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Siviculture and Management Strategies Applicable to Southern Hardwoods

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Chapter 7.

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Abstract—_Southern hardwood forests stretch from the Virginias to Florida and from the mid-Atlantic to Missouri. They can generally be grouped into upland forests and bottomland forests. The upland hardwood forests of the southern region are usually associated with the mountainous topography of the Appalachians and Ozarks. Bottomland hardwoods are found along the floodplains of larger rivers in the Atlantic and Gulf Coastal Plains, including the Mississippi River floodplain. Southern hardwood forests are owned by a variety of governmental and private owners, but the vast majority of owners are nonindustrial private individuals. These owners seldom engage in intensive forest management, often exploiting the resource. The silvicultural systems applicable to the management of hardwoods are the same as those recommended for pines, but in hardwood management, reliance on natural regeneration is more common than use of plantation silviculture. Oak species are very important in the southern hardwood forests, and lack of oak regeneration in present-day forests is a major concern. Lack of fire and the resurgence of white-tailed deer throughout the southern region are proposed as reasons for poor oak regeneration. Many stands, either due to their stage of development or neglect, are in need of intermediate management operations such as thinning and improvement cutting. Crop-tree management is a method that is particularly useful in southern hardwoods. It was concluded that although hardwoods make up a significant part of the southern forest resource, they are generally managed with less intensity than pines, and hardwood management is an opportunity area for the South in the future._

INTRODUCTION

In this chapter, we discuss the silviculture and management of upland and bottomland hardwoods in the Southeastern United States. We begin by briefly describing the physiographic, edaphic, and climatic conditions for each forest type. Land use history and ownership patterns are then discussed because these factors are important in determining what types of stands occur and the objectives of landowners. Finally we describe the appropriate silvicultural techniques for regenerating and culturing the commercially valuable species in each management type.

Upland Hardwoods

The southern upland hardwoods occur extensively in the Southern Appalachians, on the Cumberland Plateau, and in the Ozark region. A diverse array of hardwood species is represented by genera such as *Acer, Carya, Fraxinus, Liquidambar, Liriodendron, Prunus,* and *Quercus*. The southern upland hardwoods include pine-hardwood mixtures in the Piedmont and southern Coastal Plains, but by far the most commercially significant upland hardwoods in the South occur in the Southern Appalachian region. For purposes of this discussion, the Southern Appalachian region includes the hilly or mountainous area west and north of the Piedmont and south of the glaciated portion of Pennsylvania. Using Fenneman's (1938) classification, this region is termed the "Appalachian Highlands," and contains parts of the Blue Ridge, Ridge and Valley, and Appalachian Plateau physiographic provinces. The Appalachian Highlands are classified as being in the Eastern Broadleaf Forest Province (Bailey 1996). The climate is continental and part of the Humid Temperate Domain (Bailey 1996). Rainfall is favorable for plant growth and is well distributed throughout the year. Highest precipitation rates occur in the southern Blue

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Ridge of the Carolinas and north Georgia, where annual precipitation averages 60 to 80 inches per year (Hicks 1998). Across most of the region, annual precipitation averages 40 to 50 inches. The geology of the Appalachian Highlands region is predominantly sedimentary. Sandstones of the Pennsylvanian period cap the highest mountains throughout the Appalachian Plateau Province, and limestones and shales predominate in the sharply folded Ridge and Valley Province. The Blue Ridge is composed primarily of metamorphic rock substrates with some igneous intrusions and small areas with sedimentary rock. At higher elevations of the southern Blue Ridge, Precambrian rock outcrops can be found. Faulting, folding, and geologic weathering have interacted with the geologic materials to produce the complex, steep, and rocky terrain found in the Appalachian Highlands.

Deciduous hardwood species predominate in the Appalachian Highlands. These include several oaks (*Quercus* spp.), hickories (*Carya* spp.), maples (*Acer* spp.), yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), and American beech (*Fagus grandifolia* Ehrh.). The area was also a prime range for American chestnut [*Castanea dentata* (Marsh.) Borkh.], a species that was all but eliminated by the chestnut blight {*Cryphonectria parasitica* (Murrill) Barr [formerly *Endothia parasitica* (Murrill) Anderson & Anderson]} during the early part of the 20th century. Braun (1950) classified a substantial portion of the Appalachian Highlands as being in the oak-chestnut forest region. Most of the forests of the Appalachian Highlands are second growth, resulting from previous logging and fires or from revegetation of abandoned fields.

