not to affect total stand volumes, as the fewer trees that reach harvest size in grazed areas will be of larger size. These larger trees reach maturity earlier.[30]

Heavy grazing prior to planting pines may improve natural regeneration. Trampling prepares the site by reducing the broadleaf vegetation that competes with grasses and pines. Hoof prints provide a favorable microsite for receiving and germinating pine seeds as well as those of grasses and forbs. In pond pine forests, especially, trampling disturbs surface litter, permitting seeds to reach a moist layer of soil for prompt germination. Browsing and trampling these stands reduce the amount of switch cane and brush that compete with the conifer seedlings for light.

Woodland pastures planted with ryegrass must be grazed, lest the grass overtop and crowd out pine seedlings. Electric fencing placed over rows of seedlings provides some protection for the pines, guiding the cattle into grassy strips between the rows of trees.

Subterranean clover enhances beef production in loblolly pine stands grazed by cattle. This species has a remarkable ability to recover from cattle browsing and trampling, though such destruction may severely injure trees under a year old. Even that effect can be reduced by stocking adjustment, water distribution, and salt placement. As a general rule, grazing young stands should be prohibited before early May, and herds then held to a carrying capacity of one cow per acre per month (Animal Unit Month, or AUM) when good grass is available in open areas.[31]

Cattle browse shrubs as well as grazing grasses and forbs. Saw palmetto, myrtle, sweetbay, and blackgum are of some importance. While indigestible lignin in browse is high and digestible carbohydrate low, crude protein exceeds that required for the average cattle diet, especially in winter.[32]

Cattle should be removed from forests where tree basal area exceeds 50 square feet per acre. Grazing value is negligible where 35% of the ground is shaded at noon.

In southern pine and hardwood forests, nutritional quality is more important than quantity of forage in determining the land's carrying capacity. The higher quality of broadleaf tree browse over herbaceous forage explains why cattle sometimes prefer woodlands to adjacent openings.

Farmers and ranchers provide supplementary feed for cattle grazing in southern pine forests. These cattlemen also improve the range by prescribed burning, clearing brush, seeding grasses and forbs, nutrient fertilization and confining the number of domestic animals to the carrying capacity of the site.

Where fire is excluded, a mantle of litter several inches thick soon develops, smothering grass, providing food for soil fauna, and increasing soil porosity. With fire exclusion, too, species like Curtis dropseed and pineland three-awn persist because the leaf meristems, running underground, are insulated by a tightly packed mass of leaf sheaths. Both of these bunch grasses are semi-evergreen perennials, their ligneous, decay-resistant litter suppressing other more-valuable herbaceous species. Fire-follower plants, the most important of which are bluestems, lopside Indiangrass, panicums, and trinius three-awn, disappear about a decade after fire exclusion begins.[33]

While fertilization stimulates grass and forb growth, economics makes application in southern forests seldom worthwhile. However, cobalt has been found lacking in woods-grazed cattle. The element, not required even in micro-quantities for plant growth, is absorbed by blackgum trees. Foliar analysis of this tree serves to indicate the element's deficiency or sufficiency for cattle.[34]

Forage in slash pine plantations varies with the microsite. Soon after site preparation, sedges and forbs arise most abundantly, giving way to grasses; by the fifth year, shrubs become dominant and remain for a few more years. In the absence of fire, accumulated dead vegetation is the principal biomass, excluding grasses and forbs. If grazing is to be a use of a planted forest, furrowing and bedding prior to planting should be discouraged; on these culturally imposed microsites, forage is less than that in the "flats," those areas that lie between the elevated beds and plowed furrows.[35]

Grazing capacity determinations, without considering browse, are determined for an 8-month growing season, typical of the Coastal Plain, by the formula:

$$\text{cow-months} = \text{pounds of green grass} / 3000.$$

The formula provides 3000 pounds of green grass per month or 100 pounds per day, about 40% of which is utilized. One animal for 50 acres is typical for well-stocked stands of longleaf pine.

Old-growth forests produce about 600 pounds of forage per acre by midsummer; more grows later, but it is less palatable and less nutritious. In wet-site stands, such as pond pine, summer grazing capacity of one cow on about 15 acres is appropriate when the trees are well above the browse line. While grass production in slash pine forests exceeds 1400 pounds (air dry) per acre in plantations under 5 years of age; by age 15, herbage does not exceed 100 pounds per acre.

Cattle grazing in shortleaf pine forests may occur in Ozark and Ouachita mountain stands. There, beef production is a minor by-product of multiple-use management. For all pine sites, and where cattle and timber must be jointly produced, supplemental feeding reduces damage to the trees, but winter exclusion of cattle is preferable.

Grazing capacity for upland hardwood forests is extremely low. Where it is essential to the economy of farm woodlot owners, small tracts best suited for this purpose should be converted to improved pasture, for native shrubs are undesirable food and rhododendron is toxic to cattle. Palatable herbs are totally consumed in their first growing season, and unpalatable plants then enter the biome to disrupt natural succession.

In the 1960s, congressmen could get federal forest supervisors in the South transferred for initiating grazing fees on national forests; by the 1980s, supervisors could not entice cattlemen to use the woods for unimproved pasture. Abundant lands once planted in cotton were by then producing quality beef raised on nutritious coastal Bermuda and other hybrid grasses. Passing of laws that prohibit open-range cattle grazing and the high cost of fencing also encouraged the demise of the practice of grazing in the southern woods.

OUTDOOR RECREATION

As recently as the 1960s, foresters often were apt to say, "Why spend money on recreation in southern Coastal Plain forests?" Chiggers (the infamous redbugs), pit vipers, colorful coral snakes, ticks, heat, and humidity drive people from picnic areas and cam grounds, while the rapid growth of greenbrier, poison ivy, honeysuckle vines, and a multitude of brushy shrubs make the maintenance of hiking trails costly. This attitude prevailed especially if the foresters had previously labored or camped in the woodlands of the North or West. (The North of course has its mosquitoes, no-see-ums, and black flies.)

Several things changed that attitude. Camping gear that includes lightweight one-piece tents with the floor sewn in, self-contained recreational vehicles, and the construction of dammed reservoirs surrounded by woodlands that together provide aesthetically pleasing recreation sites stimulated the pleasure migration of small-town and city people to the Great Outdoors. The federal Land and Water Conservation Trust Fund enabled purchases of parklands by the states and the improvement of recreation areas on national forests in the region. Improved water and sewer systems

Figure 9.14 Problems for forest recreation managers include insistence by campground users that their cars be in the campsite, hanging lanterns that burn the bark and injure the trees; building fires outside of fireplaces; and failure to clean the area. Compacting soil through overuse is even more devastating to the site. (Texas Highway Department photo)

in public campgrounds were accompanied by electrical connections for vehicle campers. Soon the Forest Service placed visitor-information specialists (the counterpart to national park-ranger naturalists) at many of its campgrounds to encourage campers to become more familiar with the woodlands and their management.

Neither the high cost of motor fuel, as occasioned by the 1973 petroleum crisis, nor swings in the economy diminish the use of the southern woods for recreation. This is further evidenced by the development of private campgrounds, leasing of condominiums in wooded areas, and the purchase of second-home sites (encouraged by favorable tax treatment of the mortgage interest). Some absentee owners hold forest land solely for a place to "escape," others for its aesthetic quality, while some afford a private hunting preserve.

Recreational Hunting

The rapid growth of hunting leases, especially on lands belonging to the wood-using industries, encourages dual-use forest land management. Where, until the 1980s, most companies were pleased if leases paid the taxes on the land, now leases can earn 10 times the tax assessment. This enables employment of wildlife managers whose skill in improving populations of quality wildlife enables owners to charge even higher lease rates for sport-hunting privileges.

Where game is the recreational use, silvicultural treatments will be compromised between fiber production for sawtimber and pulpwood and maintenance of optimum vegetation for maximum animal populations of high quality. Sport hunters no longer bag any buck, they wait for the high-

Figure 9.15 Forests for Pleasure. The Great Smoky Mountains National Park along the Tennessee–North Carolina boundary receives thousands of visitors each year. Cars convoy bumper-to-bumper during the height of the autumn coloration as they move at a snail's pace over the scenic range. (National Park Service photo)

quality 10-pointer to appear. If they hunt on leased land, lessees expect the owner to manipulate the vegetation to produce wide, many-tined racks on the deer they pursue. Leases often exceed $500 per gun (1989) and trophy racks of white-tail deer $4000. Elaborate lodging is included in the rate. Now those with doctorates in wildlife management supervise these hunting preserves, carefully manipulating vegetation and controlling big-game inventory.

Harvest Systems

Management of recreational lands depends on the principal use or uses. Many campers prefer broadleaf species over the coniferous forest, the former providing more shade, more variety, and more autumn coloration. But in the highest reaches of the Appalachian Mountains, Fraser fir, red spruce, and eastern hemlock are favored. No matter the species and its silvical characteristics, foresters utilize selection harvests (often amounting to thinnings), if the woodland is to be enjoyed for recreational pursuits, at the cost of lower wood-fiber yields.

Clearcutting irritates people offended by its insult to the eye, while selection regeneration is more costly in both the short and long term. This method, in contrast to clearcutting, leaves minimum ugly logging slash. Dead snags and non-merchantable stems left by the loggers remain hidden from view. To illustrate, yellow-poplar requires full sunlight and an adequate seed source for its natural regeneration. The species does not enter ecological succession in the shade of an overstory, including its own. It is also one of the most economically valuable trees in most of the mountains of the East, growing straight, tall, and fast in dense, even-aged stands that exhibit colorful foliage in the autumn. A silviculturist's choice might be to clearcut a cove to produce another

Figure 9.16 An ancient baldcypress tree. Protected for its historical and scenic value, this tree now grows more than 150 feet from the river's edge, by which the seed had germinated. The old giant continued to live on a less hydric site after the stream changed its course.

generation of this worthwhile species. The wildlife manager's choice might be to employ a selection harvest, knowing that an uneven-aged oak and hickory stand will follow. In this event, the new trees likely bring lower prices when eventually marketed and grow more slowly, delaying the opportunity for later financial returns. Environmental preservationists prefer to leave the stand to decay and to allow ecological succession to take its course, producing a woodland not necessarily of scenic beauty. Park managers may choose aesthetic harvests, a type of selection accompanied by slash disposal using chipping machinery, in recreation areas.

Wilderness

Preserving a forest of natural second growth may be a proper concern. Left alone, it approaches the climax forest in perhaps 100 years. Perhaps to set it adrift is its highest use, thus satisfying a nonmaterial need of humanity. This is especially so for the Appalachian plateaus where broadleaf species cover about 90% of the forest. The prevailing original forests of the Appalachian Mountain provinces were of mixed mesophytic species, an assortment of moisture-loving, mostly shade-tolerant, commercially high-value trees: beech, maple, ash, basswood, black walnut, hemlock, and Ohio buckeye.

The southern pines were minor components of the original forest except on isolated xeric or recently burned-over sites. These species have increased since settlement, particularly on abandoned agricultural fields. Land clearing and high-grading for decades reduced the proportion of the economically more-valuable species in the region. But trees grow rapidly; vast areas of second-growth stands now reaching maturity are of the originally aesthetically pleasing species. Hence, congress has set aside considerable acreages of these forests on federal properties as wilderness, a land classification on which timber harvests are prohibited. Many of these stands were only about 50 years old when so designated.

Figure 9.17 Tupelo gum trees in a mini-wilderness. Now astride a small oxbow lake that floods and dries out with the seasons, the moisture-loving broadleaf trees seeded-in in years past along the bank of a then-present stream.

Wilderness, as a recreational use of the forest, requires special care. As southern forests are readily accessible, in contrast to the rugged remote mountainous areas of the West, they easily may be "loved to death." A preserved woodlands, so loved that it is set aside to look upon and hike into, can soon be trampled by people, destroying that which those very folks sought to preserve.

Perhaps somewhere in the high mountains of the South lives a biome that is irreplaceable, not unlike the wind-deformed elfinwood of Engelmann spruce in the high krummholz of the Colorado Rocky Mountains, a conifer that does not sexually reproduce in today's climate there. Perhaps the ancient trees were established in an earlier time of milder weather at tree-line elevations. They then spread across the land by air layering (a form of asexual reproduction). Great care must be exercised in managing such sites, using management that involves protection from mankind's intrusion more than from intentional vegetative manipulation.[36]

Recreation is usually the aim of those who want wilderness areas set aside. Maintenance of biological diversity—protection of gene pools—may be a nobler purpose. Future medicinals could come from them as many pharmaceuticals in the past have been isolated from wilderness vegetation. For such unique situations, policies inevitably will be formulated that will provide the greatest range of benefits to the largest possible number of people. Wise management depends on the particular woodland and the wishes of its users, although the users often differ in their objectives.

Some species should be maintained in the southern forest for their aesthetic beauty. Understory trees like flowering dogwood, redbud, and American holly are examples. The first two notably in legend commemorate the Easter season—for holly, it's Christmastime. Its red berries reminded the pilgrims, landing on Cape Cod the week before Christmas in 1620, of the English holly, a symbol of the Advent season in England and Europe. The easily transplanted shade-tolerant (although its crown area is reduced in shade) broadleaf tree retains its position in the woodlands by sprouting. Nectar from its flowers make good honey, while its branches and berries provide browse and food

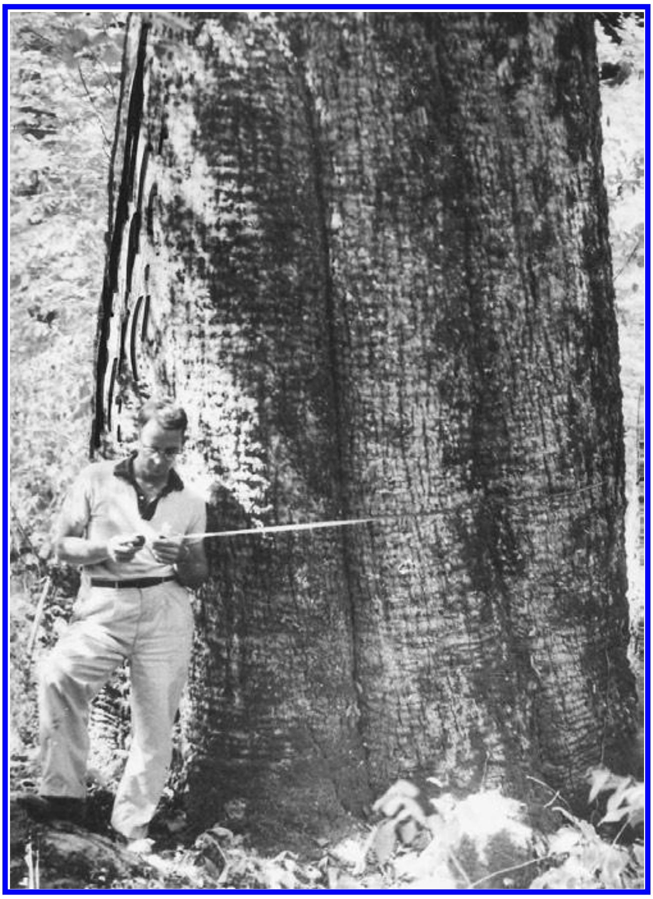

Figure 9.18 A yellow-poplar, one of the largest specimens of the species, in the Joyce Kilmer Wilderness. The World War I poet would be satisfied that this stand in a dark cove will provide for many "nests of robins in its hair."

for a variety of wildlife. But, beware, the tree is dioecious; female flowers and, thus, berries occur only on certain stems.[37]

GUM NAVAL STORES

Slash and longleaf pine forests, extending in a 100-mile-wide coastal belt from South Carolina to East Texas, supplied a large portion of the world's rosin and turpentine from colonial times until the 1950s. The industry remains important in export markets, but reduced demand—as synthetic chemicals replace oleoresins in paints and industrial processes—and the replacement of many longleaf pine stands with loblolly pines following the cut-out-and-get-out harvests have diminished production.

