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Silvicultural Options for Young Bottomland Oak-Dominated Plantations on Former Agricultural Lands

**James S. Meadows, Emile S. Gardiner,
Theodor D. Leininger, and Andrew W. Ezell**

Authors

James S. Meadows, Research Forester, **Emile S. Gardiner**, Research Forester, and **Theodor D. Leininger**, Research Plant Pathologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776; and **Andrew W. Ezell**, Professor and Department Head Emeritus, Department of Forestry, Mississippi State University, Mississippi State, MS 39762.

Cover photo

Water oak (*Quercus nigra*) plantation on Malmaison Wildlife Management Area, Grenada County, Mississippi. (USDA Forest Service photo by Emile Gardiner)

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Abstract

This handbook presents several arrays of practical silvicultural options to landowners and forest managers of young, bottomland oak-dominated plantations. Each array of options is designed specifically to achieve one of three common landowner objectives: (1) production of high-quality oak sawtimber as the sole or primary objective; (2) creation of improved habitat for wildlife as the sole or primary objective, primarily through improved acorn production; and (3) integrated management for both oak sawtimber and improved wildlife habitat as multiple objectives of roughly equal importance and priority to the landowner. The handbook is divided into eight major sections: (1) patterns of stand development and acorn production over time in young, oak-dominated plantations; (2) silvicultural tools used for site, tree, and stand assessment, and for evaluation of acorn crops; (3) generalized decision-making process for initial management of young, oak-dominated plantations; (4) types of intermediate stand practices and their objectives; (5) possible detrimental effects of intermediate cuttings; (6) important factors to consider in the development of silvicultural options; (7) appropriateness of systematic cutting in young, oak-dominated plantations; and (8) silvicultural options suitable for attaining each of the three landowner objectives. To illustrate differences and similarities among the silvicultural options, we present an example based on data collected from an existing oak plantation to compare the structure and appearance of the residual stands that would result from the application of an appropriate silvicultural prescription for each of the three management objectives. For each management objective, we simulate the application of a silvicultural prescription designed to achieve that objective.

Keywords: Acorn production, bottomland oaks, integrated management, intermediate cuttings, plantations, *Quercus*, sawtimber production.



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Introduction

Before 1985, afforestation of marginal agricultural lands in the Lower Mississippi Alluvial Valley (LMAV) was not widespread. In fact, between 1968 and 1985, only about 2,000 acres of these lands were afforested with bottomland hardwood species, mostly on lands owned by the U.S. Fish and Wildlife Service in Mississippi (Schoenholtz and others 2001).

However, creation of the Conservation Reserve Program (CRP) in 1985 and the Wetland Reserve Program (WRP) in 1990 greatly stimulated afforestation efforts on private lands throughout the LMAV. These two cost-share programs provided Federal funds to remove economically marginal farmland from crop production and to afforest these lands with bottomland hardwood species. Both programs have strict guidelines for meeting specific conservation and wildlife habitat targets. Since its inception, nearly 500,000 acres of bottomland hardwood plantations have been established across the LMAV under

WRP alone (Gardiner 2014). Total area of bottomland hardwood plantations, in public and private ownership combined, across the LMAV likely exceeds 1 million acres today. Bottomland oaks (*Quercus* L. spp.), in both pure and mixed-species plantings, dominate an estimated 50–75 percent of those acres. Willow oak (*Q. phellos* L.), Nuttall oak (*Q. texana* Buckl.), and water oak (*Q. nigra* L.) are the most common bottomland oak species planted in the LMAV, but cherrybark oak (*Q. pagoda* Raf.), Shumard oak (*Q. shumardii* Buckl.), swamp chestnut oak (*Q. michauxii* Nutt.), and overcup oak (*Q. lyrata* Walt.) have been planted in some areas. Important silvical characteristics of these species are listed in table 1.

Many of these plantations have reached the stage of development at which some type of silvicultural activity might be warranted. However, silvicultural treatments should be applied only if necessary and should be designed to achieve

Table 1—Silvical characteristics of seven oak species commonly planted in the Lower Mississippi Alluvial Valley

Species	Typical site	Shade tolerance	Flood tolerance	Diameter growth	Height growth	Timber value	Wildlife value
Cherrybark oak	Limited to well-drained, loamy ridges	Intolerant	Moderately intolerant	Excellent	Moderate	Very high	High
Nuttall oak	Common on poorly drained, clayey flats and low ridges	Intolerant	Moderately tolerant to tolerant	Good to excellent	Moderately rapid, but with rapid early growth	High	Very high
Overcup oak	Common on poorly drained, clayey low flats and sloughs	Moderately intolerant	Tolerant	Poor to medium	Slow to moderate	Low to medium	Low to medium
Shumard oak	Limited to well-drained, loamy ridges	Intolerant	Moderately intolerant	Good	Moderately rapid	Very high	High
Swamp chestnut oak	Limited to well-drained, loamy ridges	Moderately intolerant	Moderately intolerant	Medium to good	Moderate	Very high	Very high
Water oak	Common on well-drained, loamy or silty clay high flats and ridges; also common on poorly drained, clayey low flats	Intolerant	Moderately tolerant	Good on high flats and ridges; poor to medium on low flats	Moderate, but with rapid early growth	Medium to high	Very high
Willow oak	Common on well-drained loamy or clayey high flats and ridges; also common on poorly drained, clayey low flats	Intolerant	Moderately tolerant	Good on high flats and ridges; poor to medium on low flats	Moderate	High	High

Source: Putnam and others (1960).

specific landowner objectives more effectively. Unfortunately, there is limited knowledge of the effectiveness of silvicultural practices in young, oak-dominated plantations, compared to natural stands. We believe that many of the same biological and silvicultural principles that apply to natural bottomland hardwood stands also apply to young, bottomland oak-dominated plantations, with some notable exceptions. For example, the lack of species diversity in plantations creates differences in the type of competition experienced by trees in plantations versus natural stands. Trees in plantations generally experience only intra-specific competition whereas trees in mixed-species natural stands experience inter-specific competition. The effects of these differences on the response to silvicultural treatments are largely unknown. However, even though many of the silvicultural prescriptions described in this handbook were developed for natural stands, we believe that the responses of oak-dominated plantations to those prescriptions likely will be similar to the responses observed in natural stands.

This handbook presents several arrays of practical silvicultural options to landowners and forest managers of young, bottomland oak-dominated plantations. In general, our guidelines and recommendations apply to bottomland oak-dominated plantations. We do not address the guidelines and specific management targets associated with the CRP and WRP programs. Each array of options presented in this handbook is designed specifically to achieve one of three common landowner objectives. Rather than a single recommendation, we present different options for each objective so that the landowner and forest manager can select, from among an array of options, the one prescription that is most suitable for their particular needs and situation.

The focus of this handbook is on the silviculture of bottomland oak-dominated plantations 15 to 40 years old. It includes both pure oak plantations and plantations in which oaks are grown in various mixtures with other species with the intent to produce a plantation eventually dominated by oaks. We do not include information on plantation establishment techniques because this topic is addressed adequately elsewhere (e.g., see Kennedy 1993). We focus on silvicultural options and intermediate stand practices in individual oak-dominated plantations, not across a landscape or entire ownership. However, these silvicultural prescriptions must fit within the context of landowner objectives described in the management plan developed for the entire property or ownership. Finally, we

assume that the oak-dominated plantations addressed in this handbook will be managed as even-aged stands. We do not address silvicultural practices designed to convert even-aged plantations to uneven-aged stands.

This handbook is not intended to provide comprehensive discussions of all aspects of forest management and wildlife management, nor is it intended to be a comprehensive review of the literature associated with these two topics. The goal for this handbook is to provide the forest manager and landowner with some basic background information related to intermediate management and to present various silvicultural options that can be used in young, bottomland oak-dominated plantations to achieve three common landowner objectives:

1. Production of high-quality oak sawtimber as the sole or primary objective;
2. Creation of improved habitat for wildlife as the sole or primary objective, primarily through improved acorn production;
3. Integrated management for both oak sawtimber and improved wildlife habitat as multiple objectives of roughly equal importance and priority to the landowner.

We recognize that improved wildlife habitat requires attention to many other stand attributes in addition to improved acorn production. Examples include browse production, stand structure, soft mast production, ground flora composition, and species diversity. But, it is beyond the scope of this handbook to address these characteristics. Our guidelines and recommendations are limited to improved acorn production.

This handbook is divided into eight major sections: (1) patterns of stand development and acorn production over time in young, oak-dominated plantations; (2) silvicultural tools used for site, tree, and stand assessment, and for evaluation of acorn crops; (3) a generalized decision-making process for initial management of young, oak-dominated plantations; (4) types of intermediate stand practices and their objectives; (5) possible detrimental effects of intermediate cuttings; (6) important factors to consider in the development of silvicultural options; (7) appropriateness of systematic cutting in young, oak-dominated plantations; and (8) silvicultural options suitable for attaining each of the three landowner objectives previously listed.

Patterns Of Plantation Development

Plantation Development

Stand development is the process through which various stand attributes change over time. Attributes of interest typically include, but are not limited to, average tree size, species composition, stand density, and stand structure. The pattern of stand development for any given type of stand depicts the general path traversed by that stand from establishment through maturity. If we identify the expected pattern of development for a particular stand, we can use silviculture to: (1) guide the stand along the expected path, (2) correct the trajectory of the stand if needed and return it to the expected path, or (3) accelerate the rate of development so that the stand reaches the desired condition more rapidly.

More specifically, the pattern and rate of development in bottomland oak-dominated plantations are controlled by four critical factors: (1) species planted, (2) site quality, (3) initial spacing, and (4) weed control. Bottomland oak species differ somewhat in their inherent growth rates and in their intra- and inter-specific competitive abilities. For example, water oak exhibits faster early height growth than cherrybark oak. Consequently, the rate of early development in water oak plantations may be somewhat more rapid than in cherrybark oak plantations. Most bottomland oaks compete well with non-oak tree species, but do not compete well with other oaks. As a result, plantations of oaks in mixture with non-oak species, such as sweetgum (*Liquidambar styraciflua* L.), typically develop at a faster pace than pure oak plantations. Site quality affects the rate of plantation development because it affects the actual rate of growth of planted trees. The rate of growth of planted trees increases with increasing site quality and thus the rate of plantation development also increases. Initial spacing affects plantation development because it controls the onset of competition among planted trees. Narrow initial spacing leads to early competition, whereas wide initial spacing delays the onset of competition. Weed control during the first 1–2 years after plantation establishment may increase the survival and growth of planted trees, especially on sites with a heavy cover of large grasses, such as johnsongrass [*Sorghum halepense* (L.) Pers.], or woody vines.

Most bottomland oaks in plantations grow about 1–2 feet in height per year for the first 5–7 years, after which the rate of height growth increases to about 2–3 feet per year, such that most plantation-grown oaks are about 15–25 feet tall by age 10 years (Allen and Kennedy 1989). However, the rate of height growth varies considerably with differences in site quality. For example, based on site index curves published by Broadfoot (1961, 1963, 1969), average height of dominant and codominant Nuttall, water, and willow oaks on good sites should range from 75 to 85 feet at age 30 years and from 85 to 100 feet at age 40 years. Dominant and codominant cherrybark oaks on excellent sites could attain heights of 95 feet at age

30 years and 110 feet at age 40 years. In contrast, dominant and codominant trees of all four oak species on poor sites likely will attain heights of only 55–65 feet at age 30 years and 65–75 feet at age 40 years.

Rates of diameter growth and stand basal area growth also vary widely with differences in site quality. Based on published growth rates (Briscoe 1955, Putnam and others 1960), we expect average diameter at breast height (d.b.h.) of dominant and codominant Nuttall, water, and willow oaks on good to excellent sites to range from 12 to 18 inches at age 40 years. Dominant and codominant cherrybark oaks on excellent sites may average as much as 20 inches in d.b.h. at age 40 years. Conversely, dominant and codominant trees of all four oak species on poor sites likely will average only 6–10 inches in d.b.h. at age 40 years. Basal area of plantations comprised of any of the four oak species should range from 100 to 140 square feet per acre on good to excellent sites, but only 60–80 square feet per acre on poor sites, at age 40 years.

Generalized patterns of change in survival percent, average d.b.h. of dominant and codominant trees, and stand basal area over time in bottomland oak-dominated plantations are depicted in figures 1, 2, and 3, respectively. Actual values for these variables at different ages may vary widely among plantations due to the influences of the four factors described earlier. However, the patterns of change in these variables are generally consistent from one plantation to another.

We propose four general stages of undisturbed development in bottomland oak-dominated plantations through the first 40 years after establishment: (1) initial development; (2) crown closure and differentiation into crown classes; (3) severe competition among both planted and volunteer trees; and (4) periodic waves of mortality. These stages are somewhat comparable to the stand initiation and the stem exclusion stages of stand development described by Oliver and Larson (1990).

Initial development—This stage of plantation development is characterized by steady growth of planted trees until full occupancy of the site is achieved (fig. 4A). It begins immediately after the establishment of the plantation and ends with crown closure, which occurs when plantation trees fully occupy the available growing space of the site. The initial development stage lasts about 5–10 years, depending on site quality and initial spacing. It ends earlier on good sites and at narrow spacings and later on poor sites and at wide spacings.

Herbaceous plants and other non-tree species are abundant throughout the initial development stage, creating a diverse supply of browse for wildlife. Invasion by volunteer trees, especially of light-seeded species, may be widespread during

Figure 1—Generalized pattern of change in survival percent over time in bottomland oak-dominated plantations.

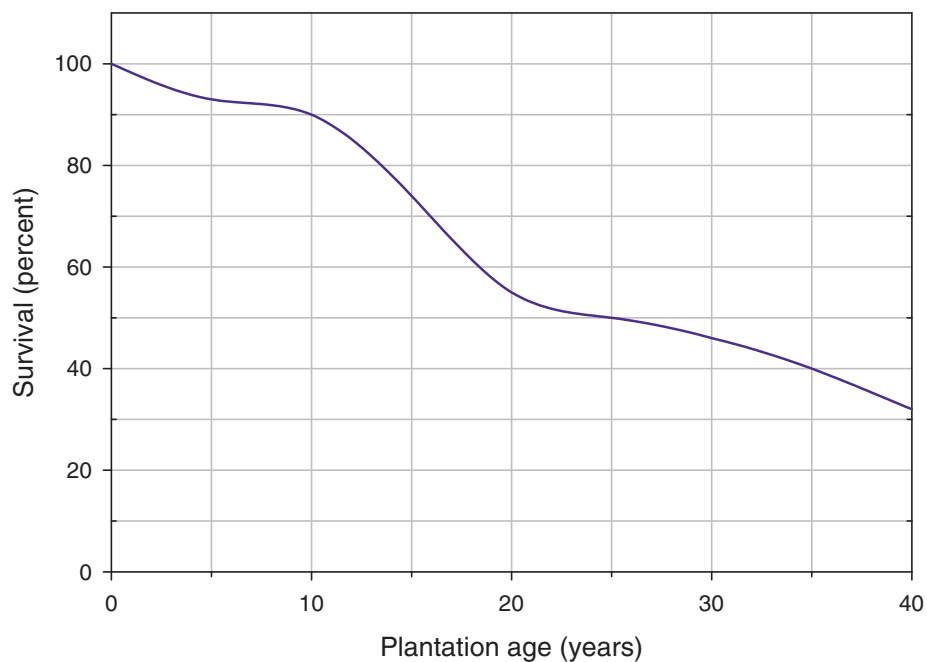


Figure 2—Generalized patterns of change in average d.b.h. of dominant and codominant trees over time in bottomland oak-dominated plantations on good-to-excellent sites and on poor sites.

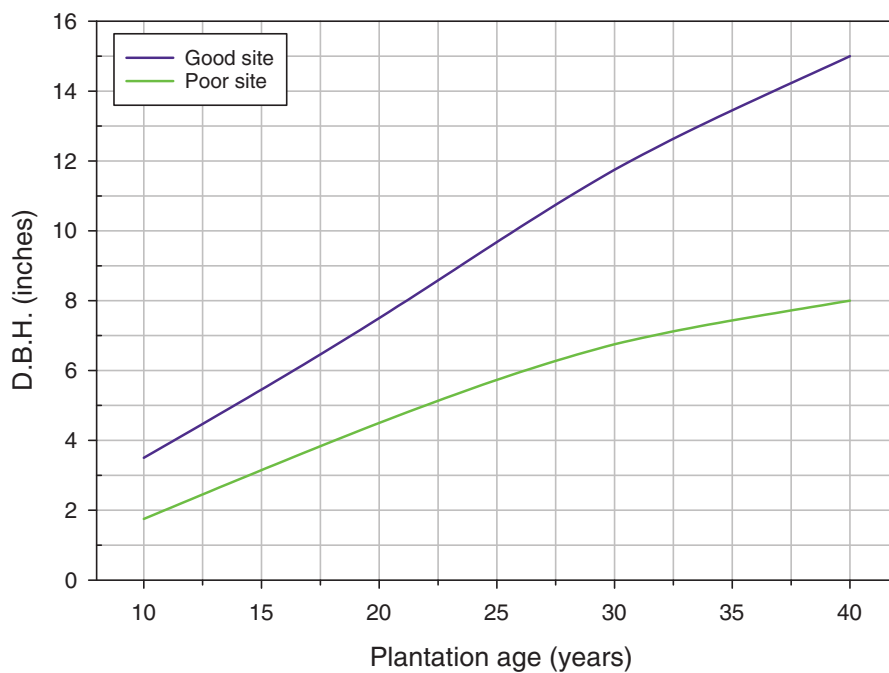
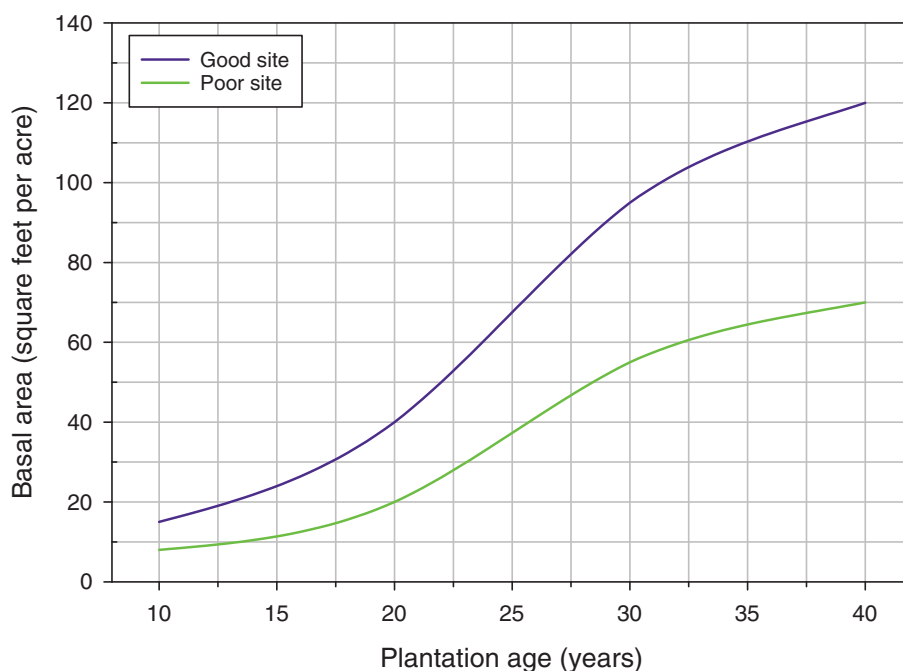


Figure 3—Generalized patterns of change in stand basal area over time in bottomland oak-dominated plantations on good-to-excellent sites and on poor sites.



the initial development stage. However, the abundance and diversity of browse, as well as the rate of invasion by volunteer trees, decline as the plantation approaches full occupancy of the site.

Planted trees may experience slight to severe competition with both non-tree species and volunteer trees. The degree of competition varies widely from one plantation to another and even within a plantation. But, competition among planted trees is limited during the initial development stage. By the end of this stage of plantation development, individual trees have not yet asserted dominance over other trees. Mortality of planted trees during this stage is typically low but can be significant in certain situations. Some planted trees may die as a result of severe competition with tall grasses, woody vines, and/or volunteer trees. However, unusually high mortality is almost always due to poor planting stock, poor planting techniques, incorrect matching of species to site, and/or adverse weather conditions or adverse climatic events during the first few years after plantation establishment (Allen and Kennedy 1989).