Bottomland Hardwoods

Southern bottomland hardwoods occur mainly in the broad, Lowland Coastal Plain Province of the Atlantic Plain physiographic division and the gulf lowlands (Fenneman 1938) extending from the eastern tip of Pennsylvania south along the Atlantic coast and west along the gulf coast to the Rio Grande River. They also occur north along the Mississippi River floodplain to southern Illinois and to some extent along all the major and minor rivers east of the Great Plains (Hodges 1995). Despite the dense tree cover and the difficulty of clearing land, this ecosystem was the first in the Southern United States to be converted to agricultural crops. It was taken for agricultural use because it occupied level terrain with inherently fertile soils. The Coastal Plain is underlain by alluvial and marine sediments of mostly Cretaceous, Tertiary, and Quaternary age. Sediments were laid down in various onshore, nearshore, and offshore environments (Stanturf and Schoenholtz 1998). Annual precipitation in the major alluvial floodplains ranges from 48 to 64 inches and is generally greater during the warm season (Kellison and others 1998, Muller and Grymes 1998). The amount of rainfall received, however, is not a reliable indicator of the magnitude and duration of the flooding that can occur. Upstream precipitation in large watersheds (some cover hundreds of thousands of acres) has a larger impact on downstream flooding than local precipitation does (Kellison and others 1998).

Bottomland forests are extremely diverse, including more than 70 tree species (Putnam and others 1960) of which 40 are of commercial value (Hosner 1962). Angiosperms predominate, but a few gymnosperms occur. A number of tree species are common throughout southern bottomlands; these include red maple (*A. rubrum* L.), water hickory [*C. aquatica* (Michx. f.) Nutt.], sugarberry (*Celtis laevigata* Willd.), persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), swamp chestnut oak (*Q. michauxii* Nutt.), water oak (*Q. nigra* L.), American elm (*Ulmus americana* L.), and baldcypress [*Taxodium distichum* (L.) Rich.] (Kellison and others 1998). Bottomland hardwood forests occur in the portions of the floodplain that are free from flooding for most of the year. These areas support the most diverse forests and sustain excellent growth (Smith 1995). Areas that are flooded for extended periods every year have fewer species, which have evolved special adaptations to these conditions (McKevlin and others 1998). Growth rates in the more flooded areas can be high, but they are highly variable (Conner 1994, Conner and Buford 1998, Megonigal and others 1997).

The quality and composition of bottomland forests have been influenced dramatically by past timber harvesting, agricultural use, grazing, and uncontrolled fires. The overall result of these influences has been a general degradation of composition and quality, even though volumes are increasing (Hodges 1995).

Pre-European Forests

Both upland and bottomland hardwood forests of the Southeastern United States were manipulated by Native Americans for thousands of years prior to the advent of Europeans (Carroll and others 2002). Native Americans used fire for many purposes. They controlled the composition and pattern of vegetation by frequently burning the southern landscape. They burned to manage wildlife habitat, ease travel, expose acorns and chestnuts, improve visibility, encourage fruiting, prepare their fields for planting, and to facilitate hunting and defense (Bonnicksen 2000, Pyne and others 1996, Williams 1989). Frequent low-intensity burning by Native Americans created a southern landscape of prairies, fields, savannas, woodlands, and dense forests. The southern hardwood forest was hardly a dense, old-growth landscape at the time of European discovery. The myth of low-impact management by Native Americans may have been reinforced by the fact that the major European occupation of interior America came after native populations had been devastated by diseases introduced by earlier European immigrants.

Some areas were burned on an annual basis and, if burning continued over long periods, became prairies or balds. Other areas, such as north-facing coves in the Southern Appalachians and frequently flooded bottomland forests, burned infrequently. Between these two extremes were forest communities that burned at varying intervals, thus creating a mosaic of forest conditions throughout the South. In the hardwood forests of the South, anthropogenic fires were complemented by occasional lightning-ignited fires (Carroll and others 2002).

Post-European Effects

The European settlers who displaced the Native Americans from the upland forests continued to burn the forest frequently to encourage forage production for their livestock (Pyne and others 1996). However with the advent of steam power for harvesting and processing of timber, wide-scale logging and the slash it produced created a different type of fire regime. High-intensity, stand-replacement fires ignited by sparks from locomotives followed logging and burned vast acreages of upland forests from the late 1880s though the early 1930s (Brose and others 2001).

Fire protection efforts begun early in the 20th century gradually became more effective and allowed the forests to develop—for the first time in millennia—in the absence of fire. However decades of fire exclusion had unintended consequences. The development of dense understories and midstories of shade-tolerant shrubs and trees is now a major contributor to the oak regeneration problem. In other areas, rhododendron (*Rhododendron maximum* L.) and mountain laurel (*Kalmia latifolia* L.) thickets have become so dense and expansive that the species diversity of cove forests is threatened. Because of these problems, there is renewed interest in using prescribed fire as a management tool in upland hardwood forests (Yaussy 2000).

Villages of early European colonists were almost always located along major streams. A rice culture developed, first in the vicinity of Charleston, SC, and then elsewhere along the Southeastern U.S. coast. On the fringes of the rice paddies and beyond, corn, wheat, and cotton supplanted hardwood forests.

Following attempts to control water flow in the major alluvial floodplains, first by private enterprise and then by public agencies, especially the U.S. Army Corps of Engineers, the forests were increasingly cleared for agricultural crops. Only about half of the original bottomland forests remained by the 1930s. From the 1930s to the 1980s, the bottomland forest area was further reduced from 11.8 to 4.3 million acres as a result of drainage and clearing for agriculture.[2] Conversion was especially rapid during the 1960s and 1970s when the price for farm crops, especially soybeans, reached unprecedented levels.