Turpentine farmers begin by smoothing the bark, attaching galvanized gutters and aprons with double-headed nails (for convenient removal when the gutters are periodically raised). Then "cups," much like breadbaking tins, are hung on the trees below the aprons. Workers raise these, too, as chipping progresses up the boles of the trees.

Removal of strips of bark, looking like 3/4-inch-wide chevron stripes, are made at 2-week intervals over a 16-week period on one side of smaller boles and on two to three faces of larger

Figure 9.19 A planted slash pine stand unselectively chipped, or streaked, for gum naval stores. Wood above the turpentine scars is useful for pulp and lumber; that of the base will likely have too much resin for paper manufacture, but may be sawn into low-quality lumber. The stand is about 20 years old and has been worked for 3 years. (authors' collection)

stems. On trees with more than one face worked, laborers maintain living bark bars of at least 7 inches of a tree's circumference. Chipping, rather than hacking, preserves the round trunk for lumber (although some mills will not accept these butt cuts, more for fear of metal in the wood than for the heavy resin impregnation). Chipping leaves faces 40 to 50 inches high by the end of the second year of being worked.

Naval stores-treated pines sometimes have "dry-face," a condition in which gum ceases to flow. In severe cases, pitch-soaked areas, called cambial blisters, or internal lesions, occur above and beside the dry areas. Chipping trees with short crowns aggravates the condition.

Gum naval stores production is usually integrated with silvicultural treatments. Only some of the pines in the stand should be utilized for resin, and these over short periods of 2 to 3 years. Insect infestations increase and gum yields decline if chipping continues after that time.

Chipping longleaf and slash pines precedes either intermediate cuttings or final harvests. Trees 9 inches dbh or larger, selected to be chipped 3 to 8 years prior to harvest, enable production of high volumes of high-quality gum and also harvests of poles, piling, and sawtimber. Economically satisfactory operations have been conducted in plantations as young as 13 years. Trees to be worked should have a crown length more than 40% of the tree's height and diameter growth faster than 8 rings per inch. Turpentining reduces tree growth as much as 25% for conventional front-face chipping, depending on the width of the wound. Gum yields, however, seem unrelated to tree growth rate before chipping, to site index, or to tree age.[38]

Thirty trees produce about 10 barrels of resin during the period of use. Longleaf pines yield about 50 barrels per "crop" of 10,000 faces more than do slash pines on similar sites. Each increase in the average stand diameter of 1 inch increases gum yields by about 25 barrels per crop. In turn, each 10% increase in crown to height ratio improves yields by about 40 barrels per crop.[39]

Spraying sulfuric acid and a patented herbicide on chipped faces stimulates the flow of gum. Laborers spray about 1 ml of 50% concentrated sulfuric acid on the fresh streak, the acid penetrating tissues above the streak, thereby increasing yields by as much as 20%. The acid dissolves the gummy crystals in the wood. Resin in the ducts is released through the phloem by collapsing or disintegrating the ray parenchyma—cells that occlude or line the radial resin ducts in the wood. Dead tissue occurs only within a zone of 3/4 inch, as the cell sap effectively buffers the strong acid. Apparently, the acid does not stimulate internal resin manufacture, but rather enhances its flow.

Yields for the first year following conventional 3/4-inch acid-treated chipping depend principally on the size of the radial resin ducts in the exposed wood, the number of resin ducts per square inch of fresh streak, the crown size, and the viscosity of the resin. Exudation pressures that force gum outward possibly play a role. As air temperatures also account for variation in gum flow, workers delay chipping until the average temperature for a two-week period exceeds 60˚F. Gum is not sap, the watery solution that moves through cells. Cells that yield gum form in the cambium layer just beneath the bark; cells that exude sap are found throughout the xylem. [40]

Although viscosity and gum yield are inherited characteristics, the number and size of the radial resin ducts appear to be inversely related, due to genetic linkage. And because duct numbers and dimensions change rapidly with tree age, there appears little opportunity to improve gum yields by breeding for these attributes. Repeated wounding with the bark-hack partially avoids crystallization of resin or distention of epithelial cells into the lumen of resin canals, thus encouraging sustained flow.

The herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) and paraquat also stimulate the flow of gum in living pines. The latter chemical is painted on a 1-square-inch wound, inducing the resin-soaked xylem to form "lightwood." An application of a spore suspension of *Fusarium lateritium* fungus on fresh wounds also stimulates gum flow. (In nature, the fungus has been found to cause pitch-soaked wood, from which cankers arise.) The fungus may increase the proportional volume of heartwood to sapwood in longleaf pines by 5 to 10%, thereby providing more highly resinous wood from which the gum flows.[41]

Plastic bottles, such as those used for beverages, placed in holes drilled in tree bases substitute for gutters and cups. Gum then drains directly into the containers, allowing no trash or air-borne matter to degrade the resin.

ENERGY FORESTS[42]

We justify the use of the forest for the production of energy as a separate component, even though the wood of the forest finds its way into the marketplace as material. Wood in the multiple-use sense of the word has usually referred to fiber for pulp and solid-wood products. But if again oil is in short supply, natural and manufactured gas is rationed, and coal use is curtailed because of site deterioration where it is surface-mined and air pollution where it is burned, wood may well be intensively grown and harvested to supply power for the needs of people. One cord produces the equivalent heat of almost a ton of lignite or four barrels of oil.

Prior to 1875, wood was the principal energy source in North America. At that time, coal overtook and surpassed wood. Until 1945, wood was still more important than hydropower as a source of electrical energy.

If the solar energy intercepted by forests could be converted with about 1% efficiency, the annual "energy harvest" would be above the present demand for power. By using wood for methanol alcohol or methane gas production, whole trees in "energy plantations" could be utilized, leaving no waste in the woods, and trees too scrubby to be utilized otherwise could be added to the inventory of economically useful forests.

Wood has a special potential because of its negligible sulfur content, which is less than 0.1%. The ash content is also low, yet has some value as fertilizer. Gasification of wood fiber requires less oxygen than does coal and the gas produced has a higher hydrogen to carbon monoxide ratio than does consumer gas made from coal.

Facilities to produce methanol could be small, the operations located near raw-material wood supplies. An intensively managed area of 20 to 40 square miles could sustain a 400-megawatt generating station operating at 34% efficiency (a low value) and 55% load factor (the national average). At current usage rates, this woodland—occupying about the area of forest needed to maintain a pulp mill—would supply electricity for 200,000 people.

In addition to presently noncommercial scrub hardwood forests, as in Texas' and Oklahoma's Post Oak Belt and Cross-Timbers Regions, presently commercial pine–hardwood sites could be designated and managed for this purpose. Slash and sand pines are also candidates for energy production, their biomass potential being well above average. In addition, silage plantations have been suggested. In these, close spacing of 5000 stems per acre allows prompt and maximum site utilization. Harvesting at 5-year intervals, when trees are 25 feet tall, would not require heavy logging equipment. Replanting need not be done, for coppice-forming species like American sycamore or sweetgum would be employed. The well-developed root systems of the severed stems, rich in starch and sugar, encourage rapid growth of the suckers. Whole trees would be harvested, their ash returned to the site as fertilizer. Superior trees for the purpose would be sought.[42]

The Southern Region of the U.S. Forest Service has a circular slide rule that enables rapid calculating of energy equivalents. For instance, if the price of natural gas is $1 per thousand cubic feet, the energy buyer could pay $17.70 per ton of oven-dry wood to get the equivalent heat.[43]

SUMMARY

In this chapter, the reader hopefully has noted how the South's forests serve many purposes. Wildlife, both game and nongame, are protected and their habitat enhanced at various stages in the life of the woodland from regeneration until the final harvest. Forest management and mismanagement influences fishing, canopy removal at harvest time warms the waters—sometimes detrimentally—and logging that disturbs streamside soils results in increased turbidity that also harms fish. Reforestation and afforestation reverses these damaging influences.

Not only are fisheries affected, water for human consumption and industrial use may be enhanced or harmed by the way in which the forest is utilized. Logging operations, animal grazing, and human recreation play a role.

While cattle grazing and hog foraging were introduced by the Europeans as they entered the southern forest, except for feral hogs the practices have greatly declined in recent years.

Specialized uses of the southern forest for commodity production, apart from timber, include gum naval stores extraction, wood fiber for energy, and game ranches for the entertainment of sportsmen. These too influence the quality of the forest and affect its utilization for other purposes.

Afterword[1]

Dwindling reserves of non-renewable raw materials heighten the need for increased forest productivity to meet current and prospective demands of the American people. The time lag between initiation of forestry measures and the marketability of wood products resulting from those measures always calls for present action to assure meeting wood requirements for 2 and 3 decades beyond the present. Many Americans have voiced objections to the manner in which forests are being managed to meet the expected demand. Harvesting methods are particularly criticized, as destruction of watersheds, wildlife, and scenery occurs. Organic pesticide use and prescribed burning as timber management practices displease the public because of environmental insults. The South's fastest-growing and most versatile timber trees are ecological pioneer species, usually requiring bare mineral soil and full sunlight for regeneration and growth. They cannot be economically regenerated by systems that remove only a small part of the stand and that do not involve the use of fire and chemicals. While such selection silviculture would minimize disturbance and disruption of non-timber resources, it would either convert stands to less-valuable tree species or require costly means—by chemicals, fire, or machinery—to eliminate competition. Greatly increased consumer prices for housing, paper, and other wood products would result.

Fortunately, there is room for compromise. Productive sites revegetate promptly and erode very little during the temporary denudation between harvest and establishment of reproduction. Clearcutting in small blocks benefits wildlife by increasing the length of timber margins. With prompt regeneration, natural or artificial, scenic values are quickly restored. Thus, intensive, even-aged forestry can be compatible with watershed protection, wildlife production, and outdoor recreation, while in some sensitive situations, timber harvests may be inappropriate.

Users of forest resources—those who live in houses, read books, wear clothes, and use energy—may be unaware that they force environmental insults upon the land. So all Americans face decisions now for which they must eventually pay a price. The choice is to endorse forest policies that will ensure increased and efficient wood production from the best forest sites while accepting minimal reductions in other amenities. Alternatives that divert commercial forest from efficient wood production will be costly in dollars and in energy resources spent for substitutes from nonrenewable raw materials.

There is an old dichotomy that partitions man's attitudes about the forest and its wilderness character into two compartments labeled "friend" and "foe." The primeval forest as a thing of beauty is, like the company of a friend, to be enjoyed. Valued friends are protected from all who would destroy them. To the tiller of the ground and the pioneer settler fearful of two- and four-footed adversaries, the forest is the foe, which must be eliminated to protect those who fear it. Loggers and their bosses cutting the forests of early America have oftentimes been classed with the latter group. Conservation historians picture them as ruthless barons who exploited the wilderness as a conqueror does his enemy. Recent care of the forest resources of the South, however, suggest that these lands, whether viewed for their aesthetics or used for their wood fiber, are to be appreciated as a friend of Man. Philosopher Henry David Thoreau doesn't seem to have been aware of the friend–foe argument, but certainly he would have recognized its inconsistency, for he wrote lyrically of sylvan nature while hewing logs from the very forest of which he wrote, for the walls of the cabin in which he would live.[2]

Eric Sloan, another New Englander and a master with pen at both the easel and the writing desk, entitled a historical work *Reverence for Wood*. Interlaced with his prose are drawings of products from trees.[3] Following a listing of things made from wood, he quotes Joseph Jenks, designer of the Massachusetts Bay Colony flag, "What better thing than a tree, to portray the wealth of our country?" Sloan, I believe, grasped the underlying attitude of our pioneering forebears who, while purchasing boards from the alleged barons, reverenced wood—and thus the woods—for its practical usefulness for survival.

The dichotomy in attitude is older than the chroniclers' first claims of land abuse in North America. Roderick Nash attributes various views in the biblical narratives to man's desire to enjoy the wilderness for its beauty, while fearing for his safety when wandering therein.[4] Joel (2:3) described Eden as a garden, and later—though after The Fall—as a desolate wilderness. Whether The Fall resulted in the dichotomy of attitude is a brief for another time, but the wilderness, either forested jungle or parched desert, would now "do you in" if not subjected to man's manipulation for man's benefit.

But we like to think we are more advanced in our reasoning than those who roamed Joel's garden both before and after The Fall. The forest can be enjoyed—though at different seasons in its ecological cycle—for its beauty, its utility, and the beauty of its utility. No question of the beauty of trees or a tree. Joyce Kilmer ("Only God can make a tree") and Henry Wadsworth Longfellow ("Under the spreading chestnut tree") acknowledge for us this gift of pleasure. But the handle for a pick or the soft paper that replaced the rough cob may come from the trees in that same woodland cathedral. And are not a Stradivarius and a graphite pencil from that same resource?

The forest is no longer the feared wilderness of Joel's time nor the pristine primeval woodland of Thoreau's lonely vigil and vision on the shores of a pond. Joel's jungle needed to be tamed; Thoreau's to be framed. With wise management, the forest that is today harvested for the building of houses and the printing of books will, after a few tomorrows, be enjoyed for its beauty. And as population soars and the land base on which to grow necessary wood diminishes, the forest now loved for its scenic pleasure must take its turn in the rotation as a woodland to serve. Ugly for a while; but in the providence of a God who understands ecological succession far better than do His creatures, beauty will return.

1. Much of this Afterword is gleaned from Walker, L.C., Ecologic Concepts in Forest Management, *Journal of the American Scientific Affiliation* 32, 204, 1980.
2. Thoreau, H.D., *Walden*, New York, Dodd, 1854.
3. Sloan, E., *Reverence for Wood*, New York, Funk, 1974.
4. Nash, R., *Wilderness and the American Mind*, New Haven, Yale University Press, 1967.