During the latter years of the initial development stage, average diameter growth of planted trees is relatively rapid and is maintained at a somewhat constant rate. Basal area growth of the plantation is initially slow but accelerates quickly as this stage of development progresses. Both diameter growth and basal area growth may begin to decline slightly as the plantation approaches full occupancy of the site.

Crown closure and differentiation into crown classes—

This stage of plantation development is characterized by the onset of competition among planted trees that culminates in

differentiation of the planted trees into crown classes (fig. 4B). It begins with crown closure, the point at which plantation trees fully occupy the available growing space of the site. It ends when plantation trees complete the process of differentiation into crown classes. This stage of plantation development generally lasts about 10–15 years, depending on several factors. For example, crown closure typically occurs early and differentiation into crown classes proceeds rapidly on good sites. In contrast, crown closure occurs later and differentiation into crown classes proceeds slowly on poor sites. Differentiation into crown classes also is affected by the type of plantation (pure oak versus mixed species) and the species planted. In general, bottomland oaks compete well with non-oak species, but do not compete well with other oaks. Consequently, differentiation into crown classes proceeds at a normal pace in plantations in which bottomland oaks are grown in mixture with non-oak species. But, differentiation into crown classes in pure oak plantations sometimes proceeds much more slowly and may take up to 25 years to complete.

Once crown closure has occurred, the amount of direct sunlight that reaches the ground is reduced. As a result, the abundance and diversity of browse on the forest floor decline rapidly during this stage of plantation development. Herbaceous plants and grasses typically are affected most by the reduction in sunlight. Also, invasion by volunteer trees is curtailed greatly.

At the time of crown closure, most planted trees are approximately the same height. Very few trees have gained dominance over other trees. However, crown closure marks the onset of direct competition among planted trees for growing

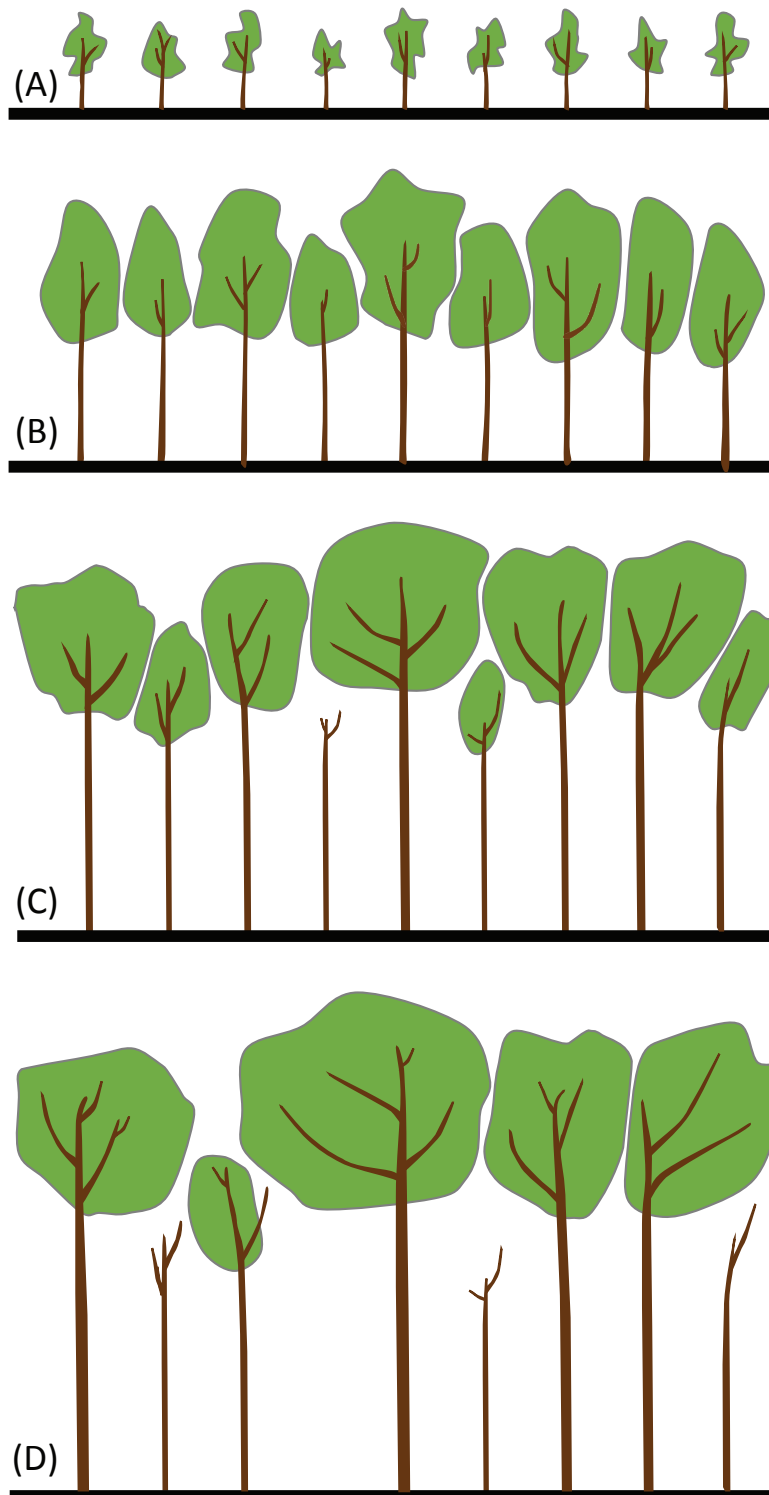


Figure 4—Stages of bottomland oak plantation development. (A) **Initial development**—oak growth during this stage of development advances with minimal competition among neighboring trees. (B) **Canopy closure and crown differentiation**—crown competition among neighboring trees begins to limit oak growth during this stage of development. The onset of canopy closure initiates crown differentiation into crown classes. (C) **Severe competition among planted trees**—oak plantations begin to exhibit “natural thinning” or “self-thinning” during this stage of development. Tree competition results in mortality of oaks relegated to suppressed crown classes, while surviving dominant and codominant trees typically show a growth response to neighboring tree mortality. (D) **Periodic waves of mortality**—this stage of development is characterized by recurring waves of self-thinning that advance through the plantation as it matures. The most competitive oaks maintain dominant or codominant crowns, while weaker trees with intermediate or suppressed crowns often continue a decline to mortality.

space and other resources. For a variety of reasons, such as differences in inherent growth rate, physiological responses to environmental stress, or injuries sustained earlier in life, trees differ in their ability to compete with neighboring trees. Consequently, once planted trees begin to compete with one another, trees with strong competitive abilities outgrow and crowd out neighbors with weak competitive abilities. Strong trees acquire more and more growing space at the expense of weak trees which then occupy less and less growing space. As this process continues, strong trees get stronger and grow faster; weak trees get weaker and grow more slowly. This growth disparity results in differentiation of individual trees throughout the plantation into one of four crown classes: dominant, codominant, intermediate, and suppressed. Mortality during this stage of plantation development is generally low but increases dramatically as intermediate and suppressed trees begin to die during the next stage of development.

Diameter growth rate, averaged across all trees in the plantation, declines sharply as trees differentiate into crown classes. However, average diameter growth rate of dominant and codominant trees is maintained at a relatively high level, especially on good sites. Basal area growth also continues at a high level during this stage of plantation development.

Severe competition among both planted and volunteer trees—This stage of plantation development is characterized by intense competition among both planted and volunteer trees that results in significant mortality across the plantation (fig. 4C). It begins immediately after most trees in the plantation differentiate into crown classes and ends when the mortality rate of intermediate and suppressed trees tapers off. Although the beginning and end are not distinctly identifiable points in time, this stage of plantation development generally lasts about 15–25 years. Duration of this stage depends on how rapidly suppressed trees die. Trees of shade-intolerant species, like most bottomland red oaks, cannot survive suppression for long periods of time. Trees of more shade-tolerant species, like swamp chestnut oak, can survive suppression for longer periods of time.

Death of suppressed trees across the plantation usually occurs as a continuous process throughout this stage of development. However, some species, particularly willow oak, often deviate from this pattern. When grown in pure plantations, willow oak does not compete well with itself, especially at narrow spacings on poor sites. Under these conditions, differentiation of individual willow oak trees is a slow, incomplete process. Most of the trees fail to exert dominance over their neighbors. Competition among planted trees becomes very intense, but few trees die as a result. Instead, growth of all trees in the plantation declines sharply. These plantations eventually may approach stand stagnation, in which mortality is low and growth is extremely slow.

Death of suppressed trees often is called natural thinning or self-thinning. As suppressed trees die, surviving dominant and codominant trees are released from the competition of their weaker neighbors. They usually respond to that release with a slight-to-moderate increase in diameter growth. Because suppressed trees do not die at a constant rate, average diameter growth of dominant and codominant trees fluctuates mildly throughout this stage of plantation development. While diameter growth of surviving trees remains strong, mortality of suppressed trees is high. Consequently, basal area of the plantation reaches a relatively stable level by the end of this stage of development.

Periodic waves of mortality—This stage of plantation development is characterized by irregular waves of mortality separated by periods of stable growth and low mortality (fig. 4D). It begins with completion of the wave of mortality associated with initial differentiation into crown classes and continues as the plantation develops to maturity.

At the end of the wave of mortality described in the previous stage of plantation development, surviving trees grow to occupy the growing space vacated by dead trees. When the surviving trees experience ever-increasing competition from other, more-distant surviving trees, a shift in crown class of the surviving trees may occur. Strong trees remain in the dominant and codominant classes, whereas weaker trees fall into the intermediate and suppressed classes. This secondary differentiation is followed by another wave of mortality as recently suppressed trees die. This pattern of periodic waves of mortality alternating with periods of stable growth and low mortality is repeated through maturity of the plantation. Distance between surviving trees generally increases with each successive wave of mortality. Timing of the waves of mortality depends on: (1) growth rates of surviving trees, (2) spacing of surviving trees, (3) duration of the secondary differentiation process, and (4) time required for suppressed trees to die. Most of the mortality observed during this stage of plantation development is due to competition. However, some tree death is caused by other factors, such as stand disturbance, insect and/or disease problems, and severe weather events.

Average diameter growth rate of surviving dominant and codominant trees is enhanced during the growth phase after each wave of mortality. This diameter growth spurt is similar to the diameter growth response of residual trees to thinning. Diameter growth of surviving trees follows a general pattern after each wave of mortality. Diameter growth accelerates as the crown expands into the growing space previously occupied by dead neighbors. As the available growing space is captured, diameter growth stabilizes, then declines as competition with other surviving trees intensifies. This severe competition then triggers another wave of mortality.

Development of Acorn Production

Biological foundations of flowering and acorn production

—The ability to flower and produce acorns, i.e., reproductive maturity, in bottomland oaks is controlled by several physiological mechanisms that are under genetic control and initiated over time as the tree grows and develops. Early growth in bottomland oaks is primarily vegetative—growth of root, stem, branch, and leaf tissues. More than a decade of vegetative growth typically occurs before bottomland oaks transition into reproductive maturity. This transition is marked by observation of reproductive growth, such as growth of flower and acorn tissues. We can determine if a bottomland oak has reached reproductive maturity by surveying the crown for flowers that appear with bud-break in the spring. Once reproductive maturity is attained, healthy trees tend to flower annually because initiation of this process is only minimally affected by environmental factors such as weather.

Acorn production by reproductively mature bottomland oaks, in its simplest form, is a function of the number of reproductively viable branches produced and maintained by the tree. Flowering and acorn development are associated with branch exposure to full sunlight. So, trees with a large proportion of their crown in full sunlight will maintain relatively high densities of flowering branches per unit of crown, produce relatively high frequencies of flowers on the sunlit branches, and maintain the relatively high photosynthesis needed to support energy allocation to acorn development. However, tree development into a favorable crown position is not the only determinant of acorn production. The underlying processes that progress to acorn maturation are controlled strongly by genetic and environmental factors. Consequently, bottomland oaks show tremendous variation in acorn production at several levels important to stand management. The following discussion highlights (1) genetic factors that govern the potential for acorn production, and (2) interacting environmental factors that foster or limit actual acorn production at species, individual tree, and stand levels over time.

To build on the very simplistic model described earlier, bottomland oaks can be separated into two species groups (subgenera) based on differences in flowering and acorn maturation. Specifically, patterns of egg-cell fertilization and acorn development distinguish species in the white oak group (Section *Lepidobalanus*) from species in the red oak group (Section *Erythrobalanus*) (Cecich and Haenchen 1995). Species in the white oak group, including swamp chestnut oak, overcup oak, and swamp white oak (*Quercus bicolor* Willd.), follow a pattern in which the egg-cell is fertilized soon after pollination in the spring, and acorns develop to maturity the subsequent autumn (fig. 5A). Those in the red oak group, including water oak, willow oak, Nuttall oak, Shumard oak, and cherrybark oak, exhibit a pattern that requires an additional growing season to complete acorn maturation. In this group, female flowers are pollinated in the spring of their

emergence, but fertilization is suspended to the following year. This delayed fertilization stalls acorn development such that maturation is not completed until the second autumn after flowering. Because they flower annually, bottomland red oaks usually maintain two acorn cohorts on reproductively mature branches—the youngest cohort is found on shoot growth of the current year and the oldest is found on shoot growth of the previous year (fig. 5B).

Within groups, the various bottomland oaks exhibit wide ranging potentials to produce acorns, which are revealed through species-specific differences in several important population traits. First, species differ in crown architecture that underlies abundance and display of reproductively mature branches. For example, the ratio of branch weight to bole weight at age 10 was about 1.2 for water oak versus 0.7 for Nuttall oak in a bottomland plantation in Arkansas (Kennedy and others 1987). Second, species differ in their ability to form flower buds. Reproductively mature branches of black oak (*Quercus velutina* Lam.) initiated about 39 female flowers while those of northern red oak (*Q. rubra* L.) initiated about 51 flowers each spring over a 5-year period on an upland site in Missouri (Sork and Bramble 1993). Third, species differ in their ability to sustain flower survival and acorn development to maturation. About 90 percent of black oak flowers but only 52 percent of northern red oak flowers were shed premature to acorn maturation during a 3-year period in Missouri (Sork and Bramble 1993). Fourth, species differ in their periodicity of masting, i.e., the ability to produce acorn crops over successive years. Swamp laurel oak (*Q. laurifolia* Michx.) may produce a large acorn crop just about every year, while Nuttall oak typically produces large acorn crops every 3–4 years (table 2) (Bonner 2008). Collectively, variation in these inherent traits governing acorn potential leads to real differences in annual acorn production among the bottomland oak species. Cypert and Webster (1948) illustrated an impactful example of this species disparity in reporting 3-year data on acorn production at White River National Wildlife Refuge in Arkansas, where water oak and willow oak of comparable age and crown size annually shed about 4,500 and 9,900 acorns per tree, respectively. Likewise, Goodrum and others (1971) reported swamp chestnut oak annually shed about 258 acorns per tree and white oak (*Q. alba* L.) annually shed about 814 acorns per tree over a 4-year period in bottomlands of Louisiana and Texas.

Genetic factors principally determine the acorn production potential of individual trees within a species, whereas the population traits described earlier simply reflect the collective variation in trait expression by individuals within the population. Reports from oak-dominated forests throughout the Eastern United States consistently have confirmed that acorn production ranges widely among individual trees of a species growing on the same site (Cypert and Webster 1948, Downs and McQuilkin 1944, Goodrum and others 1971, Sork



Figure 5—(A) Image of a swamp white oak branch showing acorn development (yellow arrow) on an acorn stalk of a current year shoot; (B) image of a water oak branch showing two acorn cohorts—current year acorns (yellow arrows) show arrested development, while acorns initiated in the previous year (red arrow) show advanced development. (USDA Forest Service photos by Emile S. Gardiner).

Table 2—Periodicity of mastings in bottomland oaks^a

White oak group	Years between large mast crops
White oak (<i>Q. alba</i>)	4-10
Swamp white oak (<i>Q. bicolor</i>)	3-5
Overcup oak (<i>Q. lyrata</i>)	3-4
Swamp chestnut oak (<i>Q. michauxii</i>)	3-5
Live oak (<i>Q. virginiana</i>)	1
Red oak group	
Swamp laurel oak (<i>Q. laurifolia</i>)	1
Water oak (<i>Q. nigra</i>)	1-2
Cherrybark oak (<i>Q. pagoda</i>)	1-2
Pin oak (<i>Q. palustris</i>)	1-2
Willow oak (<i>Q. phellos</i>)	1
Shumard oak (<i>Q. shumardii</i>)	2-3
Nuttall oak (<i>Q. texana</i>)	3-4

^aAdapted from Bonner (2008).

and Bramble 1993). For example, a willow oak stand on the White River National Wildlife Refuge had two individuals that shed an average of more than 10,000 acorns during the 1940 masting season, while two other individuals were barren (Cypert and Webster 1948). The frequency at which individual trees produce an annual acorn crop also exhibits substantial disparity. This temporal variation or consistency in annual acorn production by different trees defines the masting periodicity described earlier for a species. Greenberg (2000), who studied frequency of white oak masting during a 5-year period in Southern Appalachian uplands, found some trees never produced acorns while other trees produced acorns four of the five years. Collectively, genetic factors that underlie acorn production per unit of crown area and frequency of annual crops determine the potential of an individual tree to produce acorns. This inherent potential is revealed, and its expression can be charted when acorn production for individual trees is observed over time. Superior acorn producers in a given year often show a propensity for relatively high production in subsequent years, while inferior producers rarely shed a significant crop (Burns and others 1954, Cypert and Webster 1948, Sharp and Sprague 1967).

Environmental factors that influence flowering and acorn production

A range of environmental factors regulates the physiological functions that support tree vigor, crown growth, and reproductive growth. When an individual bottomland oak tree attains reproductive maturity, these environmental factors profoundly influence the amount of its crown that holds the potential to produce flowers and acorns, as well as its annual variation in flowering and acorn production. Several studies conducted in the Eastern United States have attempted to unravel the random and complex effects of weather on annual acorn production. During spring flowering, local air temperatures, humidity levels, rain, and wind can have negative effects on pollen shed by male flowers and on pollination and fertilization of female flowers (Cecich 1997, Feret and others 1982, Sharp and Chisman 1961, Sharp and Sprague 1967, Wolgast and Stout 1977), resulting in premature flower shedding if these processes are not completed (Cecich and Haenchen 1995). Cecich and Haenchen (1995) observed that more than 70 percent of northern red oak flowers died within 8 weeks of the pollination period at an upland site in Missouri. Their observation confirmed the high premature mortality of female flowers reported for other oaks (Feret and others 1982, Sharp and Sprague 1967) and highlighted the basic dependence of acorn production on early flowering processes. Flowers can be damaged or killed by hail and frost—heavy spring freezes, in particular, have been associated with nearly complete local failures in acorn production (Auchmoody and others 1993, Beck 1977, Goodrum and others 1971, Sharp and Sprague 1967). Beyond early spring, prevailing weather conditions later in the growing season can influence fertilization, acorn maturation rate, and date shed from the tree (Cecich 1997, Fearer and others 2008, Sork and others 1993). Air temperature and rainfall during the growing season most commonly are linked to sustained acorn development and complete maturation in the Eastern United States (Koenig and Knops 2014). Sork and Bramble (1993), for example, reported a strong negative association between growing season drought (high temperatures and low rainfall) and acorn production of northern red oak, black oak, and white oak in Missouri. Year-to-year variation in acorn shed dates for willow oak and water oak noted by Cypert and Webster (1948) was presumably due to annual variation in weather patterns. Because of the random occurrence and localized nature of some weather events and species differences in flowering phenology, impacts of weather on acorn production can vary greatly among species and individual trees growing in relatively close proximity.