Land Ownership Characteristics

The majority of hardwood forest land (upland and bottomland) is in the hands of nonindustrial private forest (NIPF) ownership (MacCleery 1990), although a substantial portion of the Blue Ridge and Allegheny Highlands is in national forests and parks. The motivation for forest activity for most nonindustrial forest landowners appears to be income, although most of these owners do not rank commercial forest production as the number one reason for holding land (Egan and Jones 1993).

It is possible to combine commercial timber operations with forest stand improvement through application of appropriate silviculture in southern hardwoods. The development of new markets for smaller diameter and lower grade materials has enhanced the opportunity for producing revenue from heretofore noncommercial stands. Unfortunately, however, the type of timber harvesting often being practiced on NIPF lands amounts to high-grading of one type or another.

[2] Allen, J.A.; Kennedy, H.E., Jr. 1989. Bottomland hardwood reforestation in the Lower Mississippi Valley. [Not paged]. On file with: Southern Research Station, Southern Hardwoods Laboratory, P.O. Box 227, Stoneville, MS 38776.

Forest landowners share certain attributes that help to explain their behavior. Many are older and have lived during times when much of today's forest land was in fields, a condition that they worked hard to preserve. In addition, many people, accustomed to the practices of the past, believe that "timbering" is a once-in-a-lifetime affair. Thus many owners fail to see the value of managing their forest land.

It is incumbent on foresters who interact with landowners to begin their association by explaining what planned forest management means and what is and is not possible. Owners need to understand that even with relatively small tracts, it is possible to spread the income out over time while enhancing the future health, productivity, and value of the forest. It may be difficult to convince owners of such facts, since foresters are going against beliefs that have been years in the making. Owners may find it difficult to accept the fact that many second-growth forests are even-aged, and the larger trees are not older, but simply faster growing.

SILVICULTURE OF UPLAND HARDWOODS

Oaks, as a group, constitute the most significant hardwood forest resource in the southern uplands. Oaks, however, are losing their position in many upland forests, being replaced by aggressive species such as red maple and yellow-poplar (Abrams 1998, Brose and others 2001).

Exclusion of periodic, low-intensity surface fires from the hardwood forests of the Appalachian Highlands in the early decades of the 20th century has changed the character of these forests. Oaks thrive under a regime of periodic disturbance by surface fires (Brose and others 1999, Van Lear and Brose 2001). Because young oaks invest heavily in root development at the expense of height, they are at a competitive disadvantage with aggressive species like yellow-poplar and red maple, especially on above-average sites. However, when surface fires kill the aboveground portion of trees, the resulting seedling sprouts of oaks have a distinct advantage over their competitors. In the absence of periodic surface fires, oaks do not maintain a position of dominance in the advance regeneration pool. Thus as wind, ice, or partial harvesting disturbs the upper canopy, other species in the advance regeneration pool are poised to dominate.

This chapter uses concepts from Hicks' (1998) book "Ecology and Management of Central Hardwood Forests" to describe the silvicultural methods that are appropriate to most upland hardwood stands. It is our goal to demonstrate that properly designed commercial harvests can utilize silviculturally sound concepts, and to provide descriptions of relevant silvicultural methods and their application to NIPF stands. We also hope to discourage the use of loose terms such as "selective cutting," and to encourage foresters to develop a vocabulary that is appropriate and descriptive of the practices being recommended. Finally we want to stress that in hardwood stands, it is often necessary to apply several silvicultural methods simultaneously, and that management of hardwood stands must remain adaptable to changing market conditions, natural occurrences such as insect and disease outbreaks, and changing social pressures.

Most silviculture and forest management texts emphasize "traditional" approaches based on German methods that were developed for use in relatively simple coniferous ecosystems. Although a great deal of research on hardwood management has been conducted in North America, the information that has been produced must be presented in a form that is useful to managers.

Silvicultural methods can generally be grouped into treatments that are used to tend existing stands (intermediate operations) and those that are aimed at regenerating new stands. Hardwood silviculture differs markedly from pine silviculture in both areas. Topographic considerations, economic factors, and the abundance of natural regeneration usually prevent the application of plantation silviculture for upland hardwood management. Also, hardwoods almost always occur in mixed species stands in which commercially valuable trees are intermingled with trees of lower value. The objective of management is to work in concert with the natural ecosystem processes to favor the regeneration, growth, and quality of desirable trees. Intermediate cuttings that are most appropriate to hardwoods are crown thinning, improvement cutting, and crop-tree management. Among regeneration systems, those that are most appropriate to hardwoods are clearcutting, the shelterwood method, and related two-age systems. All of the foregoing create even-aged or two-age stands. The single-tree selection system and variations such as group selection will work well if the objective is to grow shade-tolerant species in multiage stands. However, none of the shade-tolerant commercial species in the southern forest region provide viable management opportunities.