APPENDIX A

Scientific Names of Trees Mentioned

Common Name	Scientific Name
American beech	*Fagus grandifolia*
American chestnut	*Castanea dentata*
American holly	*Ilex opaca*
American sycamore	*Platanus occidentalis*
Arizona cypress	*Cupressus arizonica*
ash	*Fraxinus* spp.
Ashe juniper	*Juniperus asheii*
Atlantic white-cedar	*Chamaecyparis thyoides*
Autumn olive	*Olea* spp.
balsam fir	*Abies balsamea*
basswood	*Tilia americana*
bay magnolia	*Magnolia* sp.
bear oak	*Quercus ilicifolia*
birch	*Betula* spp.
bitter pecan	*Carya aquatica*
black birch	*Betula lenta*
black cherry	*Prunus serotina*
black locust	*Robinia pseudoacacia*
black oak	*Quercus velutina*
black walnut	*Juglans nigra*
black willow	*Salix nigra*
blackgum	*Nyssa sylvatica*
blackjack oak	*Quercus marilandica*
boxelder	*Acer negundo*
Carolina hemlock	*Tsuga caroliniana*
Chapman oak	*Quercus chapmanii*
cherry	*Prunus* spp.
cherrybark (red) oak	*Quercus falcata* var. *pagodaefolia*
chestnut oak	*Quercus prinus*
choke cherry	*Prunus virginiana*
dogwood	*Cornus* spp.
dune holly	*Ilex* sp.
eastern cottonwood	*Populus deltoides*
eastern hemlock	*Tsuga canadensis*
eastern redcedar	*Juniperus virginiana*
elm	*Ulmus* spp.
flowering dogwood	*Cornus florida*
Fraser fir	*Abies fraseri*
gray birch	*Betula populifolia*
green ash	*Fraxinus pennsylvanica*
hackberry	*Celtis occidentalis*
hickory	*Carya* spp.
hickory pine	*Pinus pungens*
holly	*Ilex* spp.
live oak	*Quercus virginiana*
loblolly pine	*Pinus taeda*
longleaf pine	*Pinus palustris*
mesquite	*Prosopis juliflora* *Prosopis* spp.
mountain ash	*Sorbus americana*
mountain laurel	*Kalmia latifolia*
myrtle oak	*Quercus myrtifolia*
northern red oak	*Quercus borealis*

Common Name	Scientific Name
Nuttall oak	*Quercus nuttallii*
oak	*Quercus* spp.
overcup oak	*Quercus lyrata*
persimmon	*Diospyros virginiana*
pignut hickory	*Carya glabra*
Pinchot juniper	*Juniperus pinchotii*
pitch pine	*Pinus rigida*
poison ivy	*Rhus toxicodendron (R. radicans)*
pond pine	*Pinus serotina*
pondcypress	*Taxodium distichum var. ascendens*
post oak	*Quercus stellata*
red maple	*Acer rubrum*
red oak	*Quercus rubra*
red spruce	*Picea rubens*
Rhododendron	*Rhododendron maxima*
river birch	*Betula nigra*
sand live oak	*Quercus virginiana* var. *germinata*
sand pine	*Pinus clausa*
sassafras	*Sassafras albidum*
scarlet oak	*Quercus coccinea*
scrub hickory	*Carya floridana*
scrub oak	*Quercus* spp.
scrub pine	*Pinus virginiana*
silver maple	*Acer saccharinum*
swamp ironwood	*Cyrilla racemiflora*
shortleaf pine	*Pinus echinata*
Shumard oak	*Quercus shumardii*
slash pine	*Pinus elliottii*
slippery elm	*Ulmus rubra*
soft maple	*Acer rubrum* *Acer saccharinum*
Sonderegger pine	*Pinus sondereggeri*
sourwood	*Oxydendron arboreum*
S. Florida slash pine	*Pinus elliottii* var. *densa*
baldcypress	*Taxodium distichum*
southern magnolia	*Magnolia grandiflora*
southern red oak	*Quercus falcata*
southern redcedar	*Juniperus silicicola*
spruce pine	*Pinus glabra*
sugar maple	*Acer saccharum*
sugarberry	*Celtis laevigata*
sumac	*Rhus* spp.
sweetbay	*Magnolia virginiana*
sweetgum	*Liquidambar styraciflua*
sycamore	*Platanus occidentalis*
table-mountain pine	*Pinus pungens*
tupelo gum	*Nyssa aquatica*
turkey oak	*Quercus laevis*
Virginia pine	*Pinus virginiana*
water oak	*Quercus nigra*
water tupelo	*Nyssa aquatica*
waxmyrtle	*Myrica cerifera*
white ash	*Fraxinus americana*
white oak	*Quercus alba*
white pine	*Pinus strobus*
willow oak	*Quercus phellos*
yellow birch	*Betula lutea*
yellow-poplar	*Liriodendron tulipifera*

APPENDIX B

Scientific Names of Shrubs and Herbaceous Plants Mentioned

Common Name	Scientific Name
alfalfa	*Medicago sativa*
bay	*Magnolia virginiana*
bermuda grass	*Cynodon dactylon*
blackberry	*Rubus* spp.
bluegrass	*Poa* spp.
Blueberry	*Vaccinium* spp.
bluestem grass	*Andropogon* spp.
broomsedge	*Andropogon virginicus*
bull nettle	*Cnidoscolus stimulosis*
carpet grass	*Axonopus affinis*
clover	*Lespedeza* spp.
clubmoss	*Lycopodium* spp.
corn	*Zea maize*
currant	*Ribes* spp.
Curtis dropseed	*Sporobolus curtisii*
French mulberry	*Morus* sp.
gallberry	*Ilex glabra*
gooseberry	*Ribes* spp.
honeysuckle, Japanese	*Lonicera japonica*
huckleberry	*Gaylussacia* spp.
kudzu	*Pueraria lobata*
Indian lovegrass	*Sorghastrum nutans*
milk pea	*Galctia* spp.
mountain laurel	*Kalmia latifolia*
panicum	*Panicum* spp.
pineland three-awn	*Aristida stricta*
plume grass	*Erianthus ravennae*
poison ivy	*Rhus radicans (R. toxicodendron)*
poor joe	*Diodia* sp.
prairie bunch grass	*Andropogon scoparius*
queen's delight	*Stillingia sylvatica*
ragweed	*Ambrosia* spp.
rattlebox	*Crotalaria rotundifolia*
reindeer moss	*Cladonia* sp.
Rhododendron	*Rhododendron maxima*
rosemary (dropseed)	*Sporobolus junceus*
saw-palmetto	*Sabal minor (Serenoa repens)*
sedge	*Carex* spp.
subterranean clover	*Trifolium subterraneum*
sunflower	*Helianthus* spp.
sweetbay	*Magnolia virginiana*
switch cane	*Arundinaria tecta*
titi	*Cliftonia monophylla*
trailing bean	*Epigaea repens*
trinius three-awn	*Aristida* spp.
viburnum	*Viburnum* spp.
waxmyrtle	*Myrica cerifera*
wiregrass	*Poa compressa*
yaupon	*Ilex vomitoria*

APPENDIX C

Scientific Names of Insects Mentioned

Common Name	Scientific Name
ambrosia beetle	*Scolytidae* family
aphid	*Aphididae* family
bagworm	*Thyridopteryx* spp.
balsam wooly aphid	*Adelges piceae*
black turpentine beetle	*Dendroctonus terebrans*
centipede	*Chilopod*a class
chermid	*Adelges* spp.
Columbian timber beetle	*Corthylus columbianus*
cone beetle	*Ernobius* sp.
cottonwood leaf beetle	*Chrysomela scripta*
cottonwood root borer	*Plectrodera scalator*
cottonwood twig borer	*Gypsonoma haimbachiana*
eastern tent caterpillar	*Malacosoma americanum*
elm span worm	*Ennomos subsignarius*
European elm bark beetle	*Scolytus multistriatus*
flat-headed pine borer	*Buprestus* spp.
gall-forming cynip	*Cynipoidea* family
gypsy moth	*Lymantria dispar*
harvester ant	*Pogonomyrmex* spp.
hemlock borer	*Melanophila fulvoguttata*
hemlock looper (inch worm)	*Lambdina fiscellaria*
hickory (oak) twig girdler	*Agrilus angelicus*
hickory spiral borer	*Agrilus arcuatus*
ips beetle	*Ips* spp.
Lady beetle	*Coccinellidae* family
leaf-chewing beetle	*Systena marginalis*
maggots (flies)	*Itonididae* spp.
moth	*Lepidoptera* order
Nantucket pine tip moth	*Rhyacionia frustrana*
needle miner	*Lepidoptera* spp.
nut weevil	*Curculio* spp.
pales weevil	*Hylobius pales*
pine webworm	*Tetralopha robustella*
pitch moth	*Dioryctria* spp.
pitch-eating weevil	*Pachylobius picivorus*
red turpentine beetle	*Dendroctonus valens*
redheaded pine sawfly	*Neodiprion lecontei*
sawfly	*Neodiprion* spp.
scale	*Coccidae* family
seed-eating worm	*Laspeyresia* spp.
short-tailed cricket	*Oecanthus* spp.
snow-white linden moth	*Ennomos subsignarius*
southern pine beetle	*Dendroctonus frontalis*
southern pine sawyer	*Monochamus titillator*
spider mites (red spider)	*Tetranychidae* family
spruce budworm	*Choristoneura fumiferana*
tent caterpillar	*Melacosoma* spp.
Texas leaf-cutting ant	*Atta texana*
thrips	*Gnophothrips fuscus*
tuliptree softscale	*Toumeyella liriodendri*
turpentine borer	*Buprestis apricans*
white pine weevil	*Pissodes strobi*
wooly aphid	*Homoptera* order

APPENDIX D

Diseases Mentioned and Their Causal Agents (Fungi)

Common Name	Scientific Name
annosus root rot	*Heterobasidion annosum*
	Fomes annosus
blue stain	*Ceratocystis* spp.
	Graphium spp.
	*Ceratostomella ips**
	*Ceratostomella pini**
brown cubical butt rot	*Phaeolus schweinitzii.*
brown rot	*Polyporus* spp.
brown spot needle blight	*Mycosphaerella dearnesii*
	*Scirrhia acicola**
butt rot	*Polyporus schweinitzii*
cedar-apple rust	*Gymnosporanium juniperi-virginianae*
chestnut blight	*Endothia parasitica*
Southern cone rust	*Cronartium strobilinum*
damping off	*Fusarium* spp.
	Rhizoctonia spp.
	Phythium spp.
Dutch elm disease	*Ophiostoma ulmi*
eastern gall rust	*Cronartium cerebrum*
	Cronartium quercuum
heartwood rot	*Collybia* spp.
ink root rot	*Phytophora cambivora*
juniper blight	*Phomopsis juniperovora*
little-leaf	*Phytopthora cinnamomi*
mycorrhiza	*Cenococcum graniforme*
	Glomus spp.
	Pisolithus ectomycorrhiza
	Pisolithus tintorius
nectria canker	*Nectria cinnabarina*
needle blight	*Hypoderma lethale*
	Lophodermium pinastri
needle cast	*Elytroderma deformans*
oak wilt	*Ceratocystis fagacearum*
pecky cypress	*Stereum taxodi*
phloem necrosis	virus, origin unknown
pitch canker	*Fusarium latritium*
	Fusarium moniliforme var. *subglutinans*
pocket rot	*Armillaria mellea*
red heartrot	*Phellinus pini*
	Fomes pini
rust infection	*Cronartium appalachianum*
shoestring fungus	*Armillaria mellea*
southern fusiform rust	*Cronartium quercuum*
	*Cronartium fusiforme**
top rot	*Fomes* spp.
white pine blister rust	*Cronartium ribicola*
white-cedar canker	*Gymnosporangium ellisii*
white-string rot	*Polyporus berkeleyi*
yellow-poplar dieback	*Myxosporium* sp.
	Botryosphaeria spp.

*older classification

Endnotes

Unattributed photographs were made by the authors. Those cited "authors' collection" indicate that they have no assurance as to who made them; they or a colleague might have provided these pictures at any time over a 50-year period.

Chapter 1*

* See for a bibliography of literature citations Walker, L.C. and Collier, G.L. Geography of the southern forest region. Bull. 18. Nacogdoches, Texas: School of Forestry, Stephen F. Austin State University, 1969.

1. Atwood, W.W. *The physiographic provinces of North America*. Ginn Co., New York, 1940; and Fenneman, M.M. *Physiography of the Eastern United States*, McGraw-Hill Book Co., New York, 1938.
2. *Climate and Man*, Yearbook of Agriculture, 1941, and Geiger, R., *The Climate Near the Ground*, Harvard University Press, Cambridge, 1965.
3. Livingston, B.E. and Shreve, F., *The Distribution of Vegetation in the United States*, Carnegie Institute Publication 284, Washington, 1921.
4. *Climate and Man,* op. cit., and Trewartha, G.T., *The Earth's Problem Climates.* Univ. Wisconsin Press, 1961.
5. *Climate and Man*, op. cit.
6. *Soils,* USDA Department of Agriculture Yearbook, 1957.
7. Kuchler, A.W., *Potential Natural Vegetation of the Conterminous United States,* Washington: American Geographical Society, 1964; and E.L. Braun, *Deciduous forests of Eastern North America,* New York, McGraw-Hill Book Co., 1950. Forest cover types are those described in *Forest Cover Types of North America,* Eyre, F. H. Ed., Washington, Society of American Foresters, 1980.
8. Placing the Hill Country of Central Texas—including the Lost Pine stands of loblolly pine, its post oaks, junipers, and mesquite—in the Coastal Plain section of this narrative is for convenience. The narrow zone is immediately to the west of the Plain.
9. Grissom, P. H. The Mississippi delta region. In (*Soil*) Yearbook of Agriculture, Washington, U.S. Department of Agriculture, 1957.
10. Note further in (*Soil*) Yearbook of Agriculture, Washington: U.S. Department of Agriculture, 1957.
11. Nitrogen, of course, is always the exception, its occurrence in the soil being related to lightning strikes, the presence of legumes, fire history, and recycling of foliage.
12. The Appalachian Trail was uninterrupted until Congress conveyed it by condemnation to the U.S. Government in the National Trails legislation of 1966. After passage, many farmers, industrial landowners, and others who held title to the land fenced the trail, until the federal government acquired the right-of-way by purchase.
13. Shanks, R.E., Climates of the Great Smoky Mountains, *Ecology* 35, 354, 1954.
14. Li, B., Lett, J.B. and Weir, R. J., A preliminary study of geographic variation in Fraser Fir seedlings, *Southern J. Applied Forestry* 12(2), 128, 1988.
15. Russell, N.H., The beech gaps of the Great Smoky Mountains, *Ecology* 34, 366, 1953.
16. Cubbage, F.W. and Flather, C.H., Forested wetland area and distribution: a detailed look at the South, *J. Forestry* 91(5), 35, 1993.
17. Walker, L., Bradley, T., and Burkett, V., Characteristics of an old-growth bottomland hardwood forest, in *Wilderness and natural areas in eastern North America*, D. Kulhavy and M. Legg, Eds. Stephen F. Austin State University, 1998.