Environmental factors that affect site quality, such as soil fertility and soil texture, have not been linked directly to acorn production in the Eastern United States. Tryon and Carvell (1962), for example, found no association between site index and acorn production by white oak or northern red oak in West

Virginia uplands. However, Beck (1977) pointed out that the various upland oak species of the Southern Appalachians tend to segregate by site quality, and, in this respect, site quality indirectly influences acorn production. The same can be said for bottomland oaks because species occurrence on floodplains is associated strongly with site quality (Hodges 1997). Aside from control over species distributions, much more research is needed before basic questions surrounding site quality and acorn production by bottomland oaks planted on former agricultural land can be answered. We do not know if site quality influences when bottomland oaks attain reproductive maturity. It certainly influences vegetative growth of trees and rate of stand development as described previously. Additionally, research delving into connections between site quality and acorn production traditionally has been conducted in natural forests that have experienced minimal site degradation. Oak plantations in agricultural landscapes exist on sites degraded from previous cultural practices (Groninger and others 2000). These sites are prone to further degradation from adjacent land use and cultural practices that can alter site productivity and reduce tree vigor through impaired drainage, excessive sedimentation from agricultural runoff, ground water depletion, and other factors. Because wide-scale establishment of oak plantations on farmed bottomlands has occurred only within the last few decades, questions related to site quality and acorn production of restored forests have yet to be addressed.

Acorn production has received a fair amount of study in natural stands growing on sites with altered hydrologic regimes. Managers have created artificially flooded bottomlands as “greentree reservoirs” for nearly a century to provide forested habitat for waterfowl (Wigley and Filer 1989). Long-term observations in Missouri bottomlands indicated that dormant-season flooding does not reduce pin oak (*Quercus palustris* Münchh.) acorn production (McQuilkin and Musbach 1977, Minckler and McDermott 1960). Straub and others (2019) found no evidence to the contrary during their 4-year study of several bottomland red oaks in Mississippi. However, Francis (1983), in a 5-year study of Nuttall oak on the Delta National Forest in Mississippi, found that trees in a greentree reservoir produced 55 percent fewer acorns than trees in an adjacent stand outside the reservoir. Reasons for these conflicting observations are not clear, but they could be related to characteristics of the imposed floods or health and condition of the acorn-producing oaks at the onset of the study. In fact, Francis (1983) noted 11 percent mortality among sample trees during his 5-year study. Bottomland oak health and vigor show resilience to the natural flooding regimes indicative of the particular floodplain sites for which they are associated (Hodges 1997). But, artificial flooding that deviates markedly from the seasonality, duration, depth, and flow of natural

site inundations may impose stress on bottomland oaks, particularly if the altered hydrologic regime is imposed for several consecutive years. Oak decline is a well-documented, pervasive problem in many greentree reservoirs (Keeland and others 2010). Stress resulting in root mortality and subsequent loss of crown volume will impart long-term consequences for acorn production.

Insect pests that feed on oak flowers or deposit their eggs in developing acorns rank among the most severe environmental limits to acorn production. Treehoppers (Membracidae), insects that pierce plant tissues with their stylet to feed on sap, can obliterate flower crops. Cecich and others (1991) observed as much as 95 percent mortality for female flowers of northern red oak and white oak during the pollination period in Missouri. Treehopper damage was implicated for most of this loss in potential acorn crops (Cecich 1994). Other insects typically associated with acorn damage, e.g. acorn weevils (*Curculio* spp. L.) and gall wasps (Cynipidae), oviposit eggs in developing fruit where their larvae then feed. This activity usually occurs later in the summer when acorns are large enough to withstand some damage from feeding larvae without significant negative effects and developed enough to complete maturation (Cecich 1994, Larsen and Cecich 1997). Acorn weevils pose the greatest insect threat to developing acorns and premature shedding will occur if damage is severe, e.g., if the acorn contains numerous eggs. However, most damage from these insects occurs after acorns mature and shed from the tree (Cecich 1994) and will be discussed in more detail in the section on acorn yield. Leaf-feeding insects such as the eastern tent caterpillar [*Malacosoma americanum* (Fabricius)] can defoliate bottomland oaks across extensive areas (Leininger and Solomon 1995), potentially jeopardizing developing acorn crops. Severe defoliations by leaf-feeding insects have been linked to annual failures in acorn production (Drake 1991), but these events are generally local, of infrequent occurrence, and insignificant to long-term acorn production by healthy bottomland oaks.

Grey squirrels (*Sciurus carolinensis* Gmelin) and fox squirrels (*S. niger* L.) native to bottomlands often girdle large branches by stripping bark. They also prune reproductive foliage by clipping or “cutting” branch terminals. Though many hypotheses have been forwarded, purposes for these behaviors are unknown. Nichols and others (2016) suggested that the grey squirrel strips bark to access calcium-rich phloem tissues, analogous to their “calcium-seeking behavior” of gnawing shed antlers. Nevertheless, both activities reduce acorn production by causing branch mortality that reduces acorn-producing crown volume. However, extreme cases of crown damage are reported typically in urban settings rather than in forests.

Squirrels and birds also impact production by depredating immature acorns. Downs and McQuilkin (1944) reported that 24 percent of acorns nearing maturation were damaged by birds or squirrels during a 7-year study of five Southern Appalachian oak species. In an Arkansas study, birds, primarily blue jays (*Cyanocitta cristata* L.) and red-headed woodpeckers (*Melanerpes erythrocephalus* L.), and to a lesser extent squirrels, removed about 20 percent of the immature acorns in willow oak and water oak crowns (Cypert and Webster 1948). Burns and others (1954), who studied five oak species over a 6-year period in Missouri, reported acorn damage from birds and squirrels to range from 11 to 15 percent across three upland stands. Though reports reveal considerable acorn damage or removal from trees prior to maturation and shed, the amount of depredation tends to decrease in years of high acorn production (Downs and McQuilkin 1944). Additionally, depredation of immature acorns may not be a concern where management objectives include canopy-feeding wildlife.

Acorn crops relative to tree and stand development—

Recall that acorn production, in elementary terms, is a function of the number of reproductively viable branches produced and maintained by the tree. In general, trees with relatively large, vigorous crowns in upper canopy positions will produce more acorns than trees with relatively small, declining crowns positioned lower in the canopy (Francis 1983, McQuilkin and Musbach 1977, Minckler and McDermott 1960). As such, acorn production of an individual tree in a bottomland oak plantation hinges on three interrelated elements: (1) crown size, (2) vigor, and (3) position in the stand canopy. Thus, factors associated with stand development that influence individual tree vigor and canopy development will govern tree maturation to a reproductive state and the degree to which its potential for acorn production is realized.

Acorn production by bottomland oak stands is determined by the collective productivity of individual trees that comprise the stand. Trees developing in a stand typically exhibit a delayed initiation of flowering and acorn production as compared to open-grown trees because they are subject to environmental factors of the stand that impede onset of reproductive maturity. While it is common to observe individual saplings or small poles that sporadically flower and produce acorns during initial stand development, significant acorn crops in bottomland oak plantations typically are observed after canopy closure when crowns have begun to differentiate (fig. 4). Accordingly, trees that develop dominant or codominant crowns produce the majority of acorns in a given stand (Drake 1991, Francis 1983, Johnson 1994, Sharp and Sprague 1967). These are the individuals that can produce and maintain the greatest number of reproductive-viable branches. As described earlier, initiation of crown differentiation can occur within 10–15

years of plantation establishment, or it may be delayed as much as another decade depending on site quality, stand vigor, and species composition. Acorn production at the tree- and stand-levels will continue to rise for several decades as crown differentiation and canopy stratification progress (fig. 4). This continued increase in acorn production over time occurs because crown growth and expansion in the canopy is a dynamic process in which the most competitive individuals continue to advance towards maximum crown size for the species and site as less competitive individuals die and relinquish growing space. Observations on tree-level acorn production (Francis 1983, Goodrum and others 1971, McQuilkin and Musbach 1977, Straub and others 2019), along with crown development patterns in bottomland oak plantations described earlier, suggest that mature bottomland oak plantations will sustain relatively high acorn production as long as crowns remain healthy and continue to grow. Acorn production will decline when crowns begin to senesce and growing space in the canopy vacated by tree mortality is not occupied promptly by neighboring oaks (Francis 1983, Goodrum and others 1971, Greenberg and others 2014, Straub and others 2019).

The generalizations outlined earlier have led researchers to study linkages between acorn production by individual trees in stands and various indices of crown size, vigor, and position. Tree characteristics, such as bole diameter, basal area, bole growth rate, crown volume, crown growth rate, and crown class, have been used to explain variation associated with acorn production among individuals in a stand. As examples, Goodrum and others (1971) reported a correlation between d.b.h. and water oak acorn production, Greenberg (2000) found a correlation between tree basal area and black oak acorn production, Cypert (1951) noted a correlation between radial growth rate and acorn production by relatively large cherrybark oaks, and Sork and Bramble (1993) showed a correlation between crown area and northern red oak acorn production. Though these examples appear to establish clear correspondence between variation in acorn production and tree characteristics, results obtained through other research reveal inconsistencies that blur these linkages (Burns and others 1954, Christisen 1955, Downs and McQuilkin 1944, Sork and Bramble 1993). Even so, broad relationships can be drawn to illustrate trends in acorn production relative to the respective scales of various tree characteristics. For example, the fact that acorn production is linked primarily to trees with a dominant or codominant crown has been validated soundly throughout the Eastern United States (Drake 1991, Francis 1983, Sharp and Sprague 1967). Trees with intermediate or suppressed crowns lack many reproductively viable branches and, accordingly, contribute very little acorn production in mast years (Drake 1991, Sharp and Sprague 1967).

Silvicultural Tools for Assessment, Evaluation, and Monitoring

Inasmuch as stand structure is defined by the compiled characteristics of individual trees, it is reasonable to presume that stand-level acorn production can be tied to variables of stand structure that account for the proportional status of oaks in the canopy. Stand density (number of trees per acre or basal area per acre), diameter distribution, and stocking of reproductively viable oaks, should correlate to variation in stand-level acorn production. But, Minckler and McDermott (1960), who correlated pin oak acorn production to stand basal area, provided one of the few examples supporting this presumption. In contrast, Auchmoody and others (1993) were unable to correlate northern red oak acorn production with stand diameter distribution or basal area in seven Pennsylvania stands. Beck and Olson (1968) also failed to connect stand-level acorn production with stand basal area in upland oak stands of the Southern Appalachians. Because of these inconsistencies, establishing linkages between acorn production and variables of stand structure is highly speculative (Dey 1995).

The preceding paragraphs note limited accomplishment in relating acorn production to tree characteristics and, particularly, stand structure. Weak correlations are attributed to high variation among individual trees caused by genetic and environmental factors described previously (Auchmoody and others 1993, Beck and Olson 1968, Lombardo and McCarthy 2009). With environmental factors equal, acorn production for a given stand hinges on the occurrence of dominant and codominant trees with a high genetic potential to produce acorns. Tracking individual trees in oak stands universally reveals wide disparity in the genetic propensity to produce acorns. Precocious acorn producers typically comprise a small fraction of most stands (Burns and others 1954, Greenberg 2000, Healy and others 1999, Straub and others 2019). Individuals exhibiting genetically superior acorn production were roughly 46 percent of the northern red oak, 35 percent of the scarlet oak (*Quercus coccinea* Münchh.), 34 percent of the white oak, 29 percent of the black oak, and 20 percent of the chestnut oak (*Q. montana* Willd.) studied in Southern Appalachian stands (Greenberg 2000). Lashley and others (2009) found about one-third of the white oak in upland stands of Tennessee and North Carolina to be inherently better producers. These individuals produced > 75 percent of the total acorn crop during their 3-year study. In contrast, relatively high acorn production was exhibited by only 15 percent of the bottomland red oaks in four Mississippi stands over a period of 4 years (Straub and others 2019). Undoubtedly, acorn production is under strong genetic control and the degree to which it is expressed seldom has been accounted for through measures of tree characteristics or stand structure.

A variety of silvicultural tools have been developed over the years to help forest managers make management decisions in hardwood stands. Assessment of site, tree, and stand characteristics, as well as the prediction and assessment of acorn crops, are necessary first steps in the development of effective silvicultural prescriptions designed to achieve landowner objectives. These silvicultural tools can and should be used to help us manage young, bottomland oak-dominated plantations more successfully.

Site Assessment

Site quality not only affects survival, growth, and productivity of planted trees, it also has a significant effect on the rate and trajectory of plantation development over time. Similarly, site quality affects the quantity and quality of acorn production. Site quality, therefore, has a profound influence on the ability of the site to fulfill landowner objectives, whatever they may be.

The seven oak species commonly planted in the LMAV have different site requirements and limitations (table 1). For example, cherrybark, Shumard, and swamp chestnut oaks grow best on, and generally are limited to, well-drained, loamy ridges within the bottomland. These three species rarely occur and do not grow well on poorly drained sites. In contrast, Nuttall and overcup oaks grow well and commonly occur on poorly drained clayey sites. Nuttall oak is slightly less flood-tolerant than overcup oak and primarily occurs on low ridges and flats, whereas overcup oak primarily occurs on low flats and sloughs. Water and willow oaks have fewer site restrictions and are common on a variety of sites within the bottomland. Both species grow best and commonly occur on well-drained, loamy to clayey ridges and high flats. They also both occur frequently on poorly drained, clayey low flats, but growth and development generally are poor on these wetter sites.

To make sound silvicultural decisions, the forest manager must be able to assess site quality accurately. Site index is the most widely accepted measure of site quality and is defined as the average height of dominant and codominant trees of a given species on a particular site at a base age. The base age used for oaks typically is 50 years. Because site index is species-specific, it must be determined separately for each species. Site index values generally are not equivalent across species. Ranges in site index for a given species can be used to make qualitative assessments of site quality (table 3). These qualitative expressions of site quality are also species-specific and not equivalent across species. For example, a site index of 80 feet for overcup oak indicates a good site for overcup oak, whereas a site index of 80 feet for Nuttall oak indicates a poor-to-medium site for Nuttall oak, even though the two species grow on similar sites.

Table 3—Site index ranges, in feet at age 50, that correspond with different qualitative levels of site quality for seven oak species commonly planted in the Lower Mississippi Alluvial Valley^a

Species	Unacceptable	Poor	Medium	Good	Excellent
Cherrybark oak	< 70	70-80	80-90	90-110	> 110
Nuttall oak	< 75	75-80	80-90	90-105	> 105
Overcup oak	< 60	60-65	65-75	75-90	> 90
Shumard oak	< 70	70-80	80-90	90-105	> 105
Swamp chestnut oak	< 65	65-75	75-85	85-100	> 100
Water oak	< 70	70-80	80-90	90-105	> 105
Willow oak	< 70	70-75	75-90	90-105	> 105

^aValues calculated from data presented in Broadfoot (1976).

Baker and Broadfoot (1979) developed a practical method of site evaluation for 14 important southern hardwood species, including all but one of the seven oak species commonly planted in the LMAV (site evaluation for overcup oak was not addressed). This field method of site evaluation is based on four major soil factors that heavily influence the growth of hardwood trees:

1. Soil physical condition
2. Moisture availability during the growing season
3. Nutrient availability
4. Aeration

Each major soil factor is responsible for a certain percentage of tree growth. Each consists of several soil and site properties that also affect tree growth. The proportion of total tree growth accounted for by each major factor is represented by the sum of the contributions made by that factor's soil-site properties. The proportions of growth attributed to each major factor and to its associated soil-site properties vary by species.

For each of the 14 hardwood species, Baker and Broadfoot (1979) created a numerical rating system that assigns point values for a range of possible conditions, from best to poor, for each soil-site property within each major soil factor. To evaluate a particular site for a particular species, the user matches the soil-site conditions of that site as closely as possible to the range of conditions listed for each soil-site property associated with that species and assigns the appropriate point value to that soil-site property. The user then sums the point values assigned to each soil-site property to obtain the Site Quality Rating of that particular site for that particular species. Numerically, the Site Quality Rating is equivalent to

site index. To obtain an accurate assessment of site quality, the user should conduct separate evaluations at several locations across the site and then calculate the average Site Quality Rating for the species of interest. The Baker and Broadfoot (1979) method of site evaluation is a valuable tool to match the right species to the right site at the time of plantation establishment. But, it also can be used to determine if the species in an existing plantation is suited to the site or not. If the planted species is not appropriate for the site, i.e., the plantation was established with the wrong species, the forest manager should remove the existing trees and start over.

Identification of the soil series on a site can provide a more general assessment of site quality. Broadfoot (1976) presented detailed information on soil physical and chemical properties for 40 important soil series that support hardwood forests in the mid-South. For each of the 40 soil series, he also provided management suggestions, species occurrence, suitability ratings, and site index estimates for a variety of hardwood species, as well as a measured average site index value for a sub-sample of species. Of the 40 soil series described, 17 commonly occur in the LMAV.

If the soil series associated with a particular site is known or can be identified, the forest manager simply consults the appropriate table in Broadfoot (1976) to obtain an estimated site index range and, perhaps, a measured average site index for the species of interest. For example, Nuttall and water oaks frequently occur on the Sharkey series, a poorly drained, clayey soil that is widespread throughout the LMAV. Broadfoot (1976) reported measured average site indices of 91 feet for Nuttall oak and 85 feet for water oak. Based on the site index ranges presented in table 3, the Sharkey series represents a good site for Nuttall oak, but only a medium site for water

oak. As a word of caution, assessments of site quality based solely on soil series should be regarded as general estimates and may or may not reflect the actual productivity of any specific site.

Tree Assessment

It is important to assess the characteristics of individual trees within the plantation. Crown classification, log grading, and tree classification provide subjective assessments of the capability of individual trees to achieve landowner objectives.

Crown classification—The crown class of a tree reflects both past competition and past growth, is a strong indicator of the current health of the tree, and is a fairly reliable predictor of future growth, especially in undisturbed stands. In pure, even-aged stands of conifers, position of the tree's crown within the main canopy of the stand is the dominant criterion used to assign crown class. In hardwoods, however, crown class reflects not only position in the canopy but also fullness and condition of the crown relative to the size of the tree. In other words, crown class definitions for use in hardwoods include two components: crown position and crown condition. Addition of crown condition as a modifying factor in hardwood crown classification provides a more accurate representation of current tree health and a more reliable prediction of future growth potential. Definitions used in crown classification of hardwood trees include:

Dominant: Crown extends above the general level of the main canopy and receives full sunlight from above and almost full sunlight from the sides. Crown should be wide, deep, well-shaped, and relatively full. If the crown is too small for the size of the tree or if crown deterioration has occurred, the tree should be classified as codominant.

Codominant: Crown forms the general level of the main canopy and receives almost full sunlight from above but only partial sunlight from the sides. Crown is generally deep, well-shaped, and relatively full, but may be somewhat lacking in density and spread. If the crown is too small for the size of the tree or if crown deterioration has occurred, the tree should be classified as intermediate.

Intermediate: Tree is usually shorter than the dominants and codominants, but crown may extend into the main canopy. Crown may receive some direct sunlight from above, but usually receives only little sunlight from the sides. Crown is usually small. It may be dense and very crowded on the sides or may be relatively wide but lacking in density. If crown deterioration has occurred, the tree should be classified as suppressed.

Suppressed: Crown is usually below the main canopy and receives very little direct sunlight. Almost all light received is diffused light. Crown is usually small and sparse. A tree of a shade-tolerant species that has an exceptionally well-developed crown may be classified as intermediate.

In young plantations in which the process of differentiation into crown classes has just begun, most trees will be classified in the codominant class, with a few trees in both the dominant and intermediate classes. However, as differentiation into crown classes progresses to its conclusion, all four crown classes will be represented throughout the plantation.

Log grading—If sawtimber production is one of the landowner objectives, the forest manager should have at least a basic understanding of hardwood log grades and should be able to recognize them in standing trees. Our purpose here is to emphasize the importance of bole quality and its influence on timber value. We will not attempt to teach the reader how to be an expert hardwood log grader. See Rast and others (1973) for complete details on hardwood log grading procedures and rules.