Intermediate Operations

Crown thinning—The crown-thinning method is defined by Smith (1986) as thinning that involves the removal of trees in the upper strata of the canopy to favor desirable trees in the same canopy range. In crown thinning, the focus is on the better trees (crop trees) that are to be provided with additional growing space and resources. As with all thinning methods, crown thinning is applied at the stand level where residual stocking targets are an important consideration. Crown thinning seems particularly applicable to fully stocked or overstocked mixed oak or mixed mesophytic hardwood stands on above-average sites. Although species such as northern red oak (*Q. rubra* L.) are capable of responding to release at age 50 and older, appropriate candidate stands of shade-intolerant species such as yellow-poplar and black cherry should be treated earlier than oaks. Care should be given to residual stand density, understory composition, and stem wounding of residual trees. Excessive thinning can induce epicormic branching of residuals or release undesirable midstory or understory species, or both. Sonderman and Rast (1988) recommend thinnings of moderate-to-light intensity in mixed oak stands in order to minimize branch-related defects that typically result from heavier thinnings in such stands. Residual stand density should be maintained at a level above the "B" line and below the "A" line defined by Gingrich (1967).

Improvement cutting—Smith (1986) defines improvement cutting as cuttings done in stands past the sapling stage for the purpose of improving composition and quality by removing trees of undesirable species, form, or condition from the main canopy. Unlike crown thinning and crop-tree management, the focus of improvement cutting is on the "undesirable trees." Improvement cutting is widely applicable to southern upland hardwood stands. It is appropriate for use in mixed oak, oak-hickory, and mixed mesophytic hardwood stands. The silvical characteristics of the species present should be a prime consideration, but improvement cutting can generally be applied to stands well beyond age 50. Depending on the owner's objectives, species typically targeted for removal can include red maple, American beech, hickories, blackgum (*Nyssa sylvatica* Marsh.), scarlet oak (*Q. coccinea* Muenchh.), and black locust (*Robinia pseudoacacia* L.) in addition to poor-quality individuals of more favored species. Improvement cutting is widely applicable to current upland hardwood stands because of the age and current composition of many such stands, although marketing of trees removed may be difficult. Many upland hardwood stands have a past history of high-grading (Nyland 1992) which may limit the number of desirable trees available to leave in the residual stand. At some point, it becomes advisable to regenerate severely impoverished stands rather than apply intermediate management to them.

Crop-tree management—Crop-tree management is a technique that focuses on "individual" trees that have the potential to develop into high-value crop trees. Perkey and others (1993) emphasize that crop-tree value should be defined by the landowner's objectives. The two phases in crop-tree management are assessment and enhancement. Generally the assessment phase involves the selection of trees that have the potential for meeting the objectives defined by the landowner. Enhancement consists of activities that foster the attainment of those objectives. For example, if timber management was the objective, trees of desirable species with good stem quality and capable of responding to release would be selected as crop trees. The enhancement operation would release crop trees by removing some of the trees that compete with them for sunlight, water, and nutrients. The recommended method for releasing crop trees is the "crown-touching" method described by Lamson and others (1988). To apply this method, the crop-tree crown is divided into four quadrants (sides) and one determines whether the tree is free-to-grow on each of these sides. A three-sided release has been recommended by Lamson and others (1990) for use in younger stands. For older stands or for species with a tendency toward epicormic branching, a two-sided release is more appropriate. Cutting, girdling, or the use of herbicides (Miller 1984) can accomplish release of the crop tree. The advantages of crop-tree management are:

1. It permits crop-tree designation to fit landowner objectives
2. It is simple to apply and fits well with NIPF needs
3. It provides for an even flow of forest products over time
4. It allows for continuous forest cover until crop trees are harvested
5. Management efforts are concentrated on trees with the highest potential for future gain

Crop-tree management has disadvantages:

1. It does not provide for regeneration after removal of crop trees

2. Sometimes removal of low-grade interfering trees may not be a commercial operation and thus may constitute a cost to the landowner

However generally speaking, crop-tree management like improvement cutting is a widely applicable method that is appropriate to many mixed hardwood stands. The earlier the crop-tree enhancement can be applied to a stand, the longer the effect can benefit the crop trees. However, there are risks in attempting to assess crop trees and potential competitors at early ages.