Chapter 2

1. The author of the Latin binomial probably knew of the species occurrence on sites along the Atlantic coast, for, among the locales of the South, the early plant explorers were likely to visit there first. Along the seaboard following spring rain, perched water stands on poorly drained impervious clay soils. Longleaf pines grow on such sites, though it is not the typical locale for the species. When the water dissipates, as it does during the growing season, the site is xeric; i.e., little available moisture remains in the soil profile. So droughty are these sites that scrub oaks compete with longleaf pine—to the latter's exclusion.
2. The word **serotinous,** in its classical use, is a synonym for **tardy.** Botanists adapted the word to indicate a plant whose flower development is late in occurring or that retains its seeds for long periods rather than dispersing them at specific times of the year. Foresters subsequently adapted the term to suggest a delay in the release of seeds until heat—usually from fire—has dissolved the resin that seals the cone scales or fruit. Cones may remain closed for years—sometimes completely overgrown by newer wood and bark. Heat melts the resinous coating covering the scales that protect the seeds. Scales then open, releasing the winged seeds.
3. The western race of sand pine is primarily confined to Eglin Air Force Base. During the Second World War, President Franklin Roosevelt ordered the Choctawhatchee National Forest, purchased with Clark-McNary funds in the 1930s, transferred to the War Department for use as an air base.
4. As for the loblolly x longleaf pine cross, here is a story, perhaps apocryphal. H.H. Chapman, a Yale forestry professor, worked with his students in the longleaf pine country of Louisiana. There, in a nursery bed with trees growing from seed collected from longleaf pine parents, he noted seedlings emerging from the grass-stage in their first months after germination. The young trees looked like loblolly pine seedlings, yet the female parent was longleaf pine. Subsequently, the hybrid, not uncommonly found in natural forests of the South, was named Sonderegger in mock honor of the state forester of Louisiana. Sonderegger had disagreed publicly with the professor on professional issues, especially over the propriety of using prescribed fire in these woods. When the Yankee academician was asked why he chose his adversary's name for the hybrid, reference was made in the vernacular to the state forester as one whose parental father was unknown. The name stuck. *Pinus taeda* x P. palustris is also *P. sondereggeri.*
5. Boyer, W.D., Heat accumulation: An easy way to anticipate flowering of southern pines, *J. Forestry* 76, 20, 1978.
6. Belanger, R.P., Haden, R.L., and Lennartz, M.R., Potential impact of the southern pine beetle on red-cockaded woodpecker colonies in the Georgia Piedmont, *Southern J. Applied Forestry* 12(3), 194, 1988.
7. Rowan, S.J., Triadimefon controls fusiform rust, *Southern J. Applied Forestry* 10(2), 112, 1986.
8. Sherwood, J.L. and Klarman, W.L., IAA involvement in fungal protection of Virginia pine seedlings exposed to methane, *Forest Science* 26, 172, 1980.
9. Ruark, G.A., Thomas, C.E. , Bechtold, W.A. and May, D.M., Growth reductions in naturally regenerated southern pine stands in Alabama and Georgia, *Southern J. Applied Forestry* 15(2), 73, 1991; and de Steigner, J.E., Pye, J. M. and Love, C.S., Air pollution damage to U.S. forests, *J. Forestry* 88(8), 17, 1990.
10. Skow, T.K., Allen, H.L., and Kress, L.W., Ozone impacts on seasonal foliage dynamics of young loblolly pine, *Forest Science* 38, 102, 1992.
11. Jackson, L.W.R., Radial growth of forest trees in the Georgia Piedmont, *Ecology* 33, 336, 1952; Walker, L.C., Green, R, L., and Daniels, J.M., Flooding and draining effects on slash pine and loblolly pine seedlings, *Forest Science* 7, 2,1961; Walker, L.C. Water and fertilizer effects on loblolly pine and slash pine seedlings, *Soil Science Society of America Proc.* 26, 197 1962. See also Knox, R.G., Peet, R.K., and Christensen, N.L., Population dynamics in loblolly pine stands: Changes in skewness and size inequality, *Ecology* 70(4), 1153, 1989.
12. Coile, T.S., *Soil and the Growth of Forests*, Academic Press, New York, 1952, 329-398.
13. Garten, C.T. Jr., Foliar leaching, translocation, and biogenic emission of ^{35}S in radiolabeled loblolly pines, *Ecology* 71(1), 239, 1990.
14. Copeland, O.L. Jr., The effects of an artificially induced drought on shortleaf pine, *J. Forestry* 53, 262, 1955; and Minckler, L.S. Oldfield reforestation in the great Appalachian Valley as related to some ecological factors, *Ecological Monographs* 16, 87, 1946.
15. Copeland, O.L. Jr., *op cit.*

16. Coile, T.S., *op cit.*
17. Campbell, W.A. and Copeland, O.L. Jr., Littleleaf disease of shortleaf and loblolly pines. Circular 940, U.S. Department of Agriculture, Washington, 1954; Lawson, E.R., *Pinus echinata* Mill. Shortleaf Pine. In Burns, R.M., and Honkala, B.H., *Silvics of North America*: Vol. I, Conifers. Agriculture Handbook 654. USDA Forest Service Washington, 316, 1990.
18. Stone, E.L.Jr. and Stone, M.H., Root collar sprouts of pine, *J. Forestry* 52, 487, 1954.
19. Zobel, B., Barber, J., Brown, C.L., and Perry T.O., Seed orchards: Their concept and management, *J. Forestry* 56, 815, 1958.
20. Hough, W. A., Phytomass and nutrients in the understory and forest floor of slash/longleaf pine stands, *Forest Science* 28(2), 359, 1982; and Grelen, H.E. Responses of herbage, pines, and hardwoods to early and delayed burning in a young slash pine plantation, *J. Range Management* 29(4), 301, 1976.
21. Froelich, R.C., Dell, T.R., and Walkinshaw, C.H., Soil factors associated with *Fomes annosus* in the Gulf States, *Forest Science* 12, 356, 1966.
22. Why prevailing wind out of the west has not carried mycorrhizal spores to the islands remains a mystery, for in Australia, where no pines are native, mycorrhizae were adequate to support the introduced radiata pine, the seeds of which were carried by pioneering settlers from California's Monterey Peninsula in the early 20th century. Mycorrhizae and pines, dependent on each other for continuing life, are symbiotic. Forest managers introduce the microbe where soils have been sterilized or the root-infecting fungi absent.
23. Hough, W. A. *op cit.*
24. See Wahlenberg, W.G., *Longleaf Pine,* Charles Lathrop Pack Foundation, Washington, 1946; Croker, T.C. Jr., Longleaf pine: A history of man and a forest, USDA Forest Service Report RS-FR7, Atlanta, 1987; and Walker, L.C., and Wiant, H.V. Jr., Silviculture of longleaf pine. Bull. 11 (Stephen F. Austin State University, Nacogdoches, Texas: 1973) for a detailed description of the ecology of this species.
25. Stamp, N. E., and Lucas, J. R., Spatial patterns and dispersal distances of explosively dispersing plants in Florida sandhill vegetation, *J. Ecology* 78(3), 589, 1990.
26. Grelen, H.E., *op cit.*
27. Walker, L.C., Silviculture of the minor southern conifers. Bull. 15, Stephen F. Austin State University, Nacogdoches, Texas, 1967.
28. *Ibid*.
29. *Ibid.* See also Kuser, J.E., and Ledig, F.T., Provenance and progeny variation in pitch pine from the Atlantic coastal plain, *Forest Science* 33(2), 558, 1987.
30. In the 1950s, and perhaps subsequently, residents and passersby were provided free car washes to protect auto finishes from the acidic atmosphere.
31. See Forman, R.T., Ed., *Pine Barrens*: *Ecosystem and landscape,* Academic Press, New York, 1979; and Andersen, J., A Study of pseudonanism in *Pinus rigida* Mill, *Ecological Monographs* 29, 309, 1959. Growth of trees in the Plains is apparently not related to genetics. Guries, R.P., and Ledig, F.T. Genetic diversity and population sructure in pitch pine *Pinus rigida* Mill, *Evolution* 36(2), 387, 1982.
32. Source unknown; author's recollection.
33. See Kaufman, C.M., White, J.B. and Monroe, R.J. Growth of pond pine in a Pocosin area, *J. Forestry* 52, 275, 1954; and Walker, L.C. *op. cit.* Silviculture of the minor southern conifers.
34. The Choctawhatchee race is sometimes classified as *Pinus clausa* var. *immuginata.*
35. Laessle, A. M., The origin and successional relationship of Sandhill vegetation and sand pine scrub, *Ecology Monographs* 28, 366, 1958.
36. Perhaps such sites were what Yale professor James Toumey had in mind when, as often reported, he told his students in the early days of forestry instruction, "Give me a bed of marbles and adequate water and I can grow southern pines."
37. Laessle, A. M., *op cit.*
38. Richardson, D.R., and Williamson, D.B. Allelopathic effects of shrubs on pines and grasses of the Sandhills, *Forest Science* 34(3), 592, 1988
39. Rockwood, D.L. and Frampton, L.J. Genetic variation in sand pine and slash pine for energy production, In *Fifteenth conference of southern forest tree improvement*. 156, 1979; Rockwood, R.L., Conde, L.F., and Brendemuehl, R.H. Biomass production of closely spaced Choctawhatchee sand pines, USDA Forest Service Research Note SE-293, Asheville, 1980.

40. Kossuth, S.V. and Michael, J. L., *Pinus glabra* Walt. spruce pine. In Burns, R.M. and Honkala, B.H. Eds., *Silvics of North America: Vol. 1, Conifers, Agriculture Handbook* 654. USDA Forest Service ,Washington, 355, 1990.
41. Della-Bianca., L. *Pinus pungens* Lamb. table mountain pine, In Burns, R.M., and Honkala, B.H., Eds., *Silvics of North America: Vol. 1, Conifers, Agriculture Handbook 654.* USDA Forest Service, Washington, 425, 1990.

Chapter 3

1. Three early giants of the American forestry enterprise participated in the reforestation of white pine on cutover and burned-over lands of the eastern slope of the Southern Appalachian Mountains. Gifford Pinchot, a scion of wealth, chose forestry for his life's work following graduation from Yale University. As no forestry education was available in this hemisphere, and indeed no native-born foresters lived in the United States, he sailed for France. At Nancy, locale of the French forestry academy, he gained a professional education. Pinchot then returned to the States, opened a consulting firm, and proceeded to manage lands for others. (To this day, managers of forest lands for others are called consultants.) Among these clients was George Vanderbilt. The industrialist's properties in North Carolina, then known as the Biltmore Estate, included what is now the Pisgah National Forest in the Great Smoky Mountains. On these lands and those surrounding the Vanderbilt Palace near Asheville, "The Forester," as President Theodore Roosevelt later would call his friend, supervised the planting of white pines dug from nearby woodlands. Henry Graves assisted him in this endeavor. Graves was later to be the first dean of the Yale Forest School (in those days principally endowed by the Pinchot family) and still later to follow Pinchot as the second chief of the U.S. Forest Service. Carl Alwin Schenck, a German-born and -educated forester, was employed by Vanderbilt at the urging of Pinchot. His task was to further the development of the forests of the Biltmore Estate, both on the lands in the Asheville area and in the Pisgah Mountains. Soon his job included managing the continent's first forestry school, known by the name "Biltmore," where young men were trained to handle the responsibilities of the profession of forestry.
2. Bormann, F. H. and Graham, B. F. Jr. The occurrence of natural root grafting in eastern white pine (*Pinus strobus* L.) and its ecological implications, *Ecology* 40, 677, 1959.
3. Blow, F.E., Quantity and hydrologic characteristics of litter under upland oak forests in eastern Tennessee, *J. Forestry* 53, 190, 1955.
4. Doolittle, W. T., White pine blight in relation to site and thinning, *J. Forestry* 46, 928, 1946; and L.C. Walker, *Silviculture of the Minor Southern Conifers,* Nacogdoches, Texas:Stephen F. Austin State College, 1967.
5. McLaughlin, S.B., McConathy, R.K., Duvick, D., and Naginn, L.K., Effects of chronic air pollution stress on photosynthesis, carbon allocation, and growth of white pine trees, *Pinus strobis, Forest Science* 28, 60, 1982.
6. Li, B., Lett, J.B., and Weir, R.J., Preliminary study of geographic variation in Fraser fir seedlings, *Southern J. Applied Forestry,* 12(2), 128, 1988. This report shows seeds from low-elevation stands showed better growth in field plantings than those from higher elevation sites for Fraser fir.
7. Walker, L.C., *Silviculture of the Minor Southern Conifers*. *Op cit.*
8. Brown, D. M., Conifer transplants to a grass bald on Roan Mountain, *Ecology*, 34, 614, 1953.
9. de Steigner, J. E., Pye, J., and Love, C.S., Air pollution damage to U.S. forests, *J. Forestry* 88(8), 17, 1990.
10. Walker. *Silviculture of the Minor Southern Conifers*, *op cit.*
11. Bormann, E. H. and Platt, R. B., A disjunct stand of hemlock in the Georgia Piedmont, *Ecology* 39, 16, 1958. See also Godman, R.M. and Lancaster, K. *Tsuga canadensis* (L.) Carr. Eastern Hemlock *In* Burns, R.M. and Honkala, B.H., *Silvics of North America: Vol. 1, Conifers*. Agriculture Handbook 654. Washington: USDA Forest Service, 604, 1990.
12. Walker, L.C., *Forests*, New York: John Wiley & Sons, Inc., 1990.
13. Sometime past we recalled the story of the replacement of Philadelphia sewer pipes. In the excavated trenches were the original ducts, fashioned from white-cedar heartwood, laid down in colonial days. The high value of the wood for its durability strongly suggests intensive management of the species for use by man. In the woods with Silas Little, most knowledgeable of all foresters and ecologists about this fascinating species, I (L.W.) succumbed to its mysterious intrigue.
14. Baldcypress is written as one word because it is not a true cypress; baldcypress belongs to the genus Taxodium; cypress species are classified as Cupressus.
15. Sir Charles Lyell, *A Second Visit To the United States of North America*, New York: Harper and Bros., 1849.
16. Some authorities call the variety *nutans*, meaning "nodding," from a cultivar with drooping branches.