Use of the hardwood log grading system described by Rast and others (1973) requires knowledge of and the ability to recognize various defects on the surface of the bole of standing hardwood trees. Grade defects are abnormalities or irregularities on the log surface that indicate imperfections in the underlying wood. These imperfections generally diminish the appearance of the wood or otherwise limit its utility. Scalable defects are those that reduce the volume of sound wood or lower its durability. The most common types of defects in standing hardwood trees include (1) overgrown knots, as evidenced by distortions or breaks in the normal pattern of the bark; (2) epicormic branches larger than three-eighths of an inch in basal diameter; (3) insect holes and grub holes; (4) bumps and bulges; (5) bird peck; and (6) cankers.

Grade is determined by six attributes, called grading factors, that affect the quality and value of the log:

1. Position of the log in the tree—either butt log or upper log
2. Scaling diameter—measured as diameter-inside-bark at the small end of the log
3. Log length—measured in 2-foot increments with a minimum length of 8 feet and a maximum length of 16 feet
4. Maximum number and minimum length of clear cuttings—a clear cutting is a portion of the face of the log, extending across the width of the face, that is free of defects

5. Straightness—maximum allowable sweep and crook
6. Soundness—maximum allowable rot inside the log that results in a scaling deduction

The hardwood log grading system described by Rast and others (1973) recognizes three grades for factory logs—Grades 1, 2, and 3. Factory logs, by far the most common hardwood log-use class, are those logs that can be cut into lumber. Most hardwood sawtimber trees contain factory logs.

The specifications for these three hardwood log grades are correlated closely with the specifications for standard hardwood lumber grades. Although lumber grade yield varies by log diameter within each log grade, the yield of No. 1 Common and Better lumber for Grade 1 bottomland red oak logs averages 67 percent. In other words, 67 percent of the lumber volume sawn from a Grade 1 bottomland red oak log will be graded as either First and Seconds, Select, or No. 1 Common, the three highest-value hardwood lumber grades. Volume yield of No. 1 Common and Better lumber averages 44 percent for Grade 2 bottomland red oak logs and only 23 percent for Grade 3 bottomland red oak logs (Hanks and others 1980). Clearly, Grade 1 logs (fig. 6) have the highest quality and highest value, whereas Grade 3 logs (fig. 7) have the lowest quality and lowest value. Depending on the availability of markets, there may be as much as a five-fold difference in value between Grade 1 hardwood logs and Grade 3 hardwood logs.

Obviously, trees in a young, bottomland oak-dominated plantation are not large enough to meet minimum size requirements for sawtimber and cannot be assigned an actual log grade. However, the forest manager can use the hardwood log grading system described by Rast and others (1973) to assign potential log grades to trees in the plantation. Potential log grade is based on an assessment of the four grading factors not related to log size and represents the log grade that is likely to be assigned once minimum diameter requirements are met.

Tree classification—Hardwood tree classification systems integrate several individual tree attributes, such as crown class and log grade, into a single qualitative assessment. As such, they are valuable tools used to help forest managers make sound silvicultural and management decisions.

Putnam and others (1960) developed a tree classification system for southern hardwoods that is still used today in a modified format. Although Putnam's system was designed to be used in situations in which sawtimber production is the primary landowner objective, it easily could be modified to reflect other landowner objectives.

The Putnam system focuses on sawtimber trees in sawtimber stands and consists of four tree classes (in descending order of quality and value):

1. **Preferred growing stock.** Preferred growing stock trees are the most valuable and desirable trees in the stand. They are “final crop trees” and are expected to increase in value at a satisfactory rate for many years. This tree class consists of trees that: (1) are in good condition; (2) are a desirable species for the site and for management objectives; (3) have dominant or codominant crowns; (4) can be left in the stand indefinitely if in good condition; and (5) currently meet or have the potential to meet the minimum requirements for a Grade 1 butt log.
2. **Reserve growing stock.** Reserve growing stock trees are expected to neither increase nor decrease in value over the next 10 years. This tree class consists of trees that: (1) are in good condition but do not meet the minimum qualifications for preferred growing stock; and (2) can be stored safely on the stump with little risk of mortality or degradation in merchantability if left in the stand for the next 10 years.
3. **Cutting stock.** Cutting stock trees form an unwanted component in the stand and are expected to reduce the value of the stand over time. This tree class consists of trees that currently contain merchantable sawtimber but must be cut during the next partial harvest operation. It includes trees that: (1) are fully mature or overmature; (2) are in poor condition; (3) pose a significant risk of mortality or degradation in merchantability; or (4) are a species that is unsuitable for the site or for management objectives.
4. **Cull stock.** Cull stock trees are currently unmerchantable for sawtimber and are incapable of meeting the desired product goals in the future. This tree class consists of trees that are unmerchantable because of species, poor form, excessive defects on the bole, or severe damage from insects or disease. Cull trees may or may not be marketed for pulpwood but cannot be marketed for sawtimber.

There are two critical problems associated with the use of the Putnam hardwood tree classification system on an operational scale. First, the reserve growing stock class is both poorly defined and too broad. Consequently, it is a “catch-all” class. Trees that are not desirable enough to be preferred growing stock and trees that are not poor enough to be cutting stock or cull stock often are lumped together into the reserve growing stock class. Second, Putnam's system is not well-suited for poletimber trees in sawtimber stands. Some of these poletimber trees have the potential to develop into high-quality, high-value sawtimber trees over time. But, Putnam's tree classification system was not designed to identify these high-potential poletimber trees.

To address these problems, we developed a new hardwood tree classification system for use in southern hardwood forests (Meadows and Skojac 2008). This system was



Figure 6—Dominant cherrybark oak with a Grade 1 butt log. (USDA Forest Service photo by James S. Meadows).

designed for situations in which the production of high-quality sawtimber is the primary landowner objective. Tree classes are based on the ability of each tree to achieve landowner objectives successfully.

Criteria to delineate tree classes in the Meadows system are more specific than in the Putnam system and are based on five characteristics essential to prediction of future performance and value growth potential of individual hardwood trees: (1) species, (2) crown class, (3) current condition of the tree and future risk of mortality or degradation in merchantability, (4) bole quality expressed as log grade, and (5) expected change in value over time.

The Meadows tree classification system consists of five tree classes used only for sawtimber-sized trees: (1) preferred growing stock, (2) desirable growing stock, (3) acceptable growing stock, (4) cutting stock, and (5) cull stock; and two tree classes used only for poletimber-sized trees: (1) superior poletimber stock, and (2) inferior poletimber stock (table 4).



Figure 7—Codominant water oak with a Grade 3 butt log. (USDA Forest Service photo by James S. Meadows).

Preferred growing stock trees are the best and most valuable trees in the stand. They are upper-crown-class trees of desirable species, in excellent condition, and have high-quality boles. Desirable growing stock trees are very good trees that are “desirable” for meeting landowner objectives, but do not meet the minimum qualifications for preferred growing stock. They are upper-crown-class trees of either desirable or acceptable species, in good condition, and have boles of at least medium quality. Acceptable growing stock trees do not form a desired component of the stand but are “acceptable” for meeting landowner objectives. They are trees in any crown class except suppressed, either desirable or acceptable species, and generally in fair condition. Bole quality is usually fairly low but can be high if other characteristics place the tree in this class. Cutting stock trees form an unwanted component in the stand. They are trees of any crown class and of any merchantable species, and usually in poor condition, but do contain a merchantable sawlog. They must be cut during the next partial harvest operation because they are damaged, diseased, or otherwise unsuitable for meeting landowner

Table 4—A sawtimber- and poletimber-sized tree classification system for use in management of southern hardwood forests

Sawtimber-sized trees
Preferred growing stock
1. Is a desirable species for the site and for management objectives 2. Has a dominant or codominant crown 3. Is currently in excellent condition and is likely to remain so indefinitely with very low risk of mortality or degradation in merchantability 4. Currently contains a Grade 1 log at least 10 feet in length, entirely within the 16-foot butt log section of the bole 5. Is expected to increase in value at a satisfactory rate if left in the stand for at least 10 years
Desirable growing stock
1. Is a desirable or an acceptable species for the site and for management objectives 2. Has a dominant or codominant crown 3. Is currently in good condition and is likely to remain so indefinitely with low risk of mortality or degradation in merchantability 4. Currently contains a Grade 2 or better log at least 10 feet in length, entirely within the 16-foot butt log section of the bole 5. Is expected to increase in value at a satisfactory rate if left in the stand for at least 10 years
Acceptable growing stock
1. Is a desirable or an acceptable species for the site and for management objectives 2. Has a dominant, codominant, or intermediate crown 3. Is currently in fair condition and is likely to remain so for at least 10 years with moderate risk of mortality or degradation in merchantability 4. Currently contains a Grade 3 or better log at least 8 feet in length, entirely within the 16-foot butt log section of the bole 5. Is expected to neither increase nor decrease in value if left in the stand for at least 10 years
Cutting stock
1. Must be cut during the next partial harvest operation if any of the following are true: a. Is an undesirable species for management objectives or is a species unsuitable for the site b. Has a suppressed crown c. Is currently in poor condition with significant risk of mortality or degradation in merchantability 2. Currently contains a Grade 3 or better log at least 8 feet in length within the merchantable bole 3. Is expected to decrease significantly in value if left in the stand for 10 years
Cull stock
1. Is incapable of meeting the desired product goals or is an unmerchantable species
Poletimber-sized trees
Superior poletimber stock
1. Is a desirable or an acceptable species for the site and for management objectives 2. Is currently in good condition and is likely to remain so for at least 10 years with moderately low risk of mortality or degradation in potential merchantability 3. Has the potential to contain a Grade 2 or better log at least 10 feet in length, entirely within the 16-foot butt log section of the bole, when minimum diameter requirements are reached
Inferior poletimber stock
1. Must be cut during the next partial harvest operation if any of the following are true: a. Is an undesirable or unmerchantable species for management objectives or is a species unsuitable for the site b. Is currently in poor condition with significant risk of mortality or degradation in potential merchantability c. Is diseased, damaged, or exhibits poor form 2. Is incapable, because of poor bole quality, of producing a Grade 2 or better log at least 10 feet in length, entirely within the 16-foot butt log section of the bole, when minimum diameter requirements are reached.

Source: Meadows and Skojac (2008).

objectives. Cull stock trees are incapable of meeting the desired product goals of management. Currently, they cannot be marketed as sawtimber and do not have the potential to be marketed in the future, however they may contain enough fiber to be marketed as pulpwood. Superior poletimber stock trees have high potential to develop into at least medium-quality sawtimber growing stock, whereas inferior poletimber stock have a low potential to do so.

In the Meadows tree classification system, preferred growing stock, desirable growing stock, acceptable growing stock, and superior poletimber stock, collectively, are referred to as **growing stock** and represent trees that are capable of fulfilling landowner objectives. In contrast, cutting stock, cull stock, and inferior poletimber stock, collectively, are referred to as **overburden** and represent trees that are incapable of fulfilling landowner objectives. As such, the overburden must be cut during the next partial harvest operation.

Clearly, trees in a young, bottomland oak-dominated plantation are not large enough to be classed as sawtimber. However, the Meadows tree classification system can be adapted for use in these young plantations. The forest manager should use the five sawtimber tree classes to classify trees in the overstory of the young plantation. To assess log grade requirements, these upper-crown-class poletimber trees should be evaluated on the basis of potential log grade. All other requirements for each of the five sawtimber tree classes remain the same. The forest manager should use the two poletimber tree classes to classify lower-crown-class trees in the young plantation.

Stand Assessment

It is not enough to assess just the characteristics of individual trees within the plantation. It is also important to assess the characteristics of the plantation as a whole. A stocking guide and the tree class distribution are two silvicultural tools that provide assessments of the capability of the entire plantation to achieve landowner objectives.

Stocking guide—Stocking percent is a measure of relative stand density. It is a mathematical representation of the current density of a stand relative to the ideal density for that same stand.

Based on data in Putnam and others (1960), Goelz (1995) developed a stocking guide for southern bottomland hardwood stands (fig. 8). Estimation of stocking percent requires knowledge of at least two of the following three variables: (1) trees per acre, (2) basal area per acre, or (3) quadratic mean diameter. The 100-percent line of stocking, known as the A-line, represents maximum full stocking. Stands with stocking > 100 percent (or above the A-line) are overstocked, a situation that indicates that some type of partial cutting may be required to reduce stand density. In contrast, the B-line of stocking

represents minimum full stocking. Stands with stocking below the B-line are understocked, a situation that indicates that the site is under-utilized, and that productivity is less than desired. Stands with stocking between the A-line and the B-line are fully stocked.

Figure 8 is the portion of the stocking guide for southern bottomland hardwoods (Goelz 1995) that represents stocking for stands with a quadratic mean diameter between 2 and 9 inches. In general, most young, bottomland red oak-dominated plantations will not attain a stocking percent equivalent to the B-line until quadratic mean diameter is between 5 and 6 inches. To illustrate, a bottomland red oak plantation with an initial spacing of 12 x 12 feet has 302 trees per acre at the time of plantation establishment. As the plantation develops over time, mortality may reduce density of planted trees to 250 trees per acre (survival of about 83 percent). Based on Equation (1) in Goelz (1995), a plantation with 250 trees per acre and a quadratic mean diameter of 5 inches has stocking of 39 percent, just below the B-line in figure 8. If quadratic mean diameter is 6 inches, stocking is 52 percent, just above the B-line. In other words, a young plantation does not achieve minimum full stocking until quadratic mean diameter reaches about 5 or 6 inches. Consequently, significant assessments of plantation density should be delayed until stocking approaches the B-line. However, general assessments of the plantation's progress can be made by comparing current conditions to figure 8.

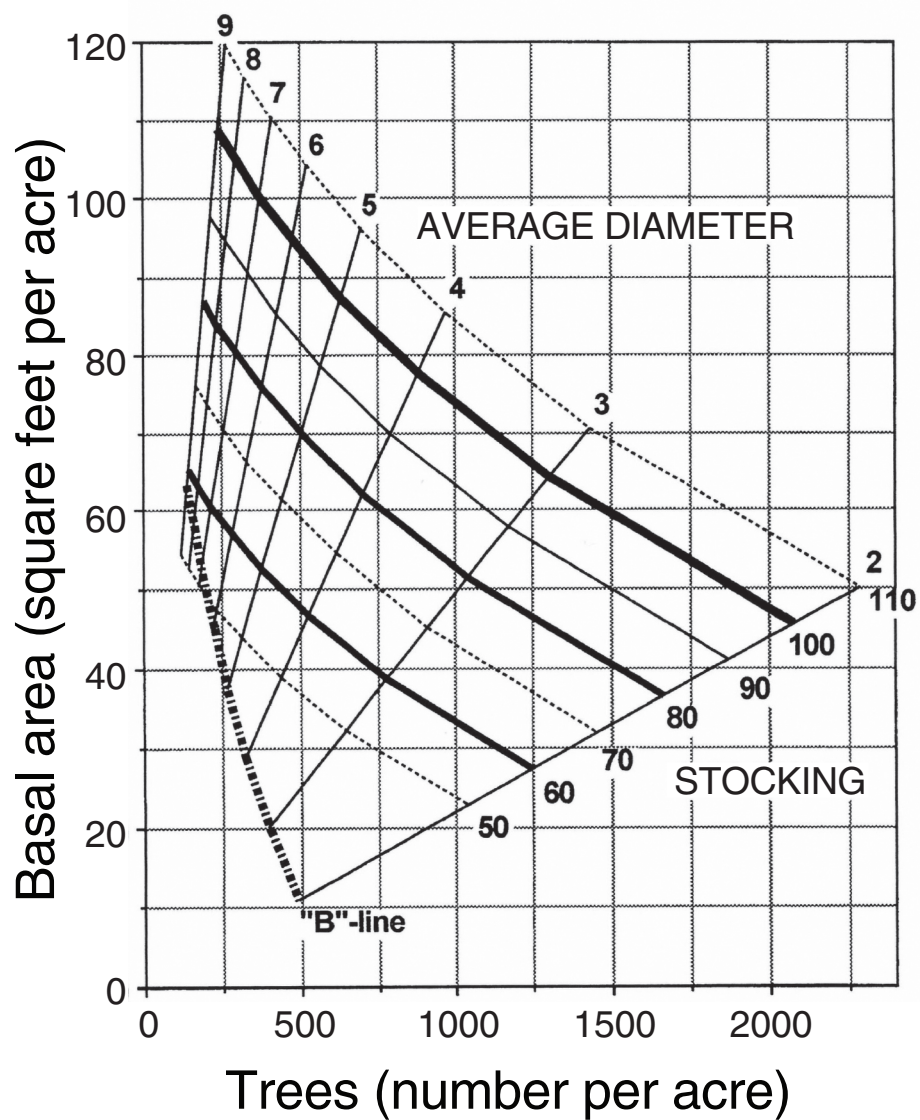
Tree class distribution—The hardwood tree classification system developed by Meadows and Skojac (2008) can be used to compile a stand-level tree class distribution that represents the proportion of total stand basal area in each of the seven tree classes. The tree class distribution is a tool used to assess stand quality. More specifically, it shows the proportion of the stand composed of trees suitable for landowner objectives (growing stock) versus the proportion of the stand composed of trees unsuitable for landowner objectives (overburden).

Ideally, a high-quality stand that is contributing fully to the fulfillment of landowner objectives will have a growing stock component of about 60–80 percent of total stand basal area. Conversely, a growing stock component of < 50 percent is indicative of a low-quality stand that contributes little to the fulfillment of landowner objectives.

Predicting and Assessing Acorn Crops

Predicting acorn production—Reliable models for predicting annual acorn production by individual trees or stands are not available because significant gaps in our understanding of flowering and fruit maturation in oaks have prevented their development. The most advanced tools currently available enable the practitioner to evaluate acorn production potential of a tree or stand based on tree characteristics or stand

Figure 8—Stocking guide for southern bottomland hardwood stands with a quadratic mean diameter between 2 and 9 inches. (from Goelz 1995)



structure. For the purposes of this document, acorn production potential as described earlier will be referred to as “acorn production capacity” to distinguish it from the genetic potential discussed earlier. In other words, **acorn production capacity** connotes the morphological attributes of a tree or the structural attributes of a stand that relate to acorn production. Rose and others (2012) developed models that use d.b.h. to predict acorn production capacity for upland oaks in the Southern Appalachians. Dey (1995) published a practical model that enables the manager to estimate acorn production capacity of northern red oak from inventories of d.b.h. and density or stocking. Equations that predict acorn production capacity of bottomland oaks also exist (Goodrum and others 1971). This guide presents a tool, developed from these equations, to index the relative capacity of individual trees and bottomland oak stands (see the following). It should be stressed that these models do not predict the genetic potential for acorn production held by individual trees, and they do not incorporate the influences of environmental variables to forecast annual crops. These models, however, are quite useful because they provide a means to evaluate how well a stand is structured for acorn production and they can be used to project relative change in acorn production capacity as a stand develops or experiences canopy disturbances, such as thinning.

The approach presented by Dey (1995) provides a straightforward method to develop a practical tool that can be used to evaluate acorn production capacity in bottomland oak plantations. The first component needed to build such a tool is a mathematical model of the relationship between tree d.b.h. and crown size. Goelz (1996) published a model of this relationship for open-grown bottomland oaks and applied it to generate a stocking equation that links tree density at 100 percent crown cover with quadratic mean diameter of the stand (fig. 9) (app. A). Because the relationship between d.b.h. and crown size was modeled from data collected on open-grown bottomland oaks (trees of maximum crown size), the stocking equation estimates minimum stand density, for a given quadratic mean diameter, required to fill 100 percent of the crown area available per acre. For example, a stand with a quadratic mean diameter of 12 inches would show 100 percent crown cover if it were composed of 52 trees per acre, each with a maximum crown area of 844 square feet (see table A.1). A stocking chart applicable to bottomland oak plantations (adapted from Goelz 1996) is presented in figure 10 (see also app. A). The work published by Goelz (1996) provides a quantitative index of stand structure that is based on crown size—a fundamentally important tree characteristic used to project the acorn production capacity of bottomland oaks.

In addition to the relationship between tree d.b.h. and crown size, a model of acorn production relative to tree d.b.h. or crown size is needed to complete the tool for evaluating relative acorn production capacity of bottomland oak stands (see app. B). Equations presented by Goodrum and others

(1971) were used to develop a general response of acorn production by bottomland oaks (fig. 11). Applying this general response to stand stocking data enabled the generation of the indices illustrated in figures 12 and 13 (see app. B). Estimates of relative acorn production capacity for individual trees or bottomland oak stands can be derived by applying basic data collected during stand inventories. Though this tool cannot be applied to estimate acorn crop size, it does provide the manager with a comparative scale to index the status of acorn production capacity for an individual tree or bottomland oak stand.