Silvicultural Systems and Regeneration Methods

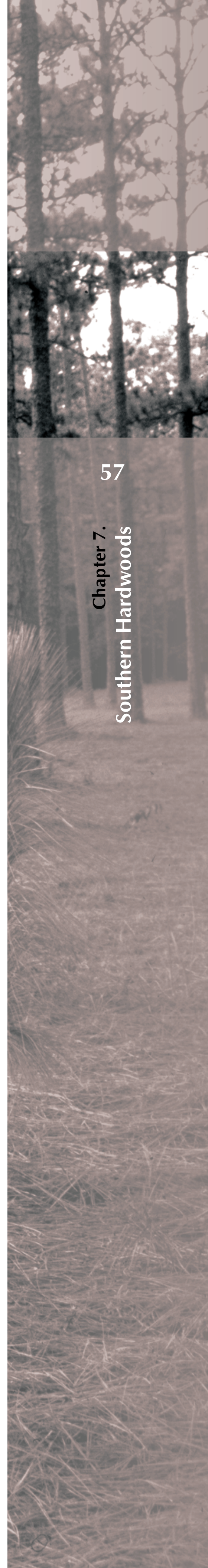
When a harvest is planned, an assessment should be made to determine how the stand would be regenerated. The information needed includes: (1) condition and size-class distribution of overstory trees by species; (2) quantity and condition of understory trees (desired initial and advanced reproduction); (3) kind and amount of competing vegetation; and (4) regeneration method, e.g., seeds, seedlings, or stump and root sprouts (Nyland 1996).

Clearcutting—In the clearcutting method, the overstory is completely removed in a single operation. The method is designed to regenerate even-aged, single-cohort stands, and generally favors relatively shade-intolerant species. Clearcutting mimics large-scale disturbances such as the fires and windstorms that have had a historic role in the creation of southern hardwood stands. In order to provide conditions that qualify as a clearcut, openings must be at least 1 to 2 acres in size (Sander 1992). In the southern uplands, clearcutting promotes regeneration of fast-growing, exploitive species such as yellow-poplar, sweetgum, and pines. On poorer sites (south- and west-facing slopes and ridges), clearcutting is effective in regenerating oaks. On the best sites in the Southern Appalachians (oak site index greater than 70), clearcutting favors yellow-poplar, often resulting in pure stands of that species. Successful regeneration can be delayed after clearcutting by the rapid development of competing vegetation such as ferns, brambles, and herbaceous species, as well as woody perennials such as sassafras [*Sassafras albidum* (Nutt.) Nees], dogwood (*Cornus florida* L.), rhododendron, and grapevine (*Vitis* spp.). In most cases, commercial woody species ultimately prevail, but other factors such as heavy browsing by white-tailed deer (*Odocoileus virginianus*) can delay the regeneration process even further. The early successional communities produced by clearcutting provide exceptionally good habitat for wildlife in the Southern Appalachians where maturing second-growth forests dominate the landscape (Harlow and others 1997).

Although clearcutting is a reliable way to regenerate a variety of hardwoods, many landowners regard it with disfavor. For a short time (1 to 10 years, depending on site quality), it produces a bare landscape that is not aesthetically acceptable to most owners. In addition, in the case of NIPF ownership, the property is often relatively small. A small owner who wants to attract a buyer for his or her timber may find it necessary to cut most or all of the timber at one time. This creates an undesirable situation in which income is produced only at very long intervals and the aesthetic value of the property is compromised for a long period. Conversely for larger ownership, clearcuts up to 20 to 30 acres might represent a relatively small percentage of their land base.

Shelterwood method—The shelterwood method is an even-aged management system that involves development of a standing crop of regeneration through a series of partial removals of the overstory (Smith 1986). In a three-cut shelterwood, the cuts are: (1) a preparatory cutting, designed to improve the quality and vigor of the residuals; (2) a seed cutting, designed to encourage regeneration; and (3) a removal cutting, designed to remove the overstory. The two-cut variation of the method eliminates the preparatory cutting and is appropriate where most of the trees in the current stand are of the desired species. The shelterwood method is often recommended for regenerating species that are intermediate in shade tolerance, such as oaks (Loftis 1990, 1993).

A shelterwood-burn technique developed by Brose and others (1999) takes advantage of basic differences between germination and root development strategies of oaks and many of their competitors to enhance the competitive position of oak regeneration on good sites. A few years after the initial shelterwood cut, a moderately hot growing-season burn is run through the developing advance regeneration to favor the oak reproduction. The reduction in competing vegetation by burning and the vigorous resprouting by oak reproduction shortens the time the shelterwood method requires. In the absence of fire, it may take 10 to 20 years to complete the shelterwood regeneration process, and this represents a longer commitment on the part of landowners and managers than they may be willing to make. Deer browsing can become a significant problem when applying the



shelterwood method, since deer often selectively browse species that are desired as regeneration.

Two-aged system—Leave-tree (deferment) cutting is receiving increasing attention for regeneration of southern upland and bottomland hardwoods. Implementation of the practice includes leaving 20 to 30 square feet per acre of basal area until the end of the following rotation in combination with the regeneration that develops in the openings created by partial harvesting of the parent stand. As opposed to the shelterwood system, where the residual overstory trees are removed to allow the regeneration to develop, leave-tree cutting maintains the overstory trees until the end of the rotation. At that time, the residual trees are removed together with about 75 percent of the basal area of the regenerated stand. The cycle is repeated in the next rotation and, thus, an overstory is present during all stages of stand development.

An additional benefit of this system is that a mixture of crop trees can be retained for the next rotation. Some of the trees might be selected for their timber value, and some for wildlife and other values. This system is equivalent to the "high forests with reserves" of European forestry (Matthews 1989). A major disadvantage of two-age systems is the vulnerability of leave trees to damage by windthrow, lightning strikes, and epicormic shoot development.