17. Ewel, K.C., Davis, H. ., and Smith, J. E., Recovery of Florida swamps from clearcutting, *Southern J. Applied Forestry*, 13(3), 123, 1989.
18. Frey, D. G., Evidence for the recent enlargement of the “Bay” Lakes of North Carolina, *Ecology*, 35, 78, 1954.
19. Anonymous. Southern Forest Experiment Station Annual Report, New Orleans: Forest Service, USDA 1960.
20. Walker, L.C., Woodland Cathedral, *Texas Parks and Wildlife* 39(7), 16, 1981. No doubt the ivory-billed woodpecker nested decades past in the Woodland Cathedral. A hole in a well-preserved baldcypress is believed to be a portal to a nest of what was once the largest woodpecker on the continent. The bird probably has not been seen in the area since shortly after logging began at about the turn of the century.
21. Quotation source unknown.
22. Walker, L.C., Blue Elbow Swamp, *Texas Magazine*, published by *The Houston Chronicle*, March 30, 1980, pp.20 et fol.; and A Slice of Texas, *Texas Parks and Wildlife* 41(2), 6, February, 1983, et fol. I (L.W.) estimate that the residual baldcypress trees, of poor quality due to high-grading in the repeated harvests, (now about 10 to 16 inches in diameter above the butt swell) are centurians. Young growth on better sites, however, exceeds 10 inches in diameter in 20 years. In Blue Elbow, cutoffs, sloughs, oxbow lakes, and low ridges mark the locations of old natural levees along the past and present stream channels. This physiographic diversity results in complex soil patterns, each with its peculiar vegetation. Stands of mixed hardwoods and loblolly pine grow on slight rises, such elevations formed on the roots of wind-thrown trees a century earlier. Pine trees on these elevated terraces are as large as 20 inches dbh and more than 100 feet tall when 50 years old. Broadleaf trees, like sweetgum and white oak, also grow well on these moderately drained lands. In the swamp’s interior lowlands, where drainage is poor, peat forms. These bog soils, contrary to expectation, are not acidic. The high pH, approaching the neutral 7, could be attributed to the effluent of a cement plant operating since 1950 north of the swamp.
23. Diersberg, E.E. and Brezonik, P. L. Tertiary treatment of municipal wastewater by cypress domes, *Water Research* 17(9), 1087, 1980.
24. Mattoon,W. R., The Southern Cypress. Bull. 272, Washington: U. S. Department of Agriculture. 1915.
25. Pecky cypress lumber finds a ready market for paneling, picture framing, and other decorative uses. One should note that only the heart of old-growth trees is especially resistant to insect attack and fungal decay. Inevitably, demand for “red” cypress, so-named in the industry because of the color of the heartwood, exhausted the supply in the southern forest. Dynamic promotional efforts led to its use for roof shingles, water towers, and house siding far beyond the region of its growth. The industry died as the Great Depression began in 1929. The chemical providing resistance is cypressene, an oil extract. Brown, C. A. and Montz, G N., Baldcypress, the tree unique, the wood eternal, Baton Rouge: Claitor’s Publishing Division, 1986.
26. Conner, W. H. and Toliver, J. R., Observations on the regeneration of baldcypress (*Taxodium distichum* [L.] Rich.) in Louisiana swamps, Southern J. Applied Forestry 14(3), 115, 1990; Pezeski, S. R., Delaune, R.D., and Patrick, W. H. Jr., Response of Baldcypress (*Taxodium distichum L.* var. *distichum*) to increases in flooding salinity in Louisiana’s Mississippi River Deltaic Plains, *Wetlands* 7, 10, 1987.
27. We treat the difficult-to-distinguish southern redcedar along with eastern redcedar in these pages. The former is more slender, has branches more pendulous, longer male cones, shorter female cones with one or two seeds (in contrast to one to four), and more likely to be found immediately inland from salt marshes. Wilhite, L. P. *Juniperus silicicola* (Small) Baily Southern Redcedar, In Burns, R.M. and Honkala, B.H., Silvics of North America: Vol. 1 Conifers. Agriculture Handbook 654 Washington: USDA Forest Service, 127, 1990.
28. Holthuijzen, A. M. A. and Sharik, T. L., Colonization of abandoned pastures by eastern red cedar (*Juniperus virginiana L.*), *Canadian J. Forest Research* 15(6), 1065, 1985.
29. Walker, L.C., *Silviculture of the Minor Southern Conifers*, *op cit.* See also Grand, J. B. and Mirarchi, R. E., Habitat use by fledged mourning doves in east-central Alabama, *J. Wildlife Management* 52(1), 153, 1988.
30. Read, R. A. and Walker, L.C., Influence of eastern redcedar on soil in Connecticut pine plantations, *J. Forestry*, 48, 337, 1950.
31. *Ibid*.

Chapter 4

1. Fraser, D. A., Growth Mechanisms in Hardwoods, *Pulp and Paper Magazine of Canada* 59, 202, 1958; Kozlowski, T. T. and Ward, R. W., Seasonal height growth of deciduous trees, *Forest Science* 3, 168, 1957; and Tryon, E. H. and True, R. P., Recent reductions in annual radial increments in dying scarlet oaks related to rainfall deficiencies, *Forest Science* 4, 219, 1958; Reich, P. B., Teshey, R.O., Johnson, P.S., and Hinckley, T. M., Periodic root and shoot growth in oak, *Forest Science* 26(4), 590, 1980.
2. Fraser, D. A., *op cit.*; Kozlowski, T. T., and Ward, R. W., *op cit.*
3. Wendel, G.W., and Gabriel, W.J., Sugar maple provenance study. Upper Darby, PA., U.S. Forest Service, Northeastern Forest Experiment Station Paper ND. 460, 1980).
4. Kormanik, P. P., Shultz, R.C., and Bryan, W. C., The influence of vesicular-arbuscular mycorrhizae on the growth and development of eight hardwood tree species, *Forest Science* 28(3), 531, 1982. See for decomposer organisms of Acer, Cornus, and Quercus species Blair, J. M., Parmelie, R. W., and Beare, M. H., Decay Rates, Nitrogen Fluxes, and Decomposer Communities of Single- and Mixed-Species Foliar Litter, Ecology 71(5), 1976, 1990.
5. Doolittle, W. T., Site index of scarlet and black oak in relation to Southern Appalachian soil and topography, *Forest Science*, 3, 114, 1957.
6. Minckler, L. S., Oldfield reforestation in the Great Appalachian Valley as related to some ecological factors, *Ecological Monographs* 16, 87, 1946.
7. Rebertus, A. J., Williamson, G. B., and Moser, E. B., Fire-induced changes in *quercus laevis* spatial pattern in Florida Sandhills, *J. Ecology* 77(3), 638, 1989.
8. Wahlenberg, W. G., An early test of levels of growing stock Appalachian Hardwoods, *J. Forestry*, 54, 106, 1956; Downs, A. A. and McQuilkin, W. E., Seed production of Southern Appalachian oaks, *J. Forestry*, 42, 914, 1944; and Christensen, D.M., Yield of seed by oaks in Missouri Ozarks, *J. Forestry* 53, 439, 1955.
9. Minckler, L.S. and Jensen, C., Reproduction of upland central hardwoods as affected by burning, topography, and litter depth, *J. Forestry*, 57, 424, 1959.
10. Walker, L.C., *Forests*, New York: John Wiley & Son, Inc., 1990.
11. Keetch, J.J., Sprout development on once-burned and repeatedly burned areas in the Southern Appalachians, Asheville, N.C.: Appalachian Forest Experiment Station Technical Note 59. 1944.
12. Woods, F. W., Disease as a factor in the evolution of forest composition, *J. Forestry* 51, 871, 1953. First noticed in northern France, Belgium, and Holland in 1918, Dutch elm disease was believed by some pathologists to have been brought into Europe from Asia during the First World War. Its discovery in North America occurred at Cincinnati, Ohio, in 1930. Importation on elm burl logs for veneer manufacture is the usually cited source.
13. Craighead, F.C. and Nelson, J. C., Oak wilt in Pennsylvania, *J. Forestry* 58, 872, 1960. Drought, accompanied by *Hypoxylon atropunctatum* infection is a cause for necrosis of southern red oak. Tainter, F. F., Williams, T. M., and Cody, J. B., Drought as a cause of oak decline and death on the South Carolina Coast. *Plant Disease* 67, 195, 1983.
14. Speers, C. F., The elm spanworm infests large areas, *Southern Lumberman* 197, 137, 1958.
15. Burkle, J. S. and Guttenberg, S. Marking guides for oaks and yellow-poplar in the Southern Uplands, New Orleans, Southern Forest Experiment Station Occasional Paper 125. 1952.
16. Phillips, D.C. and Shure, D. J., Patch-size effects on early succession in Southern Appalachian Forests, *Ecology* 71(1), 204, 1990.
17. Burkle, J. S. and Guttenberg, *op cit.*
18. Boettcher, S. E., and Kalisz, P. J., Single-Tree influence on soil properties in the mountains of eastern Kentucky, *Ecology* 71(4), 1365, 1990.
19. Walker, L.C., Silviculture of southern upland hardwoods, Nacogdoches, Texas: Bull. 22, School of Forestry, Stephen F. Austin State University, 1972.
20. Burkle and Guttenberg, *op cit.*
21. Walker, L.C., and Beacher, R. L., Fertilizer response with forest trees in North America, Washington: National Plant Food Institute, 24 pp. 1963.

22. Tryon, E. H., Cantrell, J. O., and Carvell, K. L., Effect of precipitation and temperature on increment of yellow-poplar, *Forest Science* 3, 32, 1957; and Tryon, E. H. and Myers, C. A., Periodic precipitation affects growth of yellow-poplar on a West Virginia hillside, *Castanea* 17, 97, 1952.
23. The gypsy moth does not attack yellow-poplar; which is about the only broadleaf tree in the Southern Appalachians not included in its diet. In the height of the anti-forester rhetoric of the 1960s and 1970s, some enthusiasts for natural unmanaged forests claimed that foresters introduced the insect. The determined followers of Thoreau alleged the woodland managers knew the insect's destructive nature to weed-tree species and its abhorrence of a hardwood tree preferred for timber production. The foresters, they said, were employing integrated biological pest management in reverse. The insect predations made unnecessary the use of herbicides. Chemicals would not be required to deaden the low-grade and scrub oaks and hickories and the doty, rot-infected beech trees: gypsy moths would do it for free. See also, Liebold, A., and M. McManus, The evolving use of insecticides in gypsy moth management. J. *Forestry* 97(3), 20, 1999.
24. Some craftsmen capitalize on the beauty and fine woodworking properties of the small tree. Mesquite's hardness (twice that of oak), exquisite grain, attractive finishing characteristics, and relative stability with atmospheric moisture changes commend its use for small wooden decorative pieces and rifle stocks.
25. Woods, F. W., and Shanks, R. E., Natural replacement of chestnut by other species in the Great Smoky Mountains National Park, *Ecology* 40, 349, 1959; and Beattie, R. K., and Diller, J. D., Fifty years of chestnut blight in America, *J. Forestry* 52, 323, 1954.
26. *Ibid.*
27. *Ibid*.
28. Woods, F. W. and Shanks, R. E., *op cit.*
29. Putnam, J. A., Management of bottomland hardwoods, New Orleans, Southern Forest Experiment Station Occasional Paper 93. 1951. John Bunyan visualized bottomland hardwood topography when the distraught, ever-searching Pilgrim in the 17th century allegory encountered the Slough of Despond.
30. Hosner, J. F., Survival, root, and shoot growth of six bottomland tree species following flooding, *J. Forestry* 57, 927, 1959.
31. Broadfoot, W. M., Evaluating cottonwood sites, New Orleans: Southern Forest Experiment Station Occasional Paper 178, 1960; and Bonck, J., and Penfound, W. T., Seasonal growth of twigs of trees in the batture lands of the New Orleans Area, *Ecology* 23, 473, 1944.
32. Johnson, R. L., and R. M. Krinard, R. M., Survival and growth of nuttall oak seedlings following selection cutting—28-year measurement, *Southern J. Applied Forestry*, 13(1), 43, 1989.
33. Walker, L.C. and Watterston, K.G., Silviculture of southern bottomland hardwoods, Nacogdoches, Texas: Bull. 25, School of Forestry, Stephen F. Austin State University, 1972.
34. Walker, L.C., *Forests*, New York: John Wiley & Son, Inc., 1990.
35. Broadfoot, W. M., *op cit.*
36. *Ibid*.
37. Putnam, J. A., *op cit.*
38. Tubbs, C. H., Allelopathic relationships between yellow birch and sugar maple seedlings, *Forest Science* 19(2), 139, 1973; Horsley, S. B., Glucose-l-benzoate and Prunasin from *Prunus serotina*, *Phytochemistry* 20, 1127, 1981; Griggs, M. M. Sassafras albidum (Nutt.) Nees Sassafras, In Burns, R. M., and Honkala, B. H., *Silvics of North America: Vol. 2, Hardwoods,* Washington: USDA Forest Service Agriculture Handbook 654, 773, 1990; and Cooley, J. H. and Van Sambeek, J. W., *Ulmus rubra Muhl*. Slippery Elm, In Burns, R. M., and Honkala, B. H., *Silvics of North America, America: Vol. 2, Hardwoods*, Washington: USDA Forest Service Agriculture Handbook 654, 812, 1990.
39. McDermott, R. Light as a factor in the germination of some bottomland hardwood species. *J. Forestry* 51, 203, 1953.

Chapter 5

* Phillip C. Wakeley's classic Planting the southern pines, USDA Forest Service Agriculture Monograph 18, published in 1954 by the Government Printing Office, remains a standard handbook for conifer plantation establishment in the South.

1. McClurkin, D., Soil and climatic factors related to the growth of longleaf pine, New Orleans, Southern Forest Experiment Station Occasional Paper 132, 1953.
2. Zahner, R., Mapping soils for pine site quality, *J. Forestry* 55, 430, 1957.
3. Walker, L.C. and Wiant, H.V. Jr., Silviculture of shortleaf pine, Nacogdoches, Texas, Stephen F. Austin State College School of Forestry Bulletin 9, 6, 1966.
4. Chapman, H. H., Effects of thinning on forest-grown longleaf and loblolly pines at Urania, La., *J. Forestry,* 51, 16, 1953.
5. Coile, T. S., Soil and the growth of forests, *Advances in Agronomy*, 4, 329, 1952.
6. Haywood, J. D., and Burton, J. D., Loblolly pine plantation development is influenced by site preparation and soils in the west Gulf Coastal Plain, *Southern J. Applied Forestry*, 13, 17, 1989.
7. Rich, M. F., Planting loblolly pine and sycamore vs. natural regeneration on a bottomland site, *Southern J. Applied Forestry*, 13, 22, 1989.
8. Hansen, R. S., and Bilan, M. V., Height growth of loblolly and slash pine plantations in the northern post-oak belt of Texas, *Southern J. Applied Forestry* 13, 5, 1989.
9. Arend, J. L., An early eastern redcedar plantation in Arkansas, *J. Forestry*, 45, 358, 1947.
10. Balmer, W. E. and H.L. Williston, H. L., Managing eastern white pine in the southeast, Atlanta, GA., USDA Forest Service Report R8-FRI, 11, 1983.
11. Camp, R F., Walnuts and white pine can be planted together successfully, *Tree Planters' Notes*, 37, 29, 1986.
12. Conner, W. H. and J. R. Toliver, J. R., Observations on the regeneration of baldcypress (*Taxodium distichum [L.] Rich.*) in Louisiana swamps, *Southern J. Applied Forestry,* 14, 115, 1990.
13. Shane, W. A., Plantation management of Arizona cypress for Christmas trees in Georgia, Athens, University of Georgia master of forestry thesis. 1957.
14. *Ibid*.
15. Minckler, L.S., A guide for tree planting in the southwest Virginia counties in the Tennessee Valley, Asheville, NC, Appalachian Forest Experiment Station Technical Note 61. 1946; Minckler, L. S., Old field reforestation in the Great Appalachian Valley as related to some ecological factors, Ecological Monographs 16, 87, 1946; and McGee, C. E., Expanding options for reforestation of the Cumberland Plateau, *Southern J. Applied Forestry* 4, 158, 1980.
16. Thompson, B., *Black Walnut For Profit*, Lake Mills, Iowa: Graphic Publishing Co. 1976.
17. Walker, L.C., *Forests*, New York: John Wiley and Son, Inc. 1990; Ponder, Jr., F., Schlesinger, R.C., and Funk, D.T., Autumn olive stimulates growth of walnut, *Southern Lumberman* 240, 14, 1980.
18. Scheer, R. L., Sand pine—scrub or timber tree, *Southern Lumberman* 195,191,1957; Outcalt, K.W. and Brendemuehl, R.H., Sand pine survival and growth on prepared and unprepared sites, *Southern J. Applied Forestry*, 8, 96, 1984; and Hebb, E. A., Choctawhatchee sand pine growth on a chemically prepared site—10 year results, *Southern J. Applied Forestry.* 5, 208, 1981. The chemicals utilized in the study were fenuron and paraquot, the latter ineffective for controlling wiregrass.
19. Grano, C. X., Growing loblolly and shortleaf pines in the mid-south, Washington, USDA Farmers' Bulletin 2102, 1956.
20. Minckler, L. S., Southern pine from different geographic sources show different responses to low temperatures, *J. Forestry*, 49, 915, 1951. Bethune, J. E., Performance of two slash pine varieties planted in south Florida. Asheville, Southeastern Forest Experiment Station Paper 24, 1966. An American professor teaching in the Canton province of South China introduced *Pinus elliottii* there in the early 1930s. By executive decree, over 270,000 hectares had been successfully planted by 1992—without silvicultural and management literature—in only one district of the province.
21. Nienstaedt, H. and Olson, J. S., Effects of photoperiod and source on seedling growth of eastern hemlock, *Forest Science*, 7, 81, 1961; and Schumacher, F. X. and Day, B. B., The influence of precipitation upon the width of annual rings of certain timber trees, *Ecological Monographs*, 9, 387, 1937.
22. Bonner, F. T., Measurement of seed vigor for loblolly and slash pines, *Forest Science*, 32, 170, 1986.
23. *Ibid.*