Assessing acorn production—Quantifying acorn production provides a measure of annual acorn crops. Acorn production can be sampled on individual trees or stands through a variety of techniques including visual crown surveys, ground counts, and acorn traps (Gysel 1956). Visual crown surveys are conducted by scanning the crown of a tree for reproductively viable branches and counting the occurrence of developing acorns on those branches (Perry and Thill 1999). Measuring acorn production with ground counts involves establishing small plots (e.g., 1 square foot) beneath the crown of an oak and counting acorns and/or acorn caps shed into the plot (Auchmoody and others 1993). Acorn traps, typically screened receptacles of known area, are placed beneath oak crowns to capture acorns when they shed from the tree (Gysel 1956). The most applicable technique will depend on objectives for the assessment, such as identification of prolific individuals for stand management purposes versus quantification of total caloric value for wildlife carrying capacity. Ground count and trap techniques generate data easily converted to acorn production per acre and can provide information on damage occurrence. On the other hand, visual crown surveys are perhaps the quickest and least costly assessment technique for generating data readily applicable to management.

Several different visual crown surveys have been used to assess acorn crops in the Eastern United States. They typically vary based on the extent of observations made in the crowns of sample trees. Some surveys involve counting acorn presence (with the aid of binoculars) in pre-defined sections of the crown during a brief time period (Koenig and others 1994). Others involve estimating the percentage of reproductively viable crown, counting the number of branches bearing acorns within sections of reproductively viable crown, and counting the number of acorns on those branches (Perry and Thill 1999). Perry and Thill (1999) found most visual crown survey techniques to be equally effective in identifying moderate to large differences in acorn production among trees and suggested the use of a technique that minimizes observer bias.

Visual crown surveys should be conducted in the late summer through early fall when acorns begin to mature and prior to significant depredation by arboreal wildlife or shedding from the tree. Findings reported by Perry and Thill (1999) indicate

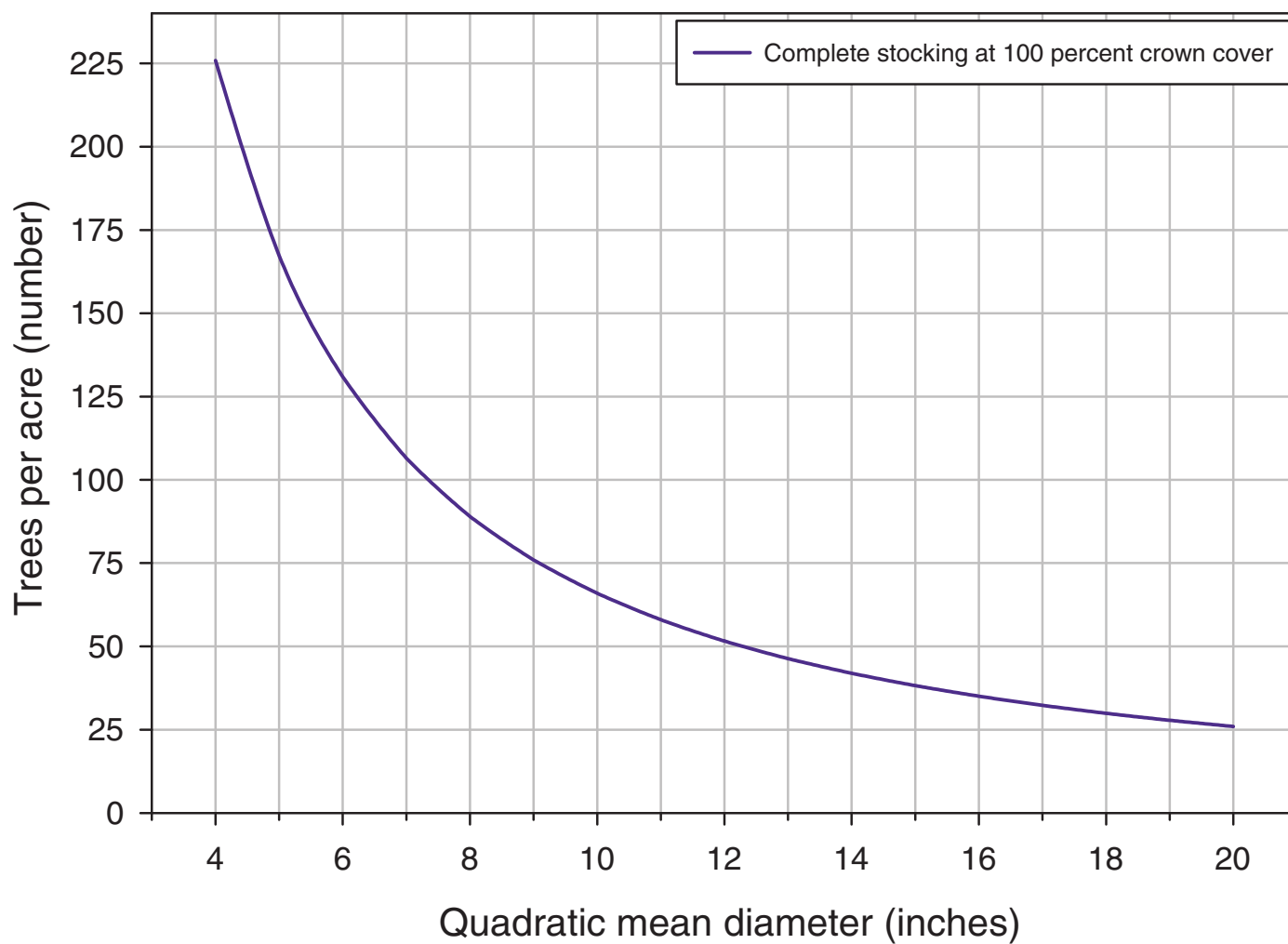


Figure 9—Relationship between quadratic mean diameter and bottomland oak stand density at 100 percent crown cover. (from Goelz 1996)

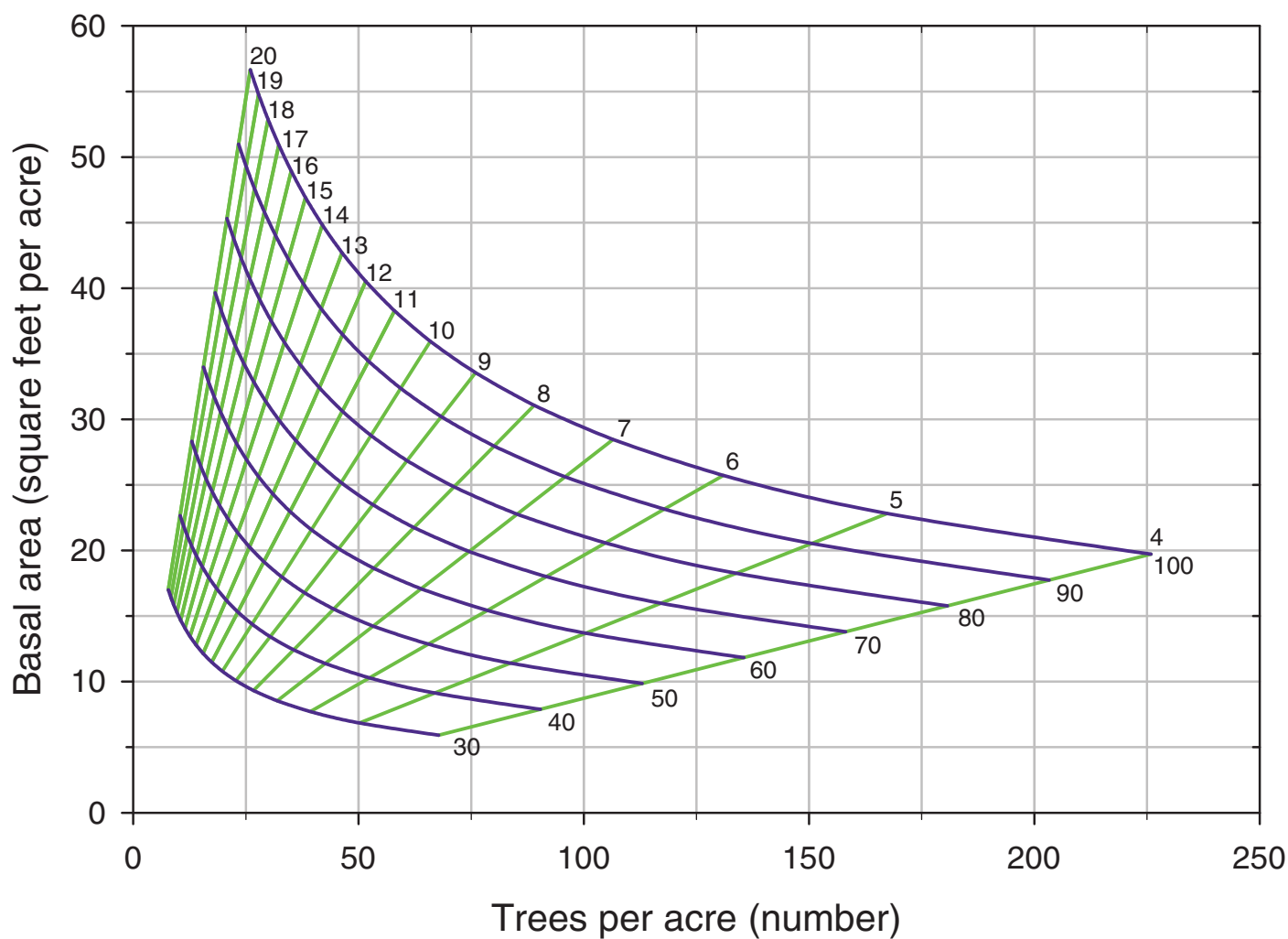


Figure 10—Stocking chart applicable to bottomland oak plantations (adapted from Goelz 1996; see app. A). Blue lines indicate stand stocking for a range of 30 percent to 100 percent as noted next to each line. Green lines indicate quadratic mean diameter for a range of 4 inches to 20 inches as noted next to each line.

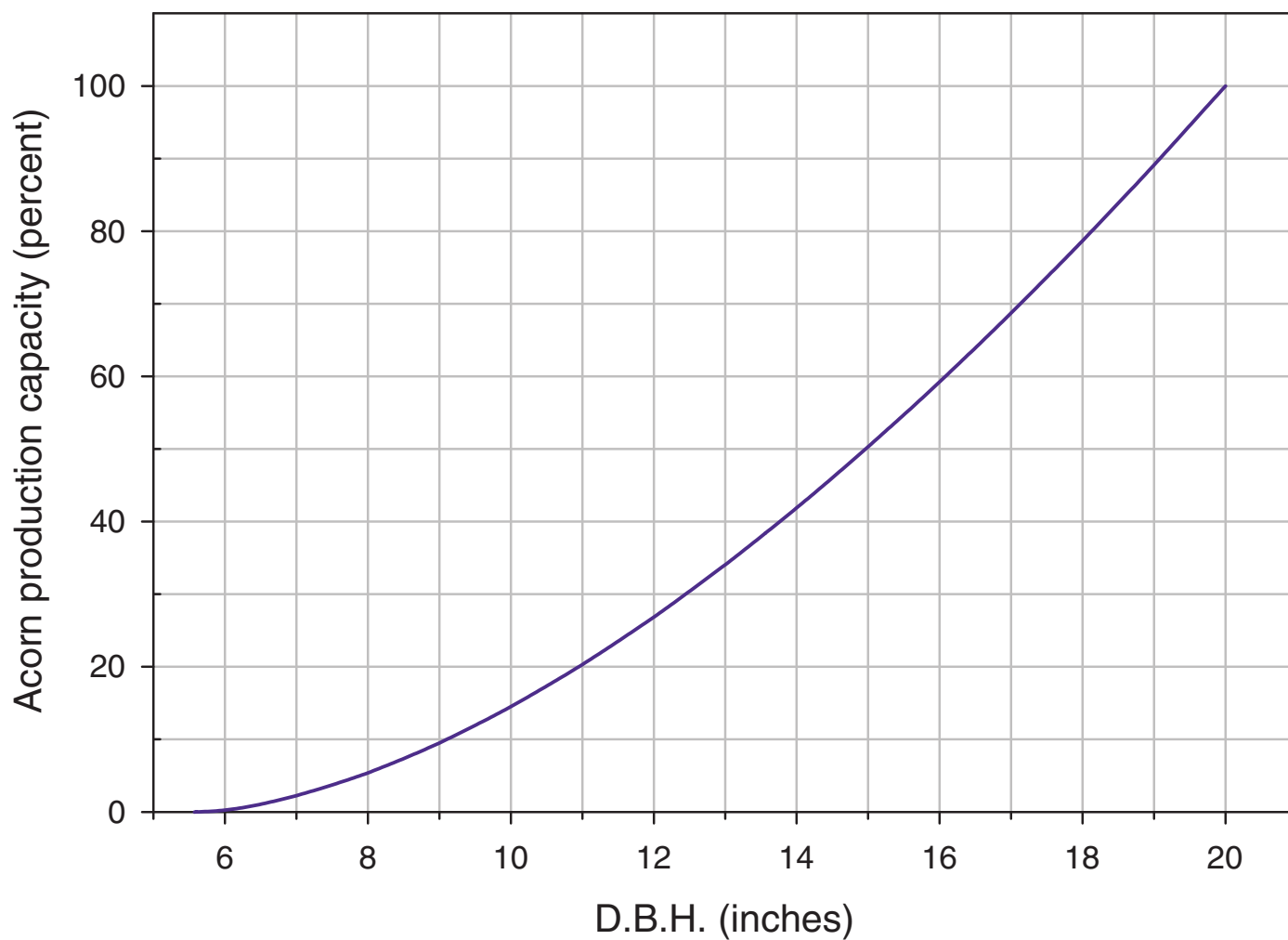


Figure 11—Acorn production capacity of individual bottomland oaks indexed to d.b.h. Methods for developing this curve are presented in appendix B.

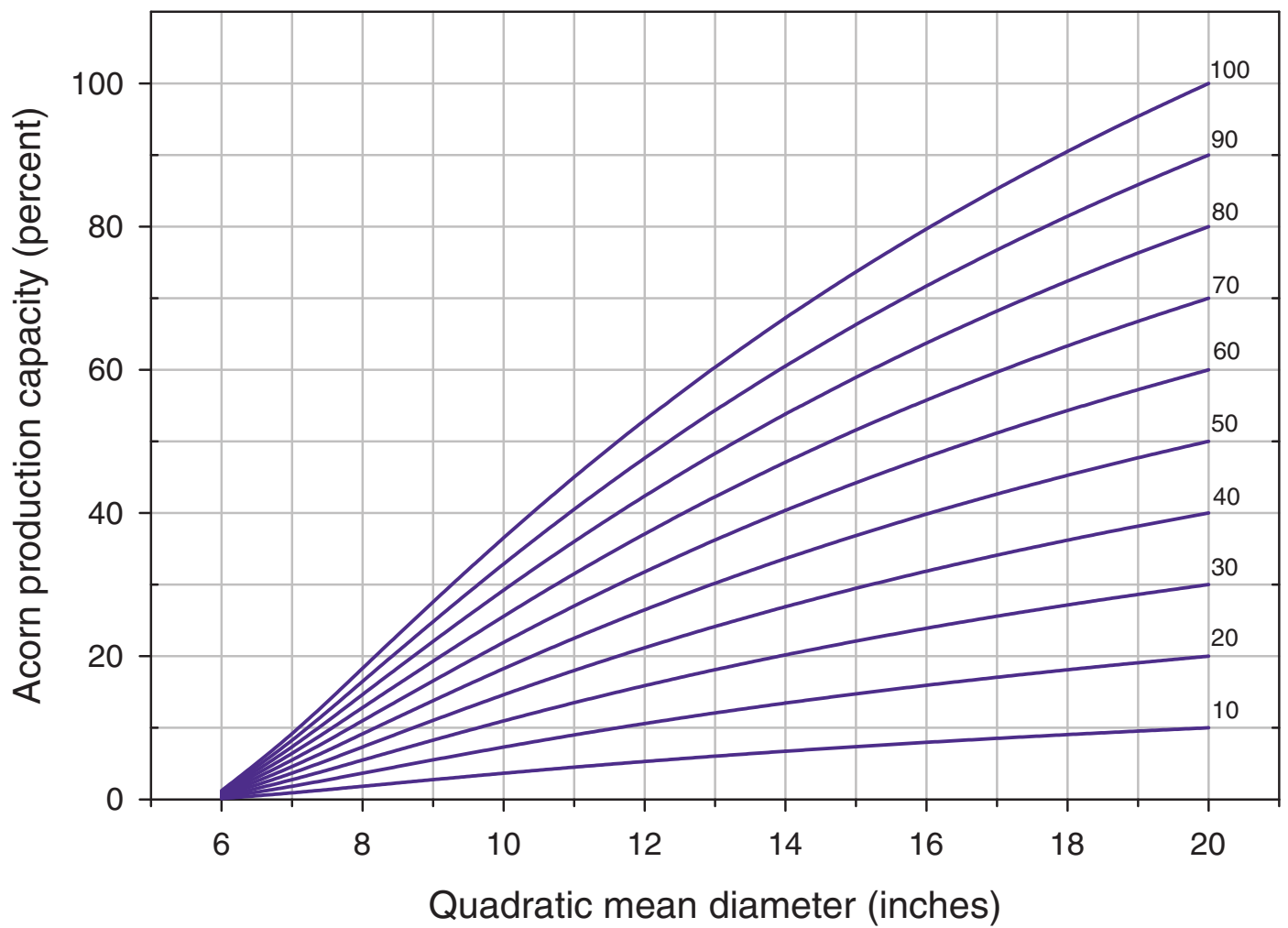


Figure 12—Acorn production capacity of bottomland oak stands indexed to quadratic mean diameter of oaks. Curves indicate capacity of the stand to produce acorns relative to a specified stand stocking percentage (noted by each curve) of oaks.