Selection system—The single-tree selection system is designed to develop a multicohort (all-age) stand of shade-tolerant species. In practice, however, it may be impractical to achieve this goal because it requires frequent stand entry and because the smallest diameter classes may not develop in the shade of trees of the larger diameter classes. Proper application of the selection system involves establishing several criteria, which include a residual basal area target, largest-tree-to-grow, a "q" factor, and a cutting cycle length (Smith and Lamson 1982). Single-tree selection is complex to apply, requires long-term commitment, and requires the presence of commercial species that are shade tolerant. In the Southern Appalachians, it may be applicable only in high-elevation stands that contain sugar maple (*A. saccharum* Marsh.). Because it has these limitations, professional foresters rarely apply the system.

Modifications of this method involve cutting trees in small groups or patches. These "group selection" systems may be more appropriate in the southern upland hardwoods than single-tree selection, although group selection, like single-tree selection, requires repeated entry into the stand. One of the common mistakes made by both foresters and landowners is to refer to "selective cutting" (cutting some trees and leaving others) as a legitimate silvicultural activity. The similarity between the terms "selective cutting" and "selection system" is unfortunate and leads to confusion.

SILVICULTURE OF BOTTOMLAND HARDWOODS

Bottomland hardwood forests are made up of an extremely heterogeneous mixture of species except in permanently flooded swamps and newly formed lands and old fields. Thirteen bottomland forest types are recognized by the Society of American Foresters (Eyre 1980). The U.S. Department of Agriculture Forest Service recognizes only two bottomland hardwood types for inventory purposes: oak-gum-cypress and elm-ash-cottonwood. The following discussion of silvicultural information draws heavily on Hodges (1995) and the chapter by Kellison and others (1998) in the book "Southern Forest Wetlands: Ecology and Management" (Messina and Conner 1998). Other primary sources include McKelvin (1992) and Kellison and Young (1997) who have compiled the findings of scientists regarding regeneration of bottomland hardwood forests.

Mixed hardwoods in the major alluvial floodplains generally have been logged one to several times since Dutch settlers (Heavrin 1981) built the first sawmill in the United States in 1633. Loggers have usually removed only the best and largest trees while leaving the smallest and least valuable trees to form the new stand. This form of timber harvesting, commonly known as selective harvesting, is in reality high-grading, a practice that should be condemned by foresters. This degenerative practice is not to be confused with the silviculturally sound selection system, in which the desired tree species mix of all size classes is maintained.

Diameter-limit cutting, improperly applied, is another form of high-grading. The principle is to harvest only those trees above a certain size, such as those 14 inches in diameter at breast height, and leave the remainder to develop into the succeeding stand. The assumption is that the small trees will grow into large trees of good quality in perpetuity. The problem is that natural stands of timber do not perpetuate themselves by like-producing-like. The openings created by removal of the larger trees will be occupied by the expanding crowns of the edge trees or by shade-tolerant understory trees that are already in place. The succeeding trees decrease the value of the stand for timber production and wildlife habitat with each partial harvest. In alluvial floodplains, cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) would likely be succeeded by green ash; green ash would be replaced by sugarberry; and boxelder (*A. negundo* L.) and American hornbeam (*Carpinus caroliniana* Walt.) would finally supplant sugarberry. Generations of selective, incomplete harvests have reduced many bottomland hardwood stands to a poorly stocked, low-value condition.

The proper management procedure for major alluvial floodplain forests is to control the undesirable trees at the same time desired ones are harvested, and to maintain natural patterns and cycles of water flow (Kellison and others 1988). Fortunately, the practices best suited for accomplishing these goals are also those best suited for timber production, wildlife management, and maintenance of the flora and fauna associated with the alluvial forest.

Stands that have been harvested repeatedly often contain two, but rarely more than three age groups, with each age group dating to a previous harvest. Even though the species composition of the older age classes is usually desirable, a high component of the trees is culls with no timber value. Conversely, a high component of the youngest age class of timber is usually of poor species composition, resulting from the development of shade-tolerant trees in the understory of the residual crown classes. However, many of these stands, especially those occupying sites of high soil quality, are worthy of timber stand improvement, in which the undesirable trees are controlled to release the desirable trees in the intermediate crown class.

Even-Aged Systems

Experience has shown that stands occupying major alluvial floodplains will regenerate following complete harvesting of the timber in a single entry (clearcutting) or in two entries (shelterwood cutting). The regeneration from such harvested stands of trees less than about 100 years old will be largely from stump and root sprouts (Mader 1990). Stands of an older age class and those with altered hydrology will largely regenerate from seed in place at the time of harvest or transported to the site by wind, water, and fauna. The types of even-aged regeneration systems having application to major alluvial floodplains are clearcutting, patch clearcutting, shelterwood cutting, and seed-tree cutting.