24. Bilan, M. V., and Kemp, A. K., Effect of gibberellin on height growth of one-year-old seedlings of loblolly pine, *J. Forestry*, 58, 35, 1960.
25. Boyer, W. B. and R.M. Farrar, R. M., Thirty years of management on a small longleaf pine forest, Southern *J. Applied Forestry*, 5, 73, 1981; and Croker, Jr., T. C., Longleaf Pine, *J. Forest History,* 23, 32, 1979.
26. Hinesley, L. E., and Saltveit, Jr., M. E., Ethylene adversely affects Fraser fir planting stock in cold storage, *Southern J. Applied Forestry*, 4, 188, 1980.
27. Nelson, L. R., et al., Use of effective herbicide treatments, Macon, GA., Georgia Forest Research Council Paper 40. 1982.; and Glover, G. R., Creighton, J. L., and Gjerstad, D. H., Herbaceous weed control increases loblolly pine growth, *J. Forestry* 87, 47, 1989.
28. Walker, L.C., and Brender, E.V., Planting following prescribed fire, *J. Forestry*, 57, 123, 1959.
29. Wakeley, P. C., Geographic source of loblolly pine seed, *J. Forestry*, 42, 23, 1944. See Duzan, H.W. Jr. and Williams, C.G., Matching loblolly pine families to regeneration sites, *Southern J. Applied Forestry,* 12, 166, 1988; Sluder, E. R., Fusiform rust in crosses among resistant and susceptible loblolly and slash pines, *Southern J. Applied Forestry*, 13, 174, 1989; and Snow, G. A., Matthews, F. R., Nance, W. L., and Foster, G. S., Effects of pollen source on loblolly pine resistance to *Cronartium quercuum* sp. *fusiforme*, *Forest Science*, 36, 304, 1990.
30. Kelley, W. D., Effect of short-term storage of triadimefon-treated loblolly pine seed on incidence of fusiform rust, *Southern J. Applied Forestry* 12, 18, 1988.
31. Hedden, R. L., Belander, B. P., Powers, H. R., and Miller, T., Relation of Nantucket pine tip moth attack and fusiform rust infection in loblolly pine families, *Southern J. Applied Forestry* ,15, 204, 1991.
32. Arabatzis, A. A., Gregoire, T. G., and Lenhart, J. D., Fusiform rust incidence in loblolly and slash pine plantations in East Texas, *Southern J. Applied Forestry*, 15, 79, 1991.
33. Wenger, K. F., Growth and prospective development of hardwoods and loblolly pine seedlings on clearcut areas, Asheville, NC., Southeastern Forest Experiment Station Paper 55. 9, 1955.
34. Walker, L.C., Black plastic mulch for pine planting, *Tree Planter's Notes*, 45, 1, 1961. Perforated brush blankets now are available that allow rainwater penetration through the plastic cover over a fibrous mulch.
35. The senior author discovered that direct seeding followed by a frost results in seed and seedling destruction. Seeds burst open and both seeds and seedlings are frost-heaved from the soil.
36. Filer, T. H. Jr., *Quercus nuttallii* Palmer Nuttall Oak, In Burns, R. M. and Honkala, B.H., *Silvics of North America:Vol.2, Hardwoods,* Agriculture Handbook 654, Washington, U.S.D.A Forest Service, 704, 1990.
37. As advertised by nursery growers in many forestry and forestry-related magazines.
38. Harkin, D. A., Every seedling from selected seed, J. Forestry, 55, 842, 1957; and Derr, H. J., Longleaf x slash hybrids at age 7, J. Forestry, 64, 236, 1966. See also Snyder, E. B., and Hankoong, G., Inheritance in a diallel crossing experiment with longleaf pine, New Orleans, Southern Forest Experiment Station Research Note 140. 1978.
39. Snyder, E. B., and Hankoong, G., *Op cit.*
40. Barrows-Broaddus, J., and Dwinell, L. D., Variation in susceptibility to the pitch canker fungus among families of Virginia pine, *Phytopathology* 74, 438, 1984.
41. Foushee, D. L., Talbert, J. T., Zobel, B. J., and Summerville, K. O., Effects of seed orchard fertilization on seed and seedling characteristics of four longleaf pine families, *Southern J. Applied Forestry*, 5, 159, 1981; and Hare, R.C., Snyder, E.B., and Schmidtling, R.C., Longleaf pine flowering in response to nitrogen fertilization, branch girdling, growth substances and cultivation, USDA Forest Service General Technical Report NC 50, 11, 1979.
42. A study conducted by the late Prof. George Switzer in 1956 and cited by Walker, L.C., and Beacher, R.L. In Fertilizer response with forest trees in North America, Washington, National Plant Food Institute. 24, 1963.
43. Bengtson, G.W., Comparative response of four southern pine species to fertilization, *Forest Science*, 22, 487, 1976; and Walker, L.C., Water and fertilizer effects on loblolly pine and slash pine seedlings, *Soil Science Society of America Proc.* 26, 197, 1962; Fisher, R.F., and Garbett, W. S., Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. *J. Soil Science Soc. of America*, 44, 850, 1980.
44. For ready conversion, about 1000 kilograms per hectare equates to 1000 pounds per acre.

45. Walker, L.C. and Beacher, R.L., *op cit.* See also for a good summary of the subject Kotela, E.J., Bittarding, A., and Troth, J. L., Decision-making criteria for forest fertilization in the southeast: An industrial perspective, *Southern J. Applied Forestry*, 12, 153, 1988.
46. Blinn, C. R., Lyons, A., and Buckner, E. R., Color aerial photography for assessing the need for fertilizer in loblolly pine plantations, *Southern J. Applied Forestr*y 12, 270, 1988.
47. Walker, L.C., Forests. *Op cit.*
48. Marx, D.H., Soil pH and nitrogen influence *Pisolithus ectomycorrhizal* development and growth of loblolly pine seedlings, *Forest Science*, 36, 224,1990.
49. Brown, D.M., Conifer transplants to a grass bald on Roan Mountain, *Ecology* 34, 614, 1953; Hinsley, L. E., and Blazichi, F. A., Propagation of Fraser fir by stem cutting, *American Christmas Tree J.*, 24, 39, 1980.
50. White, R.L., Smith, S.F., and Miler, P.J., TU system environmental research program. In: *Proc. of the American Socity for Surface Mining and Reclamation.* Austin, Texas, 1997.
51. Walker, R.F., West, D.C., McLaughlin, S.B., and Amundsen, C.C., Growth, xylem pressure potential, and nutrient absorption of loblolly pine on a reclaimed surface mine site as affected by *Pisolithus tintorius* infection, *Forest Science*, 35, 569, 1989.
52. Hardt, R. A. and Forman, R.T., Boundary form effects on woody colonization of reclaimed surface mines, *Ecology* 70, 1252, 1989.

CHAPTER 6

Texas Forest Service photographs in this chapter were taken by Dr. Ron Billings and researched and provided by Herbert (Joe) Pase, TFS entomologist.

1. Farrish, K.W., and Oswald, B. P., Relationships between selected soil properties and community species composition in Turkey Hill Wilderness area in East Texas, In: Proc. of the 10th Biennial Southern Silvicultural Research Conference, Haywood, J. D. Ed., February 15-17, 1999, in Shreveport, LA. USDA Forest Service Southern Research Station General Technical Report. In Press.
2. Wahlenberg, W. G., and Doolittle, W. T., Reclaiming Appalachian brush lands for economic forest production, *J. Forestry* , 48, 171, 1950.
3. The U.S. Forest Service chief in 1989 directed that border strips of 1200 feet radii surrounding all active and dormant colony sites in all national forests of the South must be managed by selection harvests in order to protect the bird. The order reinforced a federal district court's mandate in Texas that required such an isolation strip. As all officially listed endangered species are protected by law, owners of private forest lands fear the judicial order, a legal decision that ignores ecological requirements for all other living organisms (plant and animal). If not reversed upon the pending appeal, the rule must be applied to all forest land.
4. Froelich, R.C., Dell, T.R., and Walkinshaw, C.H., Soil factors associated with *Fomes annosus* in the Gulf States, *Forest Science* 12, 356, 1966; and Verrall, A. F., Annosus root rot survey, (New Orleans: Southern Forest Experiment Station Note 141. 1962.
5. Kuhlman, E.G., Impact of Annosus root rot 22 years after planting pine on root rot infected sites, *Southern J. Applied Forestry*, 10, 96, 1986.
6. Ostry, M. E., Preventing rust in southern pines, *J. Forestry*, 97(3), FOCUS.
7. Siggers, P. V., Observations on the influence of fire on the brown-spot needle blight of longleaf pine seedlings, *J. Forestry*, 32, 556, 1934; and Chapman, H. H., The initiation and early stages of research on natural reforestation of longleaf pine, *J. Forestry*, 46, 505, 1948.
8. Jewell, F. F., True, R. P., and Mallett, S. L. , Histology of *Cronartium fusiforme* in slash pine, *Phytopathology* 52, 850, 1962.
9. Jackson, L.W.R., Anatomy of fusiform rust galls, Georgia Academy of Science 16, 73, 1958.
10. Harms, W. R., Growth of fusiform cankers on young slash pine, Asheville, NC, Southeastern Forest Experiment Station Note 159, 1961.
11. Stone, D.M. and Powers, H.R., Sewage sludge increases early growth and decreases fusiform rust infection of nursery-run and rust-resistant loblolly pine, *Southern J. Applied Forestry* 13, 68, 1989.
12. Anderson, R. L., Costi, N. D., and McClure, J.P., Predicting severity of fusiform rust, *Southern J. Applied Forestry* 10, 38, 1986; Froelich, R. C., and Snow, G. A., Predicting site hazard for fusiform rust, *Forest Science,* 12, 21, 1986; Snow, G. A., Mathews, F. R., Nance, W. L., and Foster, G. S., Effects of pollen source on *Cronartium quercuum* sp. *fusiforme*, *Forest Science* 36, 304, 1990.
13. Toole, E R., White pine blight in the Southeast, *J. Forestry*, 47, 378, 1949; and Berry, C.R., and Hepting, G.H., Injury to eastern white pine by unidentified atmospheric constituents, *Forest Science*, 10, 2, 1964.
14. Brenner, J., and Wade, D., Florida's prescribed burning act, *J. Forestry* 90, 27, 1992.
15. Van Lear, D. H., and Danielovich, S. J., Soil movement after broadcast burning in the Southern Appalachians, *Southern J. Applied Forestry*, 12, 49, 1988.
16. Two severe ice storms covering most of a half-dozen Texas counties, provided salvage work for World War II German prisoners. They knew the Geneva Convention rules limiting what POWs could be forced to do by their captors. The rules, however, were drawn up prior to the introduction of power-driven chain saws in the southern U.S. The POWs, provided with new saws with which they were familiar (a German invention), completed the daily tasks, the required volume cut and stacked, by noon each day. They taught their guards the use of the bulky saws. Walker, L.C., Hursey, First Industry Forester in Texas, *Texas Forestry*, 22, 4, 1981.
17. McAlpine, R. G., Yellow-poplar seedlings intolerant to flooding, *J. Forestry*, 59, 566, 1961.
18. Sampson, N., and Hamilton, T., Can trees really help fight global warming? *American Forests*, 98, 13, 1992.
19. Sedjo, R. A., Forests to offset the greenhouse effect, *J. Forestry*, 88, 33, 1990.

20. Stow, T.K., Allen, H L., and Kress, L.W., Ozone impacts on seasonal foliage dynamics of young loblolly pine, *Forest Science*, 38, 102, 1992; and de Steigner, J. E., Pye, J. M., and Love, C.L., Air pollution damage to U.S. forests, *J. Forestry*, 88, 17, 1990.
21. Temple, P. J., Linzon, S. N., and Smith, M. L., Fluorine and boron effects on vegetation in the vicinity of a fiberglass plant, *Water, Air, and Soil Pollution*, 10, 163, 1980.
22. The effect of air pollution on forest ecosystems was extensively studied during the 1980s by the Southern Forest Research Cooperative and the National Acid Precipitation Assessment Program's Forest Response Program. No definitive cause and effect relationships had appeared as of mid-1991.
23. Grelen, H.E., *Betula nigra L*. River Birch, In Burns, R. M., and Honkala, B. H., *Silvics of North America, Vol. 2, Hardwoods,* Washington: USDA Forest Service Agriculture Handbook 654, 153, 1990.