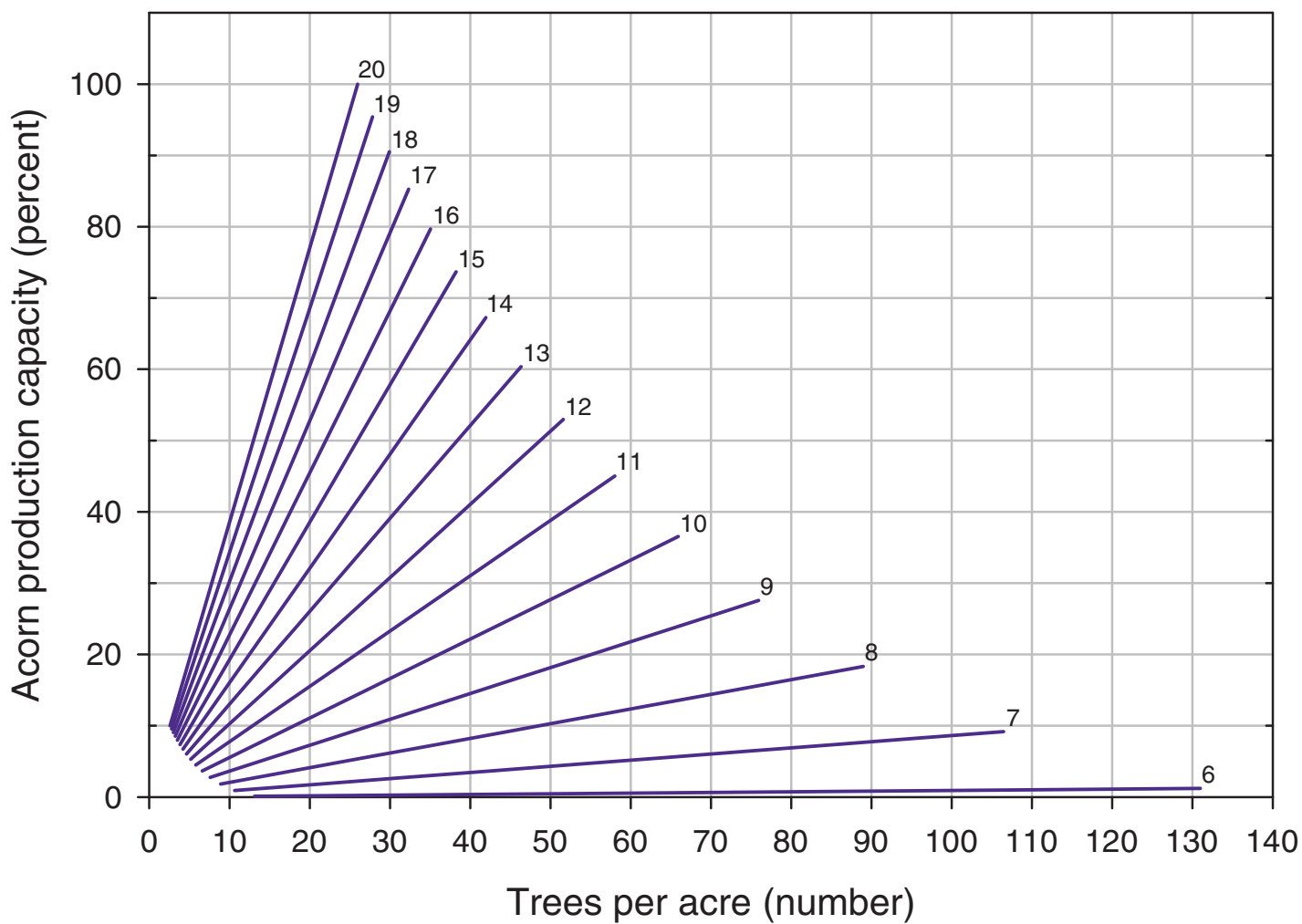


Figure 13—Acorn production capacity of bottomland oak stands indexed to oak stand density. Curves indicate capacity of the stand to produce acorns relative to a specified quadratic mean diameter (noted by each curve) of oaks.

that surveys with simple sampling schemes should provide the manager with enough data to inform stand management. If improved acorn production is a landowner objective, the manager needs to supplement conventional cruise data with basic information on acorn production: (a) whether a tree is reproductively viable; and (b) the size of its acorn crop relative to other trees in the stand (see example protocol in app. C). But, a one-time assessment is not adequate for identifying the propensity of a tree to produce acorns (Greenberg 2000, Gysel 1956, Healy and others 1999). The high genetic variation in annual acorn production observed between and among species and the high variation attributed to environmental factors as discussed earlier require that visual crown surveys must be conducted for multiple years to obtain an accurate assessment of the acorn production capacity of trees in the stand (Burns and others 1954, Greenberg 2000, Lashley and others 2009).

Assessing acorn yield—Beyond management objectives targeting acorn production, some landowners may be interested in quantifying acorn yield. Yield integrates measures of quantity and quality weighted by a common factor of tree or stand size. In oak stands managed for acorn production, yield conventionally refers to the fresh weight of sound acorns produced per acre. Yield can be improved by managing for tree characteristics and stand structures that increase stand-level acorn production, but conversely can be decreased by factors that reduce stand-level acorn production or damage acorn soundness. Acorn damage by insects, including acorn weevils and gall wasps, is a ubiquitous source of yield reduction in

most stands (fig. 14). Acorn weevils, in particular, can be a source of tremendous yield loss (Kellner and others 2013, Minckler and Janes 1965). Though these weevils attack acorns as they develop on the tree, damage typically is not recognized until after acorns mature, shed from the tree, and the weevil larva emerges from the acorn. Insects have been reported to damage between 16 and 87 percent of sound acorns produced in given mast years by a variety of oak species across the Eastern United States (Burns and others 1954, Christisen 1955, Downs and McQuilkin 1944, McQuilkin and Musbach 1977), with highest percentages of damage typically occurring in years of lowest acorn production. In bottomland oak plantations, acorn soundness also can be reduced in the seedbed by desiccation, fungal decomposers, and stagnant floodwater. Managers can assess yield with ground count or acorn trap sampling techniques introduced in the preceding section, but there is little that can be done to decrease the occurrence of insect damage or other factors that reduce acorn soundness in bottomland oak plantations.

Classifying trees for acorn production—Before a stand can be marked for a partial cutting to improve acorn production, the manager must perform an inventory that includes tree classification for purposes of acorn production. Classification should consider (1) species, (2) health and vigor, (3) crown class, and (4) acorn production potential (or capacity where potential has not been assessed). Four tree classes appropriate for grading the acorn production value of trees in bottomland oak plantations are:



Figure 14—Typical condition of sound versus damaged pin oak acorns: (A) sound acorns as shown by rich color, sharp striping, and clean cap scar; (B) acorns in advanced rot due to waterlogging as shown by dark staining; (C) acorns damaged by desiccation as shown by blotchy, bleached appearance; (D) acorn weevil damage as illustrated by exit holes; and (E) acorns that shed from the tree prior to full maturation as shown by cap retention and/or small size. (USDA Forest Service photo by Emile S. Gardiner).

Generalized Decision-Making Process

1. **Superior trees**—ideal trees for structuring the stand for acorn production. Superior trees are trees that: (1) are an oak species appropriate to the site; (2) have a healthy and vigorous condition; (3) maintain a dominant or codominant crown; and (4) have demonstrated superior acorn production relative to other individuals in the stand.
2. **Fair trees**—trees that have a lower potential than superior trees to contribute to stand-level acorn production but may contribute some acorn production where superior trees are not available. Fair trees are those that: (1) are an oak species appropriate to the site; (2) have a healthy and vigorous condition; and (3) maintain a dominant or codominant crown but have demonstrated less than average acorn production, OR maintain an intermediate crown and have demonstrated relatively superior acorn production.
3. **Inferior trees**—oaks that have very little potential to contribute to stand-level acorn production. Removing these trees will not reduce stand-level acorn production but could improve overall stand health. Inferior trees possess one or more of the following attributes: (1) oak species not appropriate to the site; (2) declining health or vigor; (3) an intermediate crown and have not demonstrated relatively superior acorn production; (4) a suppressed crown; or (5) demonstrated inferior acorn production.
4. **Non-oak trees**—trees will not contribute to stand-level acorn production. They are either planted or volunteer trees that are not a bottomland oak species. Removing these trees will not reduce stand-level acorn production.

Assigning tree class according to the four definitions described earlier requires prior documentation of the propensity for acorn production exhibited by individual trees in the stand. Research conducted throughout the Eastern United States indicates that at least 3 years of surveys are required to distinguish acorn production potential among individual trees. The protocol provided in appendix C outlines a systematic method for documenting crop size of individual trees. Data collected over several years will reveal acorn production potentials that can be used to inform tree classification. Where visual crown surveys or a similar technique have not been conducted, it is impossible to identify trees that are inherently superior acorn producers. For this situation, tree classification must be conducted by substituting acorn production capacity (fig. 11) for acorn production potential. But, the manager should recognize that this substitution greatly diminishes the accuracy of tree classification and limits the ability to improve stand quality for acorn production.

Equipped with a basic understanding of stand development in young, bottomland oak-dominated plantations and a working knowledge of various silvicultural tools used for assessment, evaluation, and monitoring of forest resources, the forest manager periodically should evaluate current conditions in the plantation and, if necessary, write silvicultural prescriptions to correct any problems that may exist. We developed a generalized, four-step process to help the forest manager make management decisions in young, bottomland oak-dominated plantations.

Step 1—Establish Landowner Objectives

The first critical step in our generalized decision-making process is to establish very specific landowner objectives. In the CRP and WRP Federal cost-share programs, management objectives are mandated by the program. The landowner has no choice but to follow program guidelines. This handbook does not address that scenario. Rather, we focus on the scenario in which the landowner is not bound by CRP or WRP guidelines and should address these two questions: (1) what does the landowner want the plantation to achieve, and (2) where does the plantation need to go?

Landowner objectives should be expressed in as much detail as possible. For example, “timber production” is not detailed enough, but “production of high-quality oak sawtimber” is a good example of a detailed landowner objective. Similarly, “wildlife habitat” is not detailed enough, but “improved acorn production for deer and turkey” is a good example of a detailed landowner objective. If the landowner has multiple objectives, such as the two previously mentioned examples, there should be a rough prioritization of the importance and desirability of those objectives. For example, are the relative priorities of these objectives roughly 50-50, 60-40, 70-30, or some other combination? Clearly, the more detailed the landowner objectives are stated, the more effective the forest manager can be in selecting appropriate silvicultural prescriptions to achieve those objectives.

Step 2—Conduct Inventory

The next step is to conduct a thorough inventory of the plantation. Data collected should be relevant to the landowner objectives. The purpose of the inventory is to determine the current condition of the plantation and how that condition relates to the landowner objectives for the plantation and the property as a whole.

If production of high-quality oak sawtimber is the sole or primary landowner objective, the following data should be collected on both planted trees and volunteer trees: (1) species, (2) d.b.h., (3) crown class, (4) potential log grade, and (5) tree

class. These individual-tree data then are used to calculate stand-level variables: (1) trees per acre, (2) basal area per acre, (3) quadratic mean diameter, (4) stocking percent, and (5) the tree class distribution across the entire plantation.

If improved acorn production is the sole or primary landowner objective, the following data should be collected on both planted trees and volunteer trees: (1) species, (2) d.b.h., (3) crown class, (4) tree class to assess acorn production, (5) visual crown survey, and (6) location of the tree. These data then are used to calculate density, stocking, and distribution of trees with good potential or capacity for acorn production, by species.

If the landowner objective is integrated management of the plantation for both oak sawtimber and improved wildlife habitat, the inventory should be designed to collect all of the previously listed data. If the inventory is planned to collect all data relevant to the landowner objectives, the forest manager will have a clear picture of the current state of the plantation.

Step 3—Assess Suitability of Plantation

Equipped with a clear understanding of the landowner objectives and a detailed accounting of current conditions across the plantation, the forest manager can make an accurate assessment of the current suitability or the potential suitability of the plantation to achieve those objectives. Very few young plantations are currently capable of achieving landowner objectives. They are simply too young and insufficiently developed to fulfill those objectives. So, the most appropriate purpose of Step 3, in nearly all cases, is to determine if the plantation is on the preferred pathway to achieve landowner objectives in the future.

There are several criteria that can be used to determine if the plantation is on the preferred path. The forest manager can compare current plantation values for survival percent, average d.b.h. of dominant and codominant planted oaks, and basal area per acre with the generalized curves depicted in figures 1, 2, and 3. For example, d.b.h. of dominant and codominant planted oaks in a 20-year-old bottomland oak-dominated plantation on a good site should average about 7–8 inches (fig. 2). A plantation of a similar age on a similar site with an average d.b.h. of dominant and codominant planted oaks that is significantly greater than 7–8 inches likely is not on the preferred path to achieve landowner objectives. Growth of planted trees is slower than desired, and some type of silvicultural operation may be warranted to shift the plantation back to the preferred pathway.

Similarly, the forest manager can compare the current stocking percent in the plantation to the stocking guide in figure 8. If stocking of the plantation falls between the A-line and the

B-line, the plantation is fully stocked, and the forest manager can conclude that the plantation is on the preferred path. If stocking is above the A-line or below the B-line, silvicultural action is needed to correct the situation.

The current tree class distribution of the plantation also can be used to determine if the plantation is on the preferred path. The tree class distribution shows the proportion of the plantation composed of trees suitable for landowner objectives (growing stock) versus the proportion of the plantation composed of trees unsuitable for landowner objectives (overburden). If the growing stock component accounts for at least 60 percent of total basal area, the plantation likely is on the preferred path and no corrective action is necessary. However, if the overburden component accounts for > 50 percent of total basal area, the plantation likely is not on the preferred path and some type of corrective action may be warranted.

Criteria used to determine if the young plantation is on a path satisfactory to management for acorn production are largely similar to those used to assess the timber management potential of an oak stand. But, additional consideration must be given to the potential to manage for oak species diversity. Survival, average d.b.h. of dominant and codominant oaks, oak basal area, and oak stocking percentages are all relevant indices of stand condition that bear suitability for acorn production, if they are calculated by species. The evaluation tool for acorn production capacity presented in figures 12 and 13 provides a handy method to judge the current status of a stand and gives an indication of the prospective trajectory for acorn production capacity as the stand develops. But, managers should consider the current capacity of the stand in light of site quality and previous stand establishment decisions that directly impacted its current structure. For example, a young stand with 60-percent stocking of cherrybark oak may be positioned to continue development towards satisfactory acorn production. But, because it lacks oak species diversity, its capacity should not be considered as high as a young stand with 20-percent stocking of cherrybark oak, 20-percent stocking of swamp chestnut oak, and 20-percent stocking of water oak. The relative contributions to the various indices of stand structure by species should be calculated and considered.

Step 4—Select Appropriate Silvicultural Prescription

If the assessment in Step 3 indicates that the plantation is currently on the preferred pathway to achieve landowner objectives, then no remedial measures are necessary, and the most appropriate management decision is to do nothing at the present time. However, if the plantation is not currently on the preferred pathway, some type of silvicultural operation is necessary to shift the plantation back onto the preferred path to achieve landowner objectives.

Intermediate Stand Practices

If some type of silvicultural operation is required, the forest manager first must decide whether to manage the plantation or to regenerate the plantation. The forest manager must decide if there are enough trees capable of achieving landowner objectives to warrant continued management of the plantation. This decision consists of two questions. First, is overall stand density sufficient to warrant continued management of the plantation? If survival is considerably below the generalized curve in figure 1 and stocking is well below the B-line in figure 8, the plantation is so severely understocked that the most appropriate management decision is to regenerate the plantation as soon as possible and start over. Second, even though overall stand density may be adequate, are there enough trees capable of achieving landowner objectives? If the overburden component of the tree class distribution accounts for > 50 percent of total stand basal area, there are simply too many trees unsuitable for landowner objectives that the most appropriate management decision is to regenerate the plantation. So, if the answer to either question is “no,” the plantation should be regenerated. If the answer to both questions is “yes,” the plantation should continue to be managed.

If a silvicultural operation is required and the initial management decision is to manage the plantation, the forest manager must select the silvicultural prescription that will be the most effective in shifting the plantation back onto the preferred pathway to achieve landowner objectives. Specific silvicultural prescriptions designed to fulfill each of our three landowner objectives will be described in detail in later sections of this paper.

Do-Nothing Scenario

As a word of caution, the forest manager should resist the temptation to perform some type of silvicultural activity in every situation. It is not always necessary or desirable to conduct a silvicultural operation in any given plantation. If the current condition of the plantation is suitable or potentially suitable for achieving landowner objectives (i.e., it is currently on the preferred pathway), there is no need to do anything. In that situation, the most appropriate management decision is to do nothing at the present time. If this decision is made after careful review and evaluation of the current condition of the plantation relative to the landowner objectives, doing nothing is a legitimate, reasonable, and appropriate management decision. The forest manager and landowner then use the inventory data collected in Step 2 previously to plan future management of the plantation.

Selection of the most appropriate silvicultural prescription requires a basic understanding of the different types of intermediate stand practices and the objectives that they were designed to achieve. All intermediate cuttings fall into one of two major categories: (1) selective cutting, or (2) systematic cutting (also called mechanical cutting). Some silvicultural prescriptions may include elements of both categories of intermediate cuttings.

In **selective cutting**, trees to be removed or retained are selected on the basis of specific characteristics of the tree, such as crown position and condition, species, and tree health. Based on these and other tree characteristics, the forest manager removes trees that are incapable of fulfilling landowner objectives and retains trees that are capable of fulfilling landowner objectives or have the potential to do so in the future.

In **systematic (mechanical) cutting**, trees to be removed or retained are chosen systematically on the basis of a pre-determined spacing or pattern, with no regard for tree characteristics. The ability of a tree to fulfill landowner objectives is not a consideration. Consequently, the forest manager does not have the opportunity to select undesirable trees for removal or to select desirable trees for retention.

In general, intermediate cuttings in young plantations < 15–20 years old are often pre-commercial operations and should be viewed by the landowner as an investment in the future value of the plantation. Trees to be removed may be deadened by herbicides or removed by cutting. However, as the trees in the plantation reach merchantable size (generally at least 6 inches d.b.h.), intermediate cuttings are commercial operations and the landowner will receive revenue from the operation.

There are five general types of intermediate cuttings that may be applicable in young, bottomland oak-dominated plantations: (1) thinning, (2) improvement cutting, (3) release cutting, (4) salvage and sanitation cutting, and (5) access corridor creation.

Thinning

Thinning is an intermediate cutting designed to regulate stand density in order to stimulate growth of residual trees. Emphasis of the thinning operation is on the manipulation of both stand density and spacing, with tree quality assigned to a role of secondary importance. The goal is to thin the plantation to some pre-determined level of residual stand density spread uniformly across the plantation. Increased growth of residual

trees usually leads to both increased economic value and increased acorn production of both individual trees and the plantation as a whole. The thinning operation can be either selective or systematic.

In **selective thinning**, the forest manager removes a sufficient number of undesirable trees (based on pre-determined tree characteristics) to reduce stand density to the target level. Because the thinning prescription is controlled by residual stand density, the forest manager often is forced either to leave some undesirable trees or to cut some desirable trees in order to maintain the target residual density.

Crop-tree thinning is a variation of the whole-stand selective thinning approach described earlier. It is designed to regulate density around a relatively small number of pre-selected residual crop trees, with or without selective thinning across the forest matrix between crop trees. Crop trees are selected for retention because they have very high potential for high-quality sawtimber production and/or abundant acorn production and, therefore, are strong candidates to fulfill landowner objectives.

In **systematic thinning**, the forest manager removes trees in single rows or in multiple adjacent rows at fixed intervals throughout the plantation. This type of systematic thinning is called **row thinning**. Regulation of stand density and spacing is the goal, with no regard for tree quality.

Improvement Cutting

In general, improvement cutting is an intermediate cutting designed to improve both species composition and stand quality in stands past the sapling stage, by removing trees of undesirable species, form, or condition. In single-species plantations, the primary focus is on improvement of stand quality rather than on improvement of species composition. Simply stated, the objective is to remove undesirable trees and to retain desirable trees, with residual stand density and spacing assigned to roles of secondary importance. Undesirable trees and desirable trees are defined by pre-determined tree characteristics that relate to the ability of the tree to fulfill landowner objectives. Trees to be removed may be deadened by herbicides or removed by cutting. Improvement cutting is always classified as a form of selective cutting.

Release Cutting

Release cutting is an intermediate cutting designed to release a young stand of desirable trees, not past sapling size, from the competition of undesirable trees that suppress them or threaten to suppress them. **Weeding** is a type of release cutting in which all individuals of an undesirable species are removed

from the stand in order to benefit the desirable species. Removal of all Chinese tallowtree [*Sapium sebiferum* (L.) Roxb.] from a young, oak-dominated plantation is an example of weeding. Release cutting is always classified as a form of selective cutting.

Salvage Cutting and Sanitation Cutting

Salvage cutting is an intermediate cutting designed to remove trees that have been killed or seriously damaged by injurious agents other than competition among trees. Sanitation cutting is designed to remove trees that are in imminent danger of being killed or seriously damaged. Examples of injurious agents include weather-related events, such as tornadoes, hurricanes, ice storms, drought, and flooding, as well as insects and disease-causing fungi. Removal of all volunteer ash (*Fraxinus* L. spp.) trees from an oak-dominated plantation because they have been attacked by emerald ash borer (*Agrilus planipennis* Fairmaire) is an example of salvage cutting. Removal of the ash trees because they are in danger of being attacked by the emerald ash borer is an example of sanitation cutting. Both salvage cutting and sanitation cutting are always classified as forms of selective cutting.

Access Corridor Creation

Access corridor creation is an intermediate cutting designed to create access corridors for harvesting or other equipment by removing two or more adjacent rows at fixed intervals throughout the plantation. This type of intermediate cutting is always classified as a form of systematic cutting.