Clearcutting—Clearcutting of hardwood forests that have the propensity to regenerate themselves from stump and root sprouts reduces species succession almost to the pioneering sere. It is only one stage short of a catastrophic event such as a hurricane in which stump and root sprouting of merchantable timber is severely limited because of windthrow and perhaps two stages short of a cleared bottomland field where all initial regeneration must be from seeds or planting.

In spite of its lack of aesthetic appeal, clearcutting is often the best way to regenerate hardwoods, especially degraded or impoverished stands. The regeneration will largely be from advanced reproduction and sprouts, but seedling reproduction will form a part of the succeeding stand in patches where sprout or advanced reproduction is absent. Seedling reproduction has little chance of developing into the succeeding stand if it occurs 3 or more years after sprout development. Species succession of advanced reproduction and sprouts proceeds much as it does with seedling reproduction, with shade-intolerant species showing fastest initial growth.

Opposition to clearcutting often results from the visual impact of the treatment and from wildlife considerations. We recommend that the size of clearcuts not exceed 20 acres. This maintains the silvicultural benefits of clearcutting while minimizing the adverse aesthetic effects. Additionally, it is desirable that (1) the harvested area should be configured to the landscape with scalloped edges; (2) declining, overmature, or hollow trees should be left standing for wildlife purposes (approximately 2 per acre); and (3) dead and downed trees should be left on site for associated flora and fauna.

Patch clearcutting—This system is a variation of clearcutting, with the size of the treated area being the major difference. The configuration implied is noncontiguous patches or strips. Areas of about 5 acres are usually considered optimum. Smaller areas are adversely affected by edge trees, the influence of which extends into the opening about the distance of the height of the dominant trees. The edge trees limit the growth of shade-intolerant species at the expense of shade-tolerant ones.

A significant limitation of patch clearcutting is that it requires frequent stand entry, which eventually results in many small patches. The small patches create innumerable problems in stand management and inventory, and they are poorly suited for forest interior-dwelling birds and certain other fauna (Sietz and Segers 1993).

Shelterwood cutting—When the shelterwood system is applied to bottomland hardwoods, best results are obtained when the overstory canopy is reduced to about 50 percent of its original cover. This level of reduction allows sufficient sunlight to reach the ground to promote seedling and sprout reproduction.

Experience has shown that clearcutting and shelterwood cutting initially give rise to similar types of reproduction, but that the intolerant species under a shelterwood will start to decline if the overstory trees are not removed within 5 to 10 years. Shelterwood cuts can help buffer against rising water tables in areas where the soil water table has risen as a result of altered hydrology. In some situations, the shelterwood system is advocated for the regeneration of oaks, especially cherrybark oak. Shelterwood cutting is not always essential for oak regeneration in alluvial floodplains because species such as water oak and willow oak (*Q. phellos* L.) can regenerate equally well with or without a partial overstory stand (Leach and Ryan 1987). In deeper water systems, such as muck swamps, shelterwood systems appear to be no more effective in developing the desired reproduction than clearcut systems (McKevlin and others 1998).

Seed-tree cutting—The prescription for seed-tree cutting is to leave four to eight seed trees per acre while removing all other overstory and understory trees. The theory is that seeds from the leave trees will be disseminated over the area, helping to ensure success in regeneration. However seed trees are usually a wasted effort in alluvial floodplains because most heavily harvested hardwood stands regenerate successfully from sprouts, from seeds buried in the duff, and from seeds disseminated by water, wind, and fauna. The primary reason for leaving such trees is for wildlife, ecological, and aesthetic values.

Uneven-Aged Systems

Stands of trees of widely different ages can be maintained by the selection system in which harvesting, regeneration, and intermediate stand treatments are applied at the same time. Stands are entered at intervals of from 1 year to perhaps every 10 years. Each cutting removes financially mature and high-risk trees, adjusts stand density to create room for the best trees to grow, and makes space for new reproduction. A specific stand structure is achieved by leaving the desired basal area levels in several diameter classes.

Single-tree selection—This is the system often advocated by the opponents of clearcutting or shelterwood cutting. The ecological basis of the system is sound, but the application is so difficult that, in practice, the exercise often approximates a selective or diameter-limit cut.

Group selection—This variant of single-tree selection involves removal of groups of trees of similar age, size, or species on an area usually not exceeding 0.25 acres. Care must be taken to remove undesirable as well as desirable trees. Group selection differs from patch clearcutting in that it employs small openings and frequent entries to promote a multiaged stand of shade-tolerant species. The necessity to enter the stand repeatedly at short intervals may make it impractical to implement the practice.

Two-aged system—We have discussed this method previously in connection with upland hardwoods. The method is similarly applicable to bottomland hardwoods and has the advantage on wet sites of requiring relatively few entries.