CHAPTER 7

1. Bull, H., Yields from 3 Spacings of Planted Slash Pine, New Orleans, Southern Forest Experiment Station Note 51, 1947; Burkhart, H. E., and Bredenkamp, B. V., Product-Class Proportions for Thinned and Unthinned Loblolly Pine Plantations, *Southern J. Applied Forestry*, 13, 192,1989; and Moorhead, D. J., Dangerfield, C. W., and Edwards, Regulating stand density by precommercial thinning in naturally regenerated loblolly pine stands: evaluation of management and economic opportunity, In *Proc. of the Ninth Biennial Southern Silvicultural Research Conference,* February 25-27, 1997, Clemson, SC, Waldrop, T. A., Ed. USDA Forest Service Gen. Tech. Rep. SRS-20, Asheville, NC. 202, 1998.
2. Kramer, P. J., Amount and duration of growth of various species of tree seedlings, *Plant Physiology*, 18, 239, 1943; and Ferguson, E. R., Stem-kill and sprouting following prescribed fires in a pine–hardwood stand, *J. Forestry* 55, 426,1957.
3. See Franklin, C., Hazel, D. W., Rucker, R. R., and Kronrad, G. D., Thinning and harvesting regimes for yellow-poplar, *Southern J. Applied Forestry* ,14, 101, 1990, for a computer model for log quality that compares thinning 10 years before harvest with immediate harvest.
4. Wackerman, A. E., Allocating cutting budgets by means of a forest sky line graph, *J. Forestry* 32, 4, 1934.
5. *Ibid*.
6. Walker, L.C., Silviculture of southern upland hardwoods, Nacogdoches, Texas, Stephen F. Austin State University School of Forestry Bulletin 22., 102, 1972.
7. Walker, L.C., Silviculture of the minor southern conifers, Nacogdoches, Texas, Stephen F. Austin State University School of Forestry Bulletin 15, 67, 1967.
8. Paul, B.H., Specific Gravity changes in southern pines after release, *Southern Lumberman* 197, 122, 1958.
9. Walker, L.C., Thinning the southern pine plantation, In Thinning Southern Pines Plantation Workshop Manual, American Pulpwood Association, Inc. 1984.
10. New court-assigned regulations regarding timber harvests in red-cockaded woodpecker nesting sites will likely result in further litigation if applied to private lands. The U.S. Constitution requires compensation for taking private property by condemnation for the public good. Restrictions by government edict of what one may do on one's own land, property owners claim, amounts to such "taking." The courts may hold that such governmental action is subject to compensation.
11. Tate, J. F., Holley, G., Kronrad, G. D., Financial analysis of pruning combined with low density management of southern yellow pine in East Texas: An Assessment. In: *Proc. of the Tenth Biennial Southern Silvicultural Research Conference,* February 16-18, 1999, Shreveport, LA, Haywood, J. D. Ed. USDA Forest Service Gen. Tech. Rep. Asheville, NC. In Press.
12. Bennett, F. A., The effect of pruning on the height and diameter growth of planted slash pine, *J. Forestry*, 53, 636, 1955.
13. Roberts, E. G., and Clapp, R. T., Effect of pruning on the recovery of ice bent slash pines, *J. Forestry*, 54, 586, 1956.
14. Rowland, C.A. Jr., Early results of bud-pruning in slash pine, *J. Forestry*, 48, 100, 1950; and Bruce, D., Fire pruning of slash pine doesn't pay, New Orleans, Southern Forest Experiment Station Note 78, 1952.
15. Walker, L.C., and Youngberg, C. T., Response of slash pine to nitrogen and phosphorus fertilization, *Soil Science Society of America Proc.*, 26, 399, 1962; and Gilmore, A. R. and Livingston, K.W., Cultivating and fertilizing a slash pine plantation, *J. Forestry*, 56, 481, 1958.
16. Fowells, H. A., and Krauss, R. W., The Inorganic Nutrition of Loblolly Pine and Virginia Pine with Special Reference to Nitrogen and Phosphorus, Forest Science, 5, 95, 1959.
17. Hughes, R. E., and Jackson, J. E., Fertilization of young slash pine in a cultivated plantation, Asheville, Southeastern Forest Experiment Station Paper 148, 1962.
18. Walker, L C., and Hatcher, R D., Variation in ability of slash pine progeny groups to absorb nutrients, *Proc. of the Soil Science Society of America*, 29, 616, 1965.
19. Jamison, G. M., Effect of litter removal on diameter growth of shortleaf pine, *J. Forestry*, 41, 213, 1943.
20. Brinkman, K. A., Fertilizers increase seed production of shortleaf pine in Missouri, *Tree Planters' Notes*, 53, 18, 1962.

21. Walker, L.C., Foliage symptoms as indicators of potassium-deficient soils, *Forest Science* 2, 113, 1956; and Stone, E. L., Magnesium deficiency in some northeastern pines, *Proc. of the Soil Science Society of America*, 17, 297, 1953.
22. Arend, F. L., Influence of fire and soil on distribution of eastern redcedar in the Ozarks, *J. Forestry,* 48, 129, 1950; and Read , R. A., and Walker, L.C., Influence of eastern redcedar on soil in connecticut pine plantations, *J. Forestry*, 48, 337, 1950.
23. Broadfoot, W. M., Forest planting sites in North Mississippi and West Tennessee, New Orleans, Southern Forest Experiment Station Occasional Paper 120, 1951; and Maki, T. E., Forest fertilization possibilities in the United States, *Better Crops with Plant Food*, 42, 1958. 12 et fol.
24. Anonymous., Annual Report, New Orleans. Southern Forest Experiment Station. 1960.
25. Ferguson, E. F., *op cit.*
26. Chaiken, L. E., Annual summer fires kill hardwood rootstocks, Asheville, N. C, Southeastern Forest Experiment Station Research Note 19. 1952.
27. Graham, B. F., Jr., and Rebuck, A. L., The effect of drainage on the establishment and growth of pond pine (*Pinus serotina*), *Ecology*, 39, 33, 1958; and McCarthy, E. J., and Skags, R. W., Simulation and evaluation of water management systems for a pine plantation watershed, *Southern J. Applied Forestry,* 16, 48, 1992.
28. Pruitt, A. A., A study of the effects of soils, water tables, and drainage on the height growth of slash and loblolly pine plantations on the Hoffman Forest, *J. Forestry*, 45,836, 1947.
29. Walker, L.C., Green, L., and Daniels, J., Flooding and drainage effects on slash pine and loblolly pine seedlings, *Forest Science*, 7, 2, 1961.
30. For relatively detailed but early discussions of the use of herbicides in forestry, see Walker, L.C., Controlling undesirable hardwoods, Macon, Ga., Georgia Forest Research Council Report 3. 24 pp. 1956; and Walker, L.C., Chemicals used in forestry operations, Forest Farmer Manual, 25, 40, 1985.
31. Clason, T.R., Impact of herbaceous weed suppression on loblolly pine sawtimber rotations, in *Proc., of the Ninth Biennial Southern Silvicultural Research Conference,* February 25-27, 1997, Clemson, SC, Waldrop, T. A., Ed. USDA Forest Service Gen. Tech. Rep. SRS-20, Asheville, NC. 38, 1998, and Lauer, D. K. and Glover, G. R., Pine and competing vegetation response to herbaceous weed control and levels of shrub control in the flatwoods. In *Proc. of the Eighth Biennial Southern Silvicultural Research Conference,* November 1–3, 1994, Auburn, AL, Edwards, M. B., Ed. USDA Forest Service Gen. Tech. Rep. SRS-1, Asheville, NC. 111, 1995.
32. Struve, D. K., and Blazich, F. A., Pre-severance environmental conditions influence rooting response of eastern white pine needle fascicles, *Forest Science*, 30, 343,1984.

Chapter 8

1. Walker, L.C., Natural areas of the Southeast, *J. Forestry,* 61, 670, 1963.
2. Chaiken, L E., Annual summer fires kill hardwood root stocks, Asheville, NC, Southeastern Forest Experiment Station Research Note 19. 1952.
3. Allen, P. H., and Trousdell, K.B., Loblolly pine seed production in the Virginia–North Carolina Coastal Plain, *J. Forestry,* 59, 187, 1981.
4. Reynolds, R. R., Managed growth, New Orleans: Southern Forest Experiment Station Occasional Paper 142. 1955; and Murphy, P. A., Baker, J. B., and Lawson, E. R., Selection management of shortleaf pine in the Ouachita Mountains, *Southern J. Applied Forestry*, 15, 61,1991; Baker, J. B., The Crossett Farm Forestry Forties after 41 years of selection management, *Southern J. Applied Forestry,* 10, 233, 1986; and Reynolds, R. R., Baker, J. B., and Ku, T. T., Four decades of selection management on the Crossett Farm Forestry Forties, Fayetteville: Arkansas Agricultural Experiment Station Bull. 872, 43. See, too, Guildin J. M., and Fitzpatrick, M. W., Comparison of log quality from even-aged and uneven-aged loblolly pine stands in Arkansas, *Southern J. Applied Forestry*, 15, 10, 1991.
5. Shelton, M. G., Effects of opening size on pine and hardwood regeneration 3 years after group selection cutting in southern Arkansas. In: *Proc. of the Ninth Biennial Southern Silvicultural Research Conference*, February 25-27, 1997, Clemson, SC, Waldrop, T. A., Ed., USDA Forest Service Gen. Tech. Rep. SRS-20, Asheville, NC. 343, 1998.
6. Walker, L.C., Silviculture of shortleaf pine, Nacogdoches, TX: Stephen F. Austin State University School of Forestry Bulletin 9, 1966.
7. Lotti, T., and LeGrande, W. P., Loblolly pine seed production and seedling crops in the lower coastal plain of South Carolina, *J. Forestry*, 57, 580, 1959.
8. Lamson, N. I., and Miller, G. W., An aesthetic alternative to clearcutting, *J. Forestry* , 87, 14,1989.
9. Sirmon, G. A., and Dennington, R. W., Longleaf pine management in the DeSoto National Forest—a case study, *Southern J. Applied Forestry,* 13, 34,1989.
10. Wakeley, P. C., The 1947 cone crop and forest fires, New Orleans, Southern Forest Experiment Station Note 51, 1947.
11. Croker, T. C., Early release stimulates cone production, *Southern Forestry Notes*, 79, 1952; Halls, L. K., and Hawley, N. R., Slash pine cone production is increased by seed-tree release, Asheville, NC, Southeastern Forest Experiment Station Note 66, 1954; Cooper, R. W., and Perry, Jr., J. H., Slash pine seedling habits, *Southern Lumberman*, 193, 198, 1956; and Boyer, W. D., Annual and geographic variations in cone production by longleaf pine, In: *Proc. of the Fourth Biennial Southern Silviculture Research Conference*, Asheville, USDA Forest Service General Technical Report SE-42, 73, 1989.
12. Haney, G. P., Seed production of shortleaf pine in the Piedmont, Asheville, NC, Southeastern Forest Experiment Station Research Note 113. 1959; and Phares, R. E., and Rogers, N. F., Improving shortleaf pine seed production in Missouri, *J. Forestry*, 60, 322, 1962.
13. Hoekstra, P. E., and Mergen, F., Experimental induction of female flowers on young slash pine, *J. Forestry,* 55, 827, 1957.
14. Parker, J., New methods for determination of forest tree seed germinability, *J. Forestry*, 51, 34, 1953.
15. Boyer, W. D., and Fartar, R. M., Thirty years of management on a small longleaf pine forest, *Southern J. Applied Forestry*, 5, 273, 1981; and Croker, T. C., Longleaf pine, *J. Forest History,* 23, 32,1979.
16. Hoekstra, P. E., Counting cones on standing slash pine, Asheville, NC, Southeastern Forest Experiment Station Note 151, 1960.
17. Parker, J., *op. cit.*
18. Haney, G. P., *op. cit.*
19. Little, S., and Somes, H. A., Sprouting of loblolly pine, *J. Forestry*, 58, 195, 1960.
20. Croker, T. C., *op. cit.*
21. Kais, A. G., Influence of Needle Age And Inoculation Spore Density On Susceptibility Of Longleaf Pine to *Scirrhia Acicola, Phytopathology*, 67, 686, 1977; and Kais, A. G., and Barnett, J. B., Longleaf pine growth following storage and Benomyl root-dip treatment, *Tree Planter's Notes* 35, 30,1984. See also English, J. T., et al., Seedling blight of longleaf pine caused by a *Binucleate Rhizoctonia Solani*-like fungus, *Plant Disease Reporter*, 70, 148,1986, who noted the pathogen infecting longleaf pine. Also, Brenner, J., and Wade, D., Florida's 1990 Prescribed Burning Act, *J. Forestry*, 90, 27,1992.

22. Peevy, F. A., Hogs still prefer longleaf, *Southern Forestry Notes* 87, 1953; Hopkins, W., Hog dog! *American Forests*, 55, 1949, 20 et fol.; and Lipscomb, D. J., Impact of feral hogs on longleaf pine, *Southern J. Applied Forestry*, 13, 177, 1989.
23. Walker, L.C., and Davis, V. B., Seed Trees retard longleaf pine seedlings, *J. Forestry*, 54, 269, 1956.
24. Hassan, A. E., and Silva, C., Effect of planting date on first-year survival of two pines. In: *Proc. of the Tenth Biennial Southern Silvicultural Research Conference,* February 16–18, 1999, Shreveport, LA, Haywood, J. D., Ed. USDA Forest Service Gen. Tech. Rep., Asheville, NC.
25. Chaiken, L. E., and Nelson, T. C., Site index curves for Piedmont Virginia pine, Asheville, NC, Southeastern Forest Experiment Station Research Note 135, 1959; and Olson, D. F. Jr. and Della-Bianca, L. Site index comparisons for several species in the Virginia–Carolina Piedmont, Asheville, NC, Southeastern Forest Experiment Station Paper 104, 1959.
26. Cooper, R. W., Schopmeyer, C. S., and McGregor, W. H. D., Sand pine regeneration on the Ocala National Forest, Washington: U.S. Department of Agriculture Production Research Report 30, 1959.
27. Outcalt, K. W., Operational trials of a scarifier-seeder for regenerating Ocala sand pine, *Southern J. Applied Forestry,* 14, 85, 1990.
28. Kaufman, C. M., White, J. B., and Monroe, R. J., Growth of pond pine in a pocosin area, *J. Forestry*, 52, 275, 1954.
29. Kaufman, C. M., and Posey, H. G., Production and quality of pond pine seed in a Pocosin Area of North Carolina, *J. Forestry*, 51, 280, 1953; and Crutchfield, D. M., and Trew, I. F., Investigation of natural regeneration of pond pine, *J. Forestry*, 59, 264, 1961.
30. Walker, L.C., Silviculture of the minor southern conifers, Nacogdoches, TX, Stephen F. Austin State University School of Forestry, Bulletin 15, 1973; and Lancaster, K. F., Managing eastern hemlock, Washington, USDA Forest Service, NA-FR-30, 1980 Korstian, C. F., Perpetuation of spruce on cut-over and burned lands in the higher Southern Appalachian Mountains, *Ecological Monographs*, 7, 1125,1937; Minckler, L.S., Preliminary results of experiments in reforestation of old fields in the Great Appalachian Valley and adjacent mountain regions, Asheville, NC, Appalachian Forest Experiment Station Technical Note 47, 1941; and Beck, D. E., *Abies fraseri (Pursh) Poir.* Fraser Fir. In: Burns, R. M., and Honkala, B. H., *Silvics of North America, Vol 1, Conifers*, Washington, USDA Forest Service, 47, 1990: and Blum, B. M., *Picea rubens Sarg*. Red Spruce, In Burns, R. M., and Honkala., B. H., *Ibid.* 250.
31. Little, S., Ecology and silviculture of white-cedar and associated hardwoods in southern New Jersey, New Haven: Yale University School of Forestry Bulletin 56, 1950.; Little, S., Silvical characteristics of Atlantic white-cedar (*Chamaecyparis thyoides*, Upper Darby, PA, Northeastern Forest Experiment Station Paper 118, 1959; and Harkin, D. A., Every seedling from selected seed, *J. Forestry,* 55, 842, 1957.
32. Ibid.
33. Korstian, L. Natural regeneration of southern white cedar, *Ecology*, 5, 188, 1924; Little, S., Silvical characteristics of Atlantic white-cedar, *op. cit.*; and Little, S. and Garrett, P. W., *Chamaecyparis thyoides, (L.)* B.S.P. Atlantic white-cedar, In: Burns, R. M., and Honkala, B. H., *Silvics of North America, Vol. I, Conifers,* Washington, USDA Forest Service Agriculture Handbook 654, 103, 1990.
34. *Ibid.*
35. DuBarty, A. P., Jr., Germination of bottomland tree seed while immersed in water, *J. Forestry,* 61, 225, 1963; and Frey, D. G., Evidence for the recent enlargement of the “Bay” Lakes of North Carolina, *Ecology*, 35, 78, 1954.
36. Mattoon, W. R., The southern cypress, Washington, U.S. Department of Agriculture Bulletin 272, 1915.
37. Della-Bianca, L., and Buck, D. E., Selection management in Southern Appalachian hardwoods, *Southern J. Applied Forestry*, 9, 191,1985; and Leopold, D. J., Parker, G. R., and Swank, W. T., Forest development after successive clearcuts in the Southern Appalachians, *Forest Ecology and Management*, 13, 83,1985; and Loftis, D. L., Herbicide treatment improves regeneration in Southern Appalachian hardwoods, *Southern J. Applied Forestry*, 9, 177, 1985.
38. Trimble, G. R., and Tryon, E. H., Crown encroachment into openings cut in Appalachian hardwood stands, *J. Forestry,* 64, 104, 1966.
39. Wahlenberg, W. G., An early test of levels of growing stock in Appalachian hardwoods, *J. Forestry*, 54, 106, 1956.
40. Williamson, M. J., and Sander, I. L., Response of a mixed hardwood stand in Kentucky to a harvest cutting, *J. Forestry*, 55, 291, 1957.