Silvicultural Prescriptions

Actual silvicultural prescriptions in young, bottomland oak-dominated plantations rarely consist exclusively of only one of these different types of intermediate cuttings. Rather, most silvicultural prescriptions, irrespective of landowner objectives, contain elements from two or more types of intermediate cuttings. For example, in a young, oak-dominated plantation managed for the two co-equal objectives of high-quality oak sawtimber production and improved habitat for wildlife, a suitable silvicultural prescription might include elements of improvement cutting and release cutting. The improvement cutting portion of the prescription might include retention of trees with characteristics indicative of a strong potential for high-quality oak sawtimber and/or for abundant acorn production. The release cutting portion of the prescription might include the removal of all volunteer trees of undesirable species, such as Chinese tallowtree. Clearly, many combinations and variations of intermediate cuttings are available to the forest manager to create silvicultural prescriptions designed to fulfill specific landowner objectives.

Possible Detrimental Effects of Intermediate Cuttings

Well-designed intermediate cuttings effectively shift the plantation onto the preferred pathway to achieve landowner objectives. Growth, quality, and value of residual trees are improved. Acorn production is enhanced. The ability of the plantation to fulfill both objectives is strengthened. However, there are two possible detrimental effects of intermediate cuttings in any hardwood stand: (1) excessive logging damage to the boles of residual trees; and (2) possible production of epicormic branches along the boles of residual trees.

Logging Damage

Any logging wound that exposes living sapwood (fig. 15) may provide an avenue for the introduction of pathogenic fungi into the tree. Successful colonization of the wound leads to eventual decay and/or discoloration of the wood in the tree. Logging wounds that result in decay of the underlying wood reduce tree health, increase the susceptibility of the tree to insect attack, and eventually may lead to death of the tree. Decay also reduces both log grade and log volume, which would decrease log value significantly.

Some wounds are small enough that they will become covered with new bark before pathogenic fungi can colonize the wound successfully. Based on a study of sugar maple (*Acer saccharum* Marsh.) in northern Michigan, Hesterberg (1957) found that logging wounds > 4 inches wide or those that exposed more than 150 square inches of sapwood were likely to develop decay within 10 years. However, even though wounds on southern hardwoods may be sealed with new bark faster, the rate of successful fungal colonization is significantly more rapid in the warm, humid climate of the Southern United States, such that the minimum wound size for development of decay in southern hardwoods is likely to be much smaller than 150 square inches.



Figure 15—Large logging wound on the lower bole of a residual green ash (*Fraxinus pennsylvanica* Marsh.) tree after an intermediate cutting operation. (USDA Forest Service photo by James S. Meadows).

The extent of logging damage as a result of some type of intermediate cutting in hardwood stands primarily depends on: (1) residual stand density; (2) size and maneuverability of logging equipment; (3) level of planning in the logging operation; (4) skill and experience of equipment operators; and (5) size of harvested logs extracted from the stand. In fact, logging damage to the lower boles of residual trees rarely is caused by the skidder scraping against the bole. Rather, it is caused by the log pulled by the skidder scraping against the bole of the residual tree. Based on these factors, we propose the following guidelines to minimize logging damage in partially cut hardwood plantations:

1. Contract with loggers that have experience in young hardwood stands.
2. Match the size of logging equipment to the size of the trees in the stand.
3. If possible, locate skid trails to avoid residual crop trees.
4. If present, leave large saplings adjacent to residual crop trees for protection against wounding.
5. Create access corridors to facilitate movement of logging equipment throughout the plantation.

Epicormic Branches

The second potentially serious problem associated with intermediate cuttings in hardwood stands is the possible production of epicormic branches along the boles of residual trees. Because they diminish the quality and value of the underlying wood, they can have a large detrimental impact on the economics of timber production. Consequently, the presence of epicormic branches is only important when sawtimber production is at least one of the landowner objectives.

Epicormic branches are adventitious twigs that develop from dormant buds found along the main bole of hardwood trees (fig. 16). These dormant buds can be released at any time during the life of the tree in response to a variety of stimuli. These small branches produce small knots that are defects on the log. Consequently, the presence of epicormic branches along the bole frequently reduces both log quality and log grade, which subsequently reduces log value. If epicormic branches are widespread on trees throughout the stand, the stumpage value of the timber in the stand likely will be reduced as well.

Epicormic branch defects in the underlying wood (fig. 17) may reduce the value of the lumber produced from the log. Because hardwood lumber grade is determined by the location and spacing of defects rather than by the size of defects, the small knots caused by epicormic branches reduce the length

and number of clearcuttings in the lumber, which may reduce both lumber grade and lumber value. In fact, Meadows and Burkhardt (2001) reported that the presence of defects caused by epicormic branches reduced the value of willow oak lumber by 13 percent.

Production of epicormic branches along the boles of individual hardwood trees is not a well understood process. In the past, most foresters believed that epicormic branches developed on residual trees after an intermediate cutting solely in response to a sudden increase in exposure of the bole to direct sunlight. However, it has been recognized for many years that hardwood species vary widely in their inherent susceptibility to epicormic sprouting. It is also now clear that tree health plays a major role in determining the propensity of a hardwood tree to produce epicormic branches.

Based on this evidence, Meadows (1995) hypothesized that the production of epicormic branches on hardwood trees is controlled by complex interactions among three major factors: (1) species, (2) stress, and (3) sunlight (fig. 18). Epicormic sprouting varies significantly among hardwood species. Of the seven oaks commonly planted in the LMAV, Nuttall, overcup, water, and willow oaks are highly susceptible to the production of epicormic branches, but cherrybark, Shumard, and swamp chestnut oaks are only moderately susceptible. Stress in individual trees may be caused by a variety of factors, such as climatic events, site and stand conditions, suppression, and both stand-level and tree-level disturbances. High levels of stress reduce tree health and may stimulate the production of epicormic branches. Sudden exposure of the bole to direct sunlight may release dormant buds that develop into epicormic branches.

According to the hypothesis advanced by Meadows (1995), species and tree health are the mechanisms that control the production of epicormic branches in hardwood trees. Each species is characterized by an inherent range of susceptibility to epicormic sprouting. Current tree health sets the actual level of susceptibility for that tree within the genetic range of that species, such that healthy trees are much less likely to produce epicormic branches than unhealthy trees of the same species. Sudden exposure of the bole to direct sunlight serves as a triggering mechanism to release dormant buds that eventually develop into epicormic branches. Under this hypothesis, healthy trees, especially of less-susceptible species, can suppress the release of those dormant buds, such that few, if any, epicormic branches are produced. In contrast, unhealthy trees, especially of susceptible species, lack the ability to suppress the release of the dormant buds, such that many epicormic branches are produced. Epicormic sprouting can be minimized if the forest manager strives to maintain healthy stands composed of healthy trees. Intermediate cutting is a sound silvicultural practice that can be used to accomplish that goal.



Figure 16—Epicormic branches along the bole of a residual water oak tree after an intermediate cutting operation. (USDA Forest Service photo by James S. Meadows).



Figure 17—Epicormic branch defect on willow oak lumber. (USDA Forest Service photo by James S. Meadows).

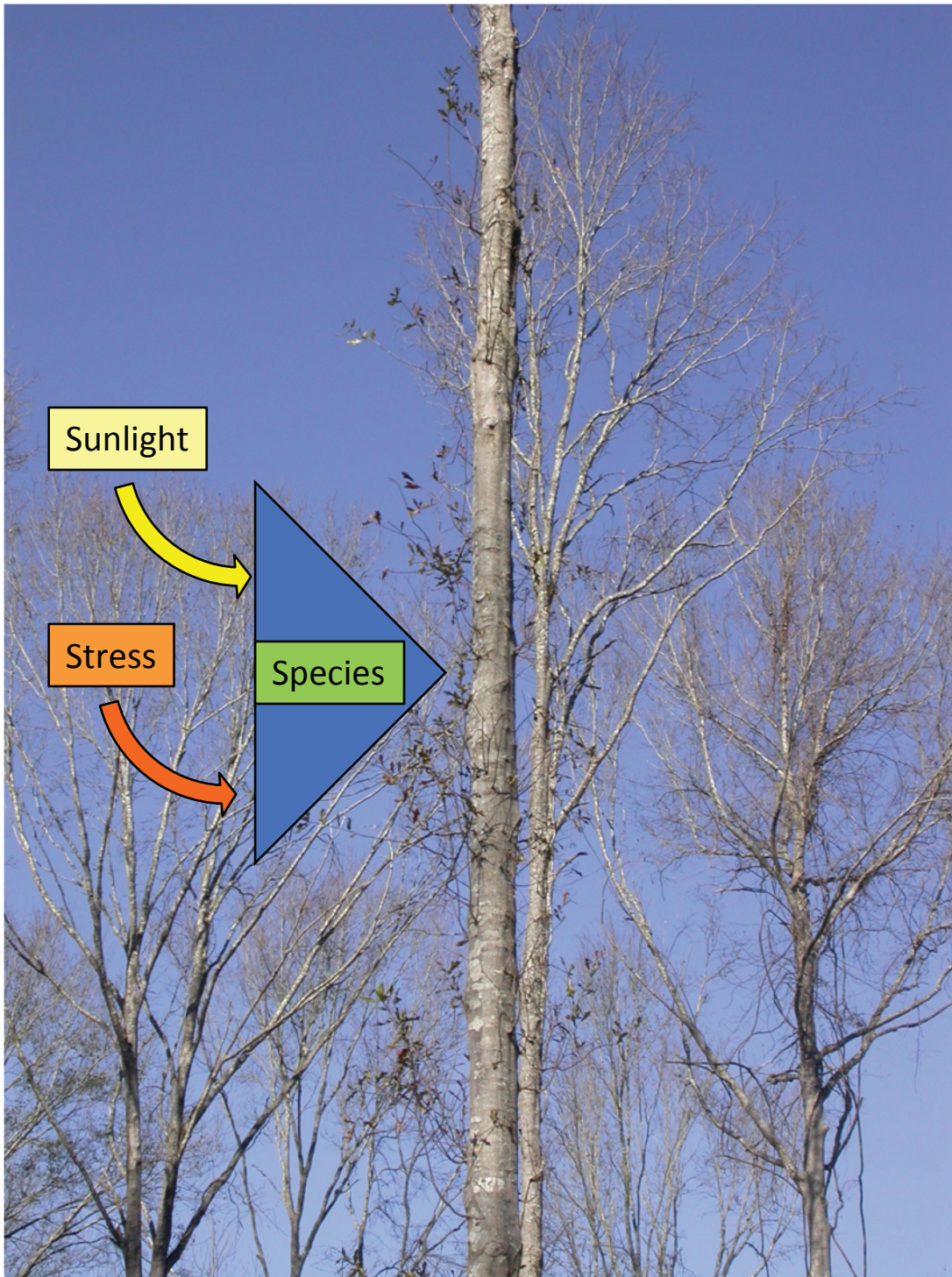


Figure 18—Production of epicormic branches is controlled by complex interactions among species, stress, and sunlight.

Important Factors in the Development of Silvicultural Options

There are several important factors that the forest manager should consider when selecting the most appropriate silvicultural option to use in young, bottomland oak-dominated plantations. We provide the following lists of those factors relative to three common landowner objectives below.

Important Factors for Production of High-Quality Oak Sawtimber

1. Availability and proximity of hardwood markets, particularly for pulpwood—the landowner needs a market for the material removed during an intermediate cutting operation in a young plantation. If no market exists, the cutting operation becomes a cost to the landowner. This factor also affects the minimum volume to be removed in order to secure a logger to conduct the cutting operation. A minimum of 10–15 tons of pulpwood per acre may be enough to secure a logger to harvest plantations near a mill, but the minimum may be considerably higher for plantations not near a mill.
2. Importance of bole quality and log grade—if a market for grade hardwood sawtimber is available, the forest manager should strive to develop trees with clear logs throughout the plantation, even at a young age. If no grade market exists, the forest manager can place less emphasis on the development of clear logs.
3. Use of the tree classification system developed by Meadows and Skojac (2008) as a tool to segregate trees into different classes of quality and suitability for achieving landowner objectives—this system can be used to identify trees to be retained and trees to be removed in any intermediate cutting operation.
4. Recognition of the possibility that some type of precommercial cutting practice may be required as a remedial measure in very dense, young plantations—remedial measures required to shift an overly dense plantation to its preferred trajectory of development should be considered even if implementation results in a cost to the landowner.

Important Factors for Improved Acorn Production

1. Importance of the plantation as a component of the entire landscape—the forest manager should consider how the plantation fits into the mosaic of vegetation types across the landscape and tailor silvicultural activities accordingly.
2. Appropriate balance between acorn production and browse production across the plantation and across the

landscape—wildlife management requires a mixture of mast and browse distributed across the plantation to take advantage of good acorn-producing trees and existing areas of low survival of planted trees.

3. Appropriate balance between red oak species and white oak species for acorn production—intervals of masting periodicity differ among and between species in the red oak group and species in the white oak group (table 2). Accordingly, synchrony in the production of a good acorn crop by all oak species in a stand or on a landscape is rare. Maintaining a diverse composition of oak species can buffer against acorn crop failures because it increases the probability that at least one species will produce an acorn crop. Red oak acorns and white oak acorns also differ in size, food value, energy value, tannins, and wildlife preference. Consequently, the forest manager should strive to create a balance of red oaks and white oaks either within the plantation or across the landscape.
4. Use of periodic visual crown surveys to identify genetically superior mast-producing trees—the best predictor of acorn production in the future is actual acorn production in the past. Visual surveys of acorn production conducted annually for several years will identify genetically superior acorn producers. Appropriate silvicultural treatments then can be applied to enhance acorn production on those trees already proven to be good producers.

Important Factors for Integrated Management for Oak Sawtimber and Wildlife Habitat

1. Optimization rather than maximization of landowner objectives—when integrated management for oak sawtimber and wildlife habitat create multiple landowner objectives, it generally is not possible to maximize both objectives within a single plantation. Thus, the goal of management becomes optimization of these two objectives.
2. Possible reduction in benefits due to potential tradeoffs—specific benefits associated with either timber production or wildlife habitat improvement may be reduced because management compromises may be required as a result of the desire to achieve multiple landowner objectives.
3. Ultimate goal of integrated management—the forest manager should strive to create a management scheme that strikes the optimum balance between these two, equally important landowner objectives.

Suitability of Systematic Cutting in Young Oak Plantations

We briefly described systematic cutting, also called mechanical cutting, earlier in this handbook, but a more detailed discussion is warranted here. By definition, systematic cutting is a type of intermediate cutting in which trees to be removed or retained are chosen on the basis of a pre-determined spacing or pattern, with no regard for tree characteristics. In plantations, the most common use of systematic cutting is to remove one or more adjacent rows at fixed intervals throughout the plantation.

More specifically, there are two types of systematic cuttings commonly used in plantations:

1. **Row thinning:** Removal of a single row at fixed intervals, such as every other row, every third row, every fourth row, etc. The objective is to reduce plantation density by about 50 percent, 33 percent, 25 percent, respectively.
2. **Access corridor creation:** Removal of one or more adjacent rows at fixed intervals. The primary objective is to provide access corridors for harvesting equipment. A secondary objective is to produce wide strips of browse throughout the plantation.

Systematic cutting is a low-cost, easy-to-implement technique to reduce plantation density or to provide access for harvesting equipment. However, because it is systematic, and not selective, it removes or retains trees with no regard for their suitability for achieving landowner objectives. In other words, trees are cut or left arbitrarily on the basis of their location within the plantation rather than on the basis of their desirability for fulfilling landowner objectives.

In general, there are three situations in which systematic cutting may be an acceptable silvicultural practice to use in young, bottomland oak-dominated plantations. First, systematic cuttings can be used to create access corridors for harvesting equipment, if necessary. Creation of access corridors also will increase browse at regular intervals throughout the plantation. Second, if production of high-quality sawtimber or improved acorn production are significant landowner objectives, systematic cutting to regulate density and increase growth of residual trees should be used only in very dense, young plantations in which individual trees have not yet differentiated into crown classes. Plantations in which crown class differentiation has not occurred generally are < 15–20 years old. A systematic cutting in this situation should be regarded as a remedial measure to correct an excessively narrow initial spacing. Third, systematic cuttings can be used to reduce the density of volunteer trees in plantations with excessive invasion by volunteer species.

However, because trees are removed or retained arbitrarily, systematic cuttings generally are unacceptable in plantations in which individual trees have differentiated into crown classes and in which quality and value of residual trees are important considerations (i.e., when production of high-quality sawtimber

or improved acorn production are significant landowner objectives). Systematic cuttings simply do not allow the forest manager to select unsuitable trees for removal or to select suitable trees for retention. Trees are removed or retained by random chance.

Hypothetical Example

We developed a hypothetical example to illustrate the effects of selective cutting, row thinning, and a hybrid of these two techniques on the residual composition of a young oak plantation. Figure 19A depicts a portion of a hypothetical pure oak plantation. The example consists of 20 planted rows with 12 planting spots in each row, for a total of 240 trees. At an initial spacing of 10 x 10 feet, the sample area is approximately 0.55 acres. For the sake of simplicity, we assumed 100 percent survival in the sample area. We also assumed that the plantation had completed the process of differentiation into crown classes. Based on criteria specific to landowner objectives, whatever they may be, the forest manager identified those trees that are suitable and unsuitable for achieving landowner objectives. In our example, 110 trees (about 46 percent of the original 240 trees) were identified as having the potential to achieve landowner objectives in the future. These 110 trees are classified as growing stock trees and are designated by having no symbol on their crown in all parts of figure 19. Trees unsuitable for achieving landowner objectives are designated by a **red X** on their crown in figure 19. We randomly located the 110 growing stock trees from across all trees in the sample area of the plantation depicted in figure 19A. This random distribution created several natural clusters of growing stock trees and a few areas where no growing stock trees occurred. This pattern of distribution of growing stock trees within our hypothetical oak plantation is similar to the pattern of distribution of growing stock trees within natural bottomland hardwood stands.

A common selective cutting prescription is to remove all unsuitable trees and to retain all suitable trees, based on criteria relative to landowner objectives. Under this prescription, there is no attempt to regulate spacing among residual trees. Figure 19B depicts the spatial distribution of the 110 residual growing stock trees across the plantation after this selective cutting prescription was applied. It created natural clusters of growing stock trees scattered across the plantation and several irregularly shaped gaps in areas where no growing stock trees occurred. The major advantage of selective cutting is that the forest manager can select which trees to cut and which trees to leave. Only trees suitable for achieving landowner objectives remain in the plantation to continue to grow and develop over time. Most importantly, selective cutting allows the forest manager to control and shape the character and structure of the residual stand and provides an opportunity for the forest manager to improve the capability of the plantation to achieve landowner objectives.