Plantation Management and Restoration

Procedures have been developed for establishing hardwood plantations on alluvial floodplains (Malac and Herren 1979). Industrial foresters have focused on developing eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) and sycamore (*Platanus occidentalis* L.) plantations. Eastern cottonwood has shown more promise than other species in the Mississippi River Delta, but sycamore—and to some extent sweetgum, green ash, water oak, and willow oak—have proven more adaptable than cottonwood to some of the other alluvial floodplains of the South. About 125,000 acres of commercial hardwood plantations currently exist in southern bottomlands. Despite successes on the floodplains, with growth rates of 3 to 4 cords per acre per year at rotations of 15 to 18 years, the trend is to establish hardwood plantations outside of the alluvial floodplains. The causes for this shift in site location include environmental concerns and the difficulty of managing and harvesting the resource in areas with episodic flooding. Few industrial forestry organizations are willing to invest in plantation forestry in alluvial floodplains when there is significant uncertainty about the implications of the Clean Water Act for such operations.

Floodplain forest restoration efforts have been limited, and most have focused on reestablishment of forest cover for timber, stream protection, or wildlife habitat values (King and Keeland 1999, Stanturf and others 1998b). Typically forest managers have tended to increase the numbers of certain preferred tree species in the stands (Chambers and others 1987). In the past 10 to 15 years there has been a preference for planting oaks (Haynes and others 1995, King and Keeland 1999), and this practice could result in a greater occurrence of oak regionally than was typical of presettlement forests (The Nature Conservancy 1992). More recently, greater emphasis has been given to planting a wider variety of bottomland species (Allen and others 2001, King and Keeland 1999).

Several of the largest reforestation efforts today are in areas of the Lower Mississippi River Valley, including parts of the Yazoo National Wildlife Refuge, the Tensas National Wildlife Refuge, and the Ouachita Wildlife Management Area, and on privately owned land enrolled in the Wetland Reserve Program. About 193,000 acres have been seeded or planted, with the potential of 494,000 acres being returned to forest by the year 2005 (King and Keeland 1999). Many of the areas being reforested are on poorly drained lands cleared for agricultural crops in the 1960s and 1970s and abandoned later because of substandard crop yields and limited accessibility. Reforestation and restoration efforts are proving successful in reestablishing bottomland hardwood species that may provide commercial timber and wildlife habitat (Allen and Kennedy 1989, Clewell and Lea 1990, Haynes and Moore 1988).

Various forest establishment techniques have been used, including direct seeding of oaks and planting of seedlings or cuttings of several bottomland species (Stanturf and others 1998a). Although direct seeding is about half the cost of planting seedlings (Bullard and others 1992), the technique is reliable only for oaks and, to a lesser degree, other large-seeded species such as pecan [*Carya illinoensis* (Wangenh,) K. Koch]. Smaller seeds are more susceptible to damage by heat and dry soil. Allen (1990), who compared 4- to 8-year-old stands in the Yazoo National Wildlife Refuge, concluded that planting of tree seedlings was more effective than direct seeding in establishing wildlife habitat quickly. He reported extensive drought-caused mortality of newly germinated seeds, even though there was effective invasion of light-seeded species, especially sweetgum, green ash, and American elm.

CONCLUSIONS

Because of the ownership characteristics, age and composition of stands, and the silvical characteristics of the species present, many hardwood stands in the South are appropriately managed by means of intermediate cuttings (notably improvement cutting and crop-tree management). The method of harvest regulation that seems most appropriate to hardwood stands is volume regulation, since it is more compatible with partial cutting methods.

Selecting the method of regeneration is more troublesome. Shelterwood methods, or some modification of them, are often recommended for regenerating oaks. If prescribed fire is an option, it is possible to favor oak regeneration on better upland sites by employing a shelterwood-burn method.

Clearcutting is an effective way to regenerate a variety of hardwood species (generally shade-intolerant ones) in both upland and bottomland forests, while group selection can be used to regenerate and maintain multiaged hardwood stands. Plantation silviculture of bottomland species like cottonwood, sweetgum, and American sycamore has been successful, but plantations of upland hardwoods have had limited success. Maintaining an adaptive strategy to take advantage of bumper crops of advance regeneration and to capture value from market changes is important in hardwood management. As long as certain rules are followed, such as matching harvesting with periodic growth, avoiding high-grading, and providing for regeneration, southern hardwoods can be managed sustainably.

The array of premium-grade hardwoods in the eastern deciduous forest is second to none in the world (Hicks 1998). The timber from genera such as *Acer*, *Juglans*, *Prunus*, and *Quercus* is in demand for furniture in every developed country. Therefore the future will be to manage for premium-grade timber while using the residual for fiber products. The challenge will be for professional foresters to convince landowners, public officials, and environmental advocates to embrace the practice of proper timber harvesting on a region-wide scale. Failure to implement proper silviculture will result in continuation of the high-grading that has been normal practice since the inception of timber harvesting in the eastern deciduous forest. High-quality saw logs and veneer logs are among the most profitable markets for hardwoods, but a limitation to the strategy of managing hardwoods exclusively for premium-grade logs is that it could reduce the emphasis on hardwood fiber production. This will force many North American pulp and paper companies to rely on offshore suppliers for their wood, and eventually for their pulp. As North American pulp and paper manufacturing plants become obsolete from lack of capital investment, they may relocate closer to the source of the raw material.

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