41. Penfound , W. T., and Hall, T. F., A photosociological analysis of a Tupelo gum forest, *Ecology*, 20, 358, 1939.
42. Applequist, M. B., Longevity of submerged Tupelo-gum and baldcypress seed, Baton Rouge, Louisiana State University School of Forestry Note 27, 1959; and Hosner, J., Survival, root and shoot growth of six bottomland tree species following flooding, *J. Forestry*, 57, 927, 1959.
43. Guttenberg, S., How far does sweetgum seed fly?, New Orleans, Southern Forest Experiment Station Notes 81, 1952.
44. Roth, E. R., and Hepting, G. H., Origin and development of oak stump sprouts, *J. Forestry*, 41, 27, 1943; Keetch, J. J., Sprout development on once-burned and repeatedly burned areas in the Southern Appalachians, Asheville, NC, Appalachian Forest Experiment Station Tech. Note 59, 1959; Liming, F. G., and Johnston, J. P., Reproduction of oak-hickory stands of the Missouri Ozarks, *J. Forestry*, 42, 175, 1944; Hepting, G. H., Early removal of surplus oak sprouts desirable to reduce butt rot, Asheville, NC, Appalachian Forest Experiment Station Technical Note 40, 1940; and Merz , R. W., and Boyce, S. G., Age of oak seedlings, *J. Forestry*, 54, 774, 1956.
45. *Ibid*.
46. Brose, P. H., and Van Lear, D. H. Effects of seasonal prescribed fires on density of hardwood advanced regeneration in oak-dominated shelterwood stands. In: *Proc. of the Ninth Biennial Southern Silvicultural Research Conference*, February 25–27, 1997, Clemson, SC, Waldrop, T. A., Ed. USDA Forest Service Gen. Tech. Rep. SRS-20, Asheville, NC. 310, 1998.
47. Keetch, J. J., *op. cit.*; and McGee, C. E., Northern red oak seedling growth varies by light intensity and seed source, Asheville, NC, Southeastern Forest Experiment Station Note 90, 1968. Water sprouting could be related to inherited susceptibility. As with other species, I (L.W.) have tested growth-regulating hormones for controlling or killing epicormic branches without otherwise damaging the trees, but was unsuccessful. See also Jones, R.H., and Raynal, D.J., Root sprouting in American beech (*Fagus grandifolia Ehrh.*): Effects of root injury, root exposure, and season. Notes in Burns, R.M., and Honkala, B.H., *Silvics of North America, Vol. 2, Hardwoods,* Washington, USDA Agriculture Handbook 654, 328, 1990.
48. Waldrop, T.A., Variations in the fell-and-burn system to regenerate pine-hardwood mixtures in the piedmont. In: *Proc. of the Eighth Biennial Southern Silvicultural Research Conference*, November 1–3, 1994, Auburn, AL, Edwards, M. B., ed. USDA Forest Service Gen. Tech. Rep. SRS-1, Asheville, NC. 401, 1995.
49. Waldrop, T. A., Editor, Proc. of pine-hardwood mixtures: a symposium on management and ecology of the type, Asheville, USDA Forest Service, Southern Forest Experiment Station. 271, 1989.
50. Lickwar, P. M., Cubbage, F. W., and Hickman, C. A., Current southern state programs for control of forestry nonpoint source pollution, *Southern J. Applied Forestry*, 14, 64, 1990.
51. Lickwar, P. M., Hickman, C. A., and Cubbage, F. W., Costs of protecting water quality during harvesting on private forestlands in the Southeast. *Southern J. Applied Forestry*, 16, 13,1991. See also, Reisinger, T. W., Simmons, G. L., and Pope, P. E., The impact of timber harvesting on soil properties and seedling growth in the South. *Southern J. Applied Forestry*, 12, 58,1988.

Chapter 9

1. Biodiversity need not be a favorable condition if maintaining the naturalness of the land is the aim. For the cypress domes of Florida, as an example, establishing biodiversity would destroy the uniqueness of these natural phenomena. See "Biological Diversity in Forest Ecosystems", a Position Statement of the Society of American Foresters, *J. Forestry*, 90, 42, 1992.
2. From a position statement of the Northern California Society of American Foresters, in *Northern California Society Newsletter*, 8, July-September 1991.
3. Walker, L.C., *The Southern Forest: A Chronicle*, Austin, University of Texas Press, 1991.
4. Beck, D. E., Thinning increases forage production in Southern Appalachian cove hardwoods, *Southern J. Applied Forestry*, 7, 53, 1983; and Harlow, R. F., et al*.,* Deer habitat on the Ocala National Forest: Improvement through forest management, *Southern J. Applied Forestry,* 4, 98, 1980. See for a habitat index Crawford, H. S., and Marchinton, R. L., A habitat suitability index for white-tailed deer in the Piedmont, *Southern J. Applied Forestry,* 13, 12, 1989.
5. Locascio, C.G., Lockaby, B.F., Caulfield, B., Edwards, M.B., and Causey, M.K., Influence of mechanical site preparation on deer forage in the Georgia Piedmont, *Southern J. Applied Forestry*, 14, 77, 1990.
6. Goodrum. P., and Reid, V. H., Deer browsing in the Longleaf Pine Belt, *Proc. of the Society of American Foresters*, Washington, Society of American Foresters, 1958.
7. Blair. R. M., and Brunett, L. E., Deer habitat potential of pine-hardwood forests in Louisiana, New Orleans, USDA Forest Service Research Paper SO-136, 1977.
8. Thill, R. E., Deer and cattle forage selection on Louisiana pine-hardwood sites, New Orleans, Southern Forest Experiment Station, USDA Forest Service SO-196, 1983.
9. Moore, E. B., Forest and wildlife management in the South Jersey Pine Barrens, *J. Forestry*. 34, 879, 1940.
10. Stransky, J. J., Managing for quail and timber in longleaf pine forests, Nacogdoches, Texas, Texas Forestry Paper 9, Stephen F. Austin State University, 1971.
11. Stransky, J. J., et al*.,* Plants following timber harvest: importance to songbirds, Nacogdoches, Texas, Texas Forestry Paper 28, Stephen F. Austin State University, 1976.
12. Barden, L. S., Regrowth of shrubs in grassy balds of the Southern Appalachians after prescribed burning, Castanea, 43, 238, 1978.
13. Rosenberg, D. K., Fraser, J. D., and Stauffer, D. F., Use and characteristics of snags in young and old forest stands in southwest Virginia, *Forest Science*, 34, 224, 1988.
14. As of mid-1991, the South's regional forester was asking the public for its opinion of his tentative decision to approve certain thinning and regeneration practices within 3/4 of a mile of colony sites on national forest land in order to enhance the habitat and thereby sustain the woodpeckers.
15. Billings, R. F., At issue: 'Fritz and the Feds, American forests, 98, 55 et fol. 1992.
16. Roise, J. P., Chung, J., and Lancia, R., Red-cockaded woodpecker habitat management and longleaf pine straw production: an economic analysis, *Southern J. Applied Forestry*, 15, 88, 1991.
17. Kelley, G. A., et al*.,* Changes in distribution of trout in Great Smoky Mountains National Park, 1900–1977, Washington, U.S. Fish and Wildlife Service Technical Paper 102, 1980.
18. Metz, L., Moisture held in pine litter, *J. Forestry*, 56, 36, 1958; Weitzman, S., and Trimble, G. R., Jr., Integrating Timber and Watershed Management in Mountain Areas, J. Soil and Water Conservation. 10, 70, 1955.
19. Jemison, G. M., Effect of Litter Removal on Diameter Growth of Shortleaf Pine, *J. Forestry*, 41, 213, 1943.
20. Broadfoot, W. M., Soil and litter under pine plantations, *Southern Forestry Notes*, 55, 1948.
21. Mergen, F., and Malcolm, R. M., Effect of hemlock and red pine on physical and chemical properties of two soil types, *Ecology*, 36, 468, 1955.
22. Voigt, G. K., Alteration of the composition of rainwater by trees, *Am. Midland Naturalist*, 63, 321, 1982.
23. Alderfer, R. B., and Bramble, W. C., The effect of plant succession on infiltration, State College, Penn State School of Forestry Paper 5, 1942.
24. Miller, E. L., Sediment yield and storm flow response to clear-cut harvest and site preparation in the Ouachita Mountains, Water Resources Research, 20, 471,1984.

25. Blackburn, W. H., *et al.,* Forest site preparation and water quality in Texas, In: *Proc. of the Specialty Conference on Environmentally Sound Water and Soil Management* , New York, American Society of Civil Engineers, 1982.
26. Dickerson, B. F., Soil Compaction after tree length skidding in Northern Mississippi, *J. Soil Science Society of America*, 40, 965, 1976; and Gent, J. A., Jr., and Ballard, R., Impact of Intensive forest management practice on the bulk density of lower coastal plain and Piedmont soils, *Southern J. Applied Forestry* 9, 44, 1985.
27. Burns, R. G., and Hewlett, J. D., A decision model to predict sediment yield from forest practices, Water Resources Bulletin, 19, 9, 1983.
28. Johnson, M. K., and Pearson, H. A., Esophageal, fecal, and exclosure estimates of cattle diets on a longleaf pine-bluestem range, *J. Range Management*, 34, 232, 1981.
29. Lewis, C. E., Simulated cattle injury to planted slash pine: girdling, *J. Range Management*, 33, 337, 1980.
30. Pearson, H. A., Southern pine plantations and cattle grazing, *J. Forestry* 85, 36, 1987.
31. Cassady, J. T., et al., Cattle grazing damage to pine seedlings, New Orleans, Southern Forest Experiment Station Occasional Paper 141, 1955.
32. Halls, L. K., et al., Common browse plants of the Georgia coastal plain, Asheville, Southern Forest Experiment Station Paper 75, 1957.
33. Lemon, P. C., Successional responses of herbs in the longleaf-slash pine forest after fire, *Ecology*, 30, 135, 1949.
34. Kubota, J., *et al.,* The study of cobalt status of soils in Arkansas and Louisiana using the black gum as the indicator plant, *Soil Science Society of America Proc.,* 24, 527, 1960.
35. Bell, M. J., Hunter, D. H., and Swindel, B. F., Understory biomass response to microsite and age of bedded slash pine plantations, *J. Range Management* 34, 38, 1981.
36. Ives, J. D., and Dow, V., The Indian Peaks Wilderness Area, map separate of Indian Peaks Environmental Atlas, Boulder, International Mountain Society, 1981.
37. Grelen, H. E., *Ilex opaca Ait*. American Holly, in: Burns R. M., and Honkala, B. H., *Silvics of North America*, *Vol. 2, Hardwoods,* Washington, USDA Forest Service Agriculture Handbook 654, 379, 1990.
38. Schopmeyer, C. S., and Larson, P. R., Effects of diameter, crown ratio, and growth rate on gum yields of slash and longleaf pine, *J. Forestry*, 53, 822, 1955.
39. Schopmeyer, C. S., and Larson, P. R., Gum-yield tables for slash and longleaf pine on poorer than average sites, *Naval Stores Review*, 65, 14, 1954; and Bengtson, G.W., et al., Intensive gum extraction, *Forest Farmer* 18, 8 et fol., 1959; and Clements, R.W., Air temperature and gum yield, Asheville, Southeastern Forest Experiment Station Research Note 168, 1961.
40. Butler, C. B., *Treasures of the Longleaf Pines Navel Stores*, Shalimer, Florida: Teaskel Publishing, 1998.
41. Schopmeyer, C. S., The characteristics of a high gum-yielding tree, Asheville, Southeastern Forest Experiment Station Research Note 39, 1953.
42. True, R. P., and Snow, A. G., Jr., Gum flow from turpentine pines inoculated with the pitch canker fusarium, *J. Forestry*, 47, 894, 1949.
43. Walker, L.C. and Hicks, R. R., Jr., America's forests: an energy enterprise, In: *Agriculture and Energy*, New York, Academic Press, 1977.
44. Demmon, E. L., Rate of formation of heartwood in southern pines, *J. Forestry*, 34, 775, 1936.

Afterword

1. Much of this Afterword is gleaned from Walker, L.C., Ecologic concepts in forest management, *J. the American Scientific Affiliation* 32, 204, 1980.
2. Thoreau, H. D., *Walden*, New York, Dodd, 1854.
3. Sloan, E., *Reverence for Wood*, New York, Funk, 1974.
4. Nash, R., *Wilderness and the American Mind*, New Haven, Yale University Press, 1967.