(A) Before cutting

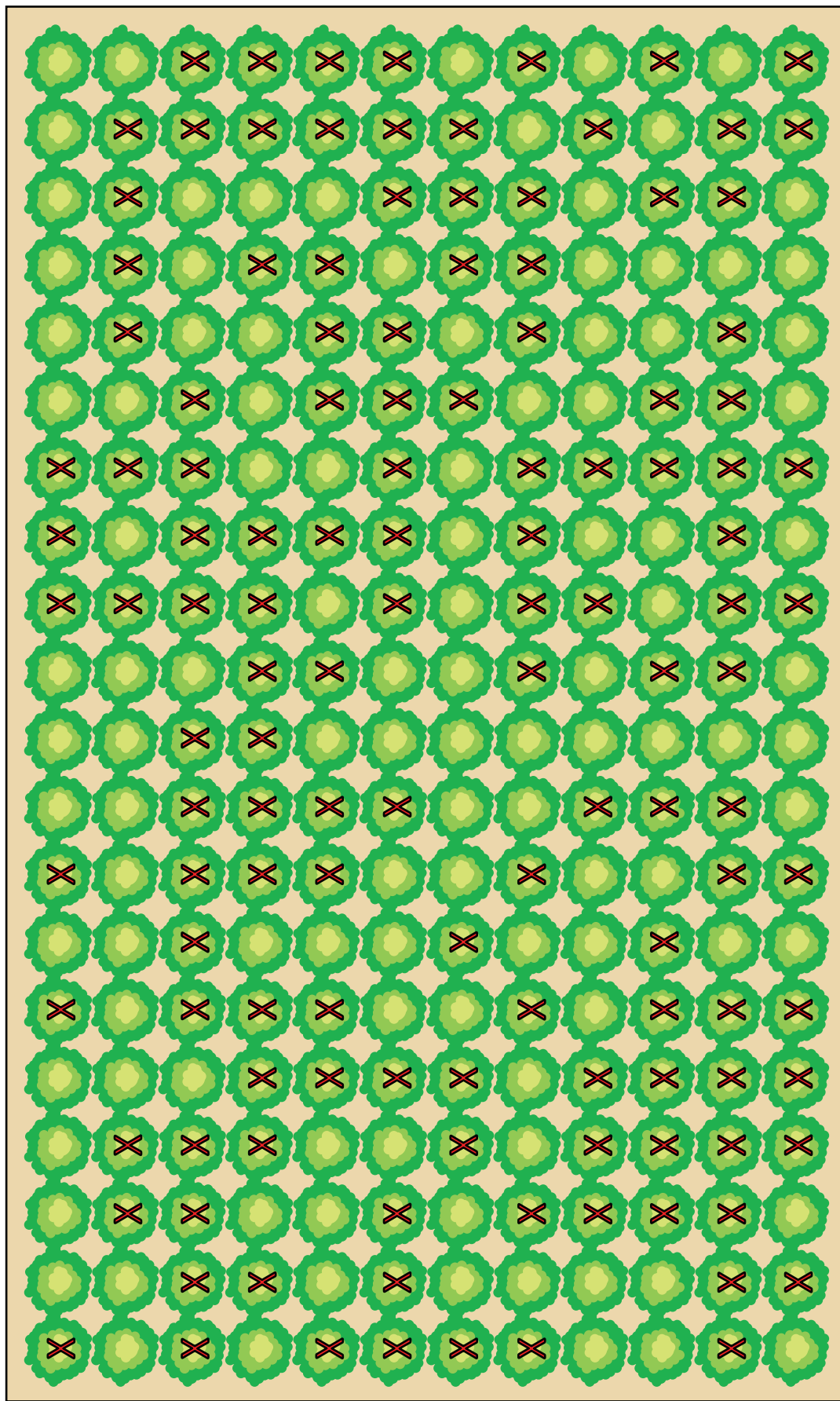


Figure 19(A)—Hypothetical example of the spatial distribution of trees in a young, bottomland oak plantation before cutting. Trees are either suitable (no symbol in the crown) or unsuitable (X) for achieving landowner objectives.

(B) After selective cutting

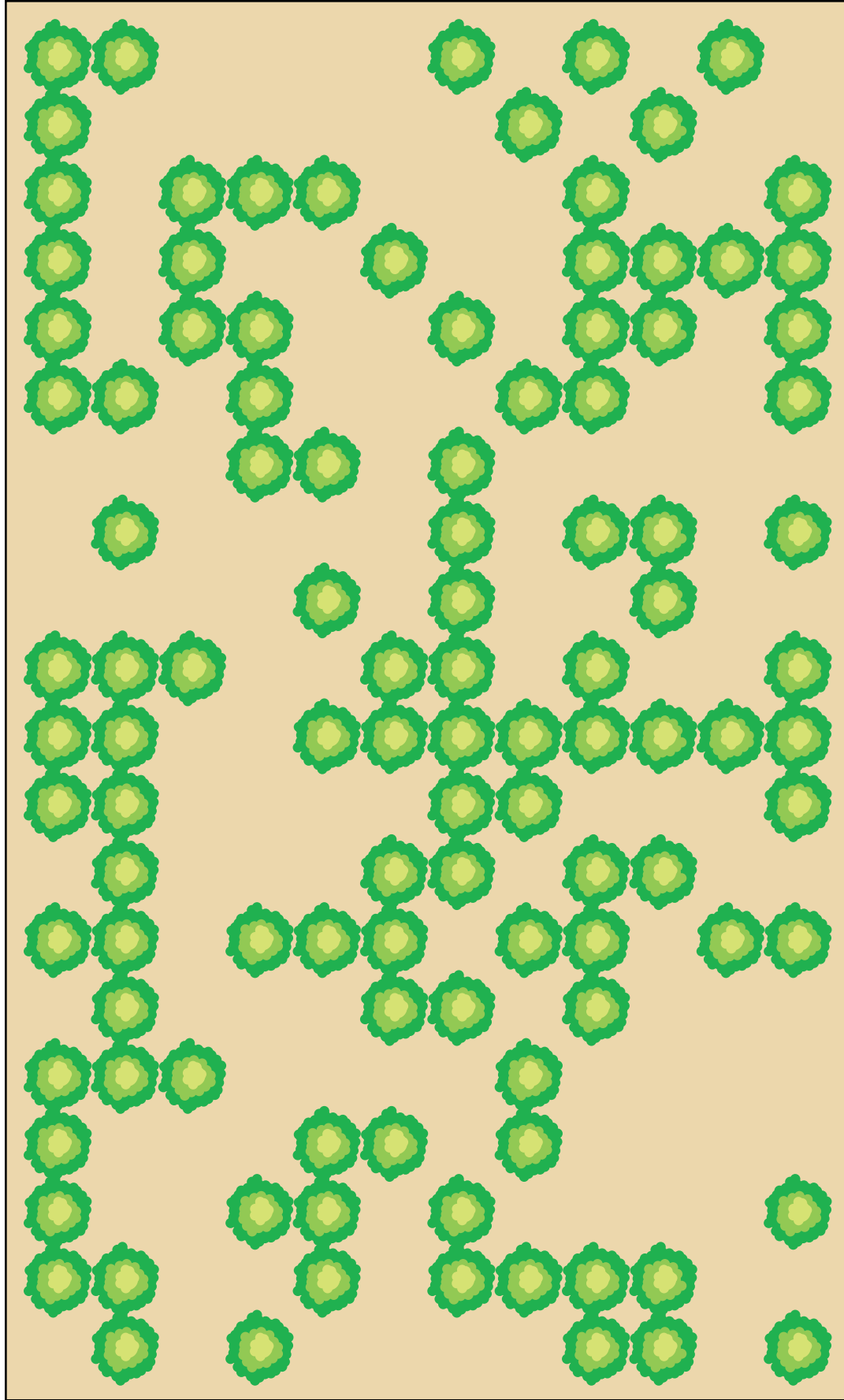


Figure 19(B)—Hypothetical example of the spatial distribution of trees in a young, bottomland oak plantation after selective cutting. Empty spaces indicate places where unsuitable trees [marked with a red **X** on figure 19(A)] have been removed to achieve landowner objectives.

(C) After row thinning

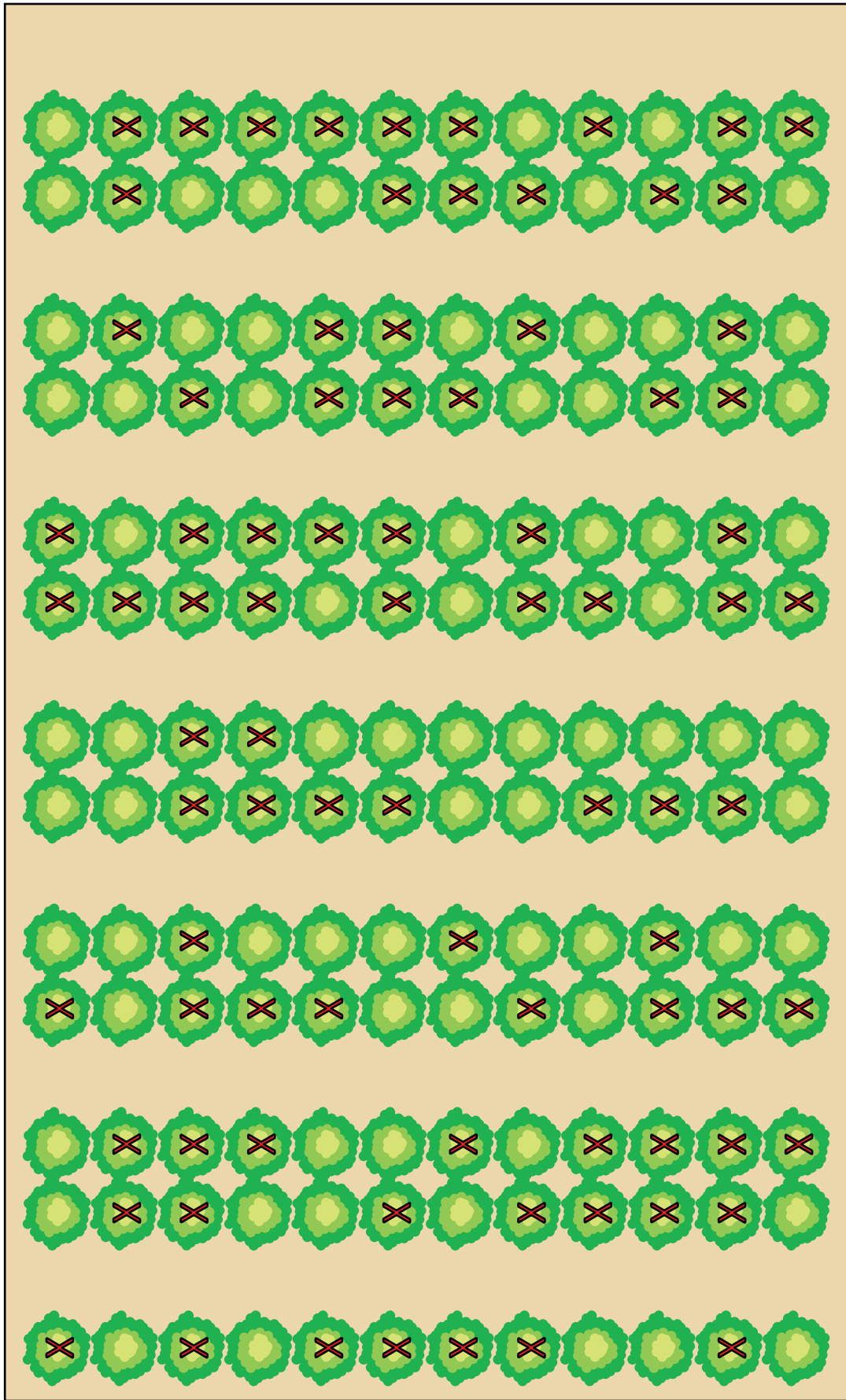


Figure 19(C)—Hypothetical example of the spatial distribution of trees in a young, bottomland oak plantation after row thinning. Trees are either suitable (no symbol in the crown) or unsuitable (X) for achieving landowner objectives.

(D) After hybrid cutting

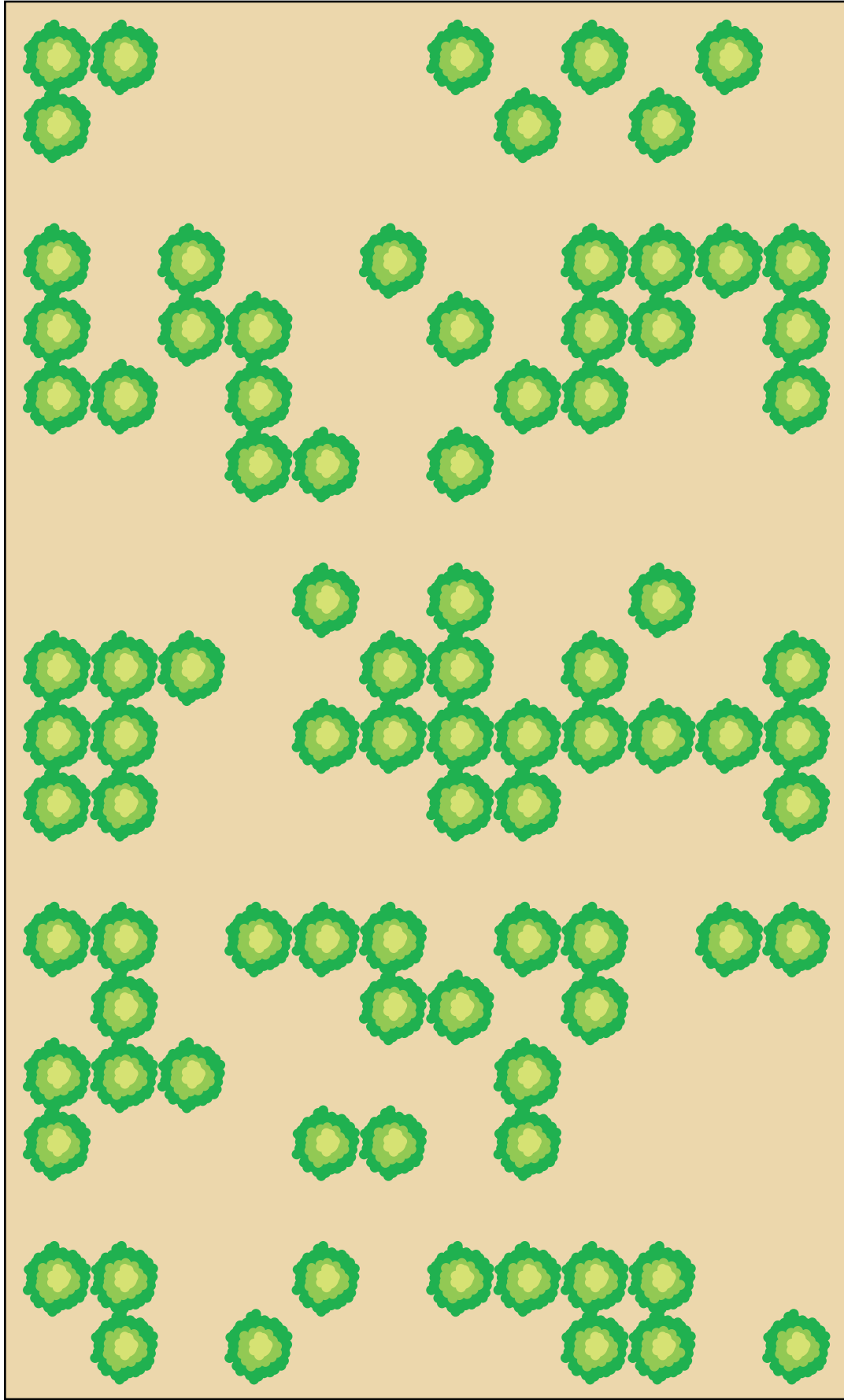


Figure 19(D)—Hypothetical example of the spatial distribution of trees in a young, bottomland oak plantation after a hybrid cutting that combines selective cutting and row thinning. All residual trees are suitable for achieving landowner objectives.

Silvicultural Options for High-Quality Oak Sawtimber

At the other extreme, a typical row thinning prescription is to remove all trees from every third row, with no attempt made to cut unsuitable trees from within the adjacent uncut rows. Consequently, trees in the plantation are cut or left purely by random chance. Figure 19C represents the spatial distribution of residual trees across the plantation after this traditional row thinning prescription was applied. Removal of every third row arbitrarily across the plantation left 156 residual trees, of which only 72 are growing stock trees. Trees suitable for achieving landowner objectives now constitute about 46 percent of the residual trees, the same percentage as the original uncut plantation. In our example, row thinning removed 38 growing stock trees and retained 84 unsuitable trees. In other words, the row thinning prescription cut 35 percent of the most beneficial trees in the plantation and left 65 percent of the most inferior trees in the plantation, an unsatisfactory outcome. In contrast to the irregularly shaped gaps created through selective cutting, row thinning only created narrow, linear gaps at fixed intervals throughout the plantation. The major disadvantage of row thinning is that the forest manager cannot select which trees to cut and which trees to leave. It does not allow the forest manager to shape the nature of the residual stand. Furthermore, selection of row thinning as the preferred silvicultural option to use in a young, bottomland oak plantation precludes the forest manager from taking advantage of an opportunity to improve the capability of the plantation to achieve landowner objectives.

There is a hybrid technique that combines row thinning and selective cutting to create a silvicultural option that can be used in young, oak-dominated plantations. This hybrid prescription consists of the removal of every fifth row, to provide access for harvesting equipment and to create wildlife corridors, and the selective removal of unsuitable trees from within the adjacent uncut rows. It removes 20 percent of the trees from the plantation by random chance but allows the forest manager to select the remainder of the trees to be removed. Figure 19D depicts the spatial distribution of residual trees across the plantation after this hybrid prescription was applied. The prescription removed all growing stock trees that occurred in cut rows, but also removed all unsuitable trees from uncut rows. In our example, there are now 89 residual trees in the thinned plantation, all of which are growing stock trees. The prescription removed 21 growing stock trees (about 19 percent) that, by random chance, were within the cut rows. Like the selective cutting prescription, this hybrid prescription also created irregularly shaped gaps scattered across the plantation. This hybrid technique provides a compromise between selective cutting and traditional row thinning. Although it sacrifices some growing stock trees, it produces a residual stand similar to the stand produced through purely selective cutting. It allows the forest manager to shape the structure of the residual stand and provides an opportunity to improve the capability of the plantation to achieve landowner objectives, but perhaps to a somewhat lesser extent than selective cutting alone.

In the next three major sections of this handbook, we present landowners and forest managers with several arrays of silvicultural options suitable for achieving each of three common landowner objectives: (1) production of high-quality oak sawtimber as the sole or primary objective; (2) creation of improved habitat for wildlife through improved acorn production as the sole or primary objective; and (3) integrated management for both oak sawtimber and improved wildlife habitat as multiple objectives of roughly equal importance and priority to the landowner.

For all silvicultural options described in the next three sections, we assume that, based on a recent inventory of the plantation, the decision has been made that application of some type of intermediate silvicultural prescription is currently necessary to improve the capability of the plantation to achieve landowner objectives, whatever they may be.

In the first section, we present two silvicultural options suitable for the production of high-quality oak sawtimber as the sole or primary landowner objective: (1) stand density management, and (2) stand quality management.

Stand Density Management

Stand density management is a silvicultural strategy designed to use intermediate cuttings to improve the growth of residual trees through regulation of plantation density. Consequently, all intermediate cuttings applied under the concept of stand density management are classified as thinnings.

Thinning prescriptions in most hardwood stands traditionally have been based on the concept of stand density management. The presumption is that hardwood stands are managed best through the regulation of stand density. Stands to be thinned are marked to some pre-determined level of residual stand density spread uniformly across the stand. For example, in mid-rotation natural bottomland hardwood stands in the South, a typical prescription is to thin the stand to 70 square feet of residual basal area per acre.

A more general thinning prescription based on stand density management—one that could be used in young, oak-dominated plantations—is to thin the plantation to the B-line level of residual stocking (fig. 8). The B-line represents minimum full stocking and is the recommended level of residual density after thinning in even-aged stands. In practice, the forest manager marks the plantation so that the combination of the number of trees per acre and the basal area per acre of the residual stand falls somewhere on the B-line. For example, in a young oak plantation, the forest manager estimates that the quadratic mean diameter of the residual stand will be about 6 inches. Based on the stocking chart in figure 8, the target residual density under stand density management is about 240 trees per acre and slightly more than 45 square feet of basal area per acre. Residual stocking in the thinned plantation will

be slightly less than 50 percent. These numbers include both planted and volunteer trees. Once the target residual density has been determined, the forest manager must decide which trees to cut and which trees to leave in the plantation after thinning. Marking rules to identify trees to be removed and trees to be retained can be based on either the Putnam tree classification system or the Meadows tree classification system (see table 4). Both systems were discussed in detail in the section on Silvicultural Tools for Assessment, Evaluation, and Monitoring.

If the Putnam tree classification system is used, the following marking rules are applied to implement the recommended thinning prescription based on stand density management:

1. Leave all trees in the preferred growing stock class.
2. Cut all trees in the cutting stock and cull stock classes.
3. Cut none, some, or all of the trees in the reserve growing stock class in order to reach the target residual density.

If the Meadows tree classification system, as modified for use in young stands below sawtimber size, is used to select which trees to cut and which trees to leave, the following marking rules are applied to implement the recommended thinning prescription based on stand density management:

1. Leave all trees in the preferred and desirable growing stock classes and in the superior poletimber stock class.
2. Cut all trees in the cutting stock and cull stock classes and in the inferior poletimber stock class.
3. Cut none, some, or all of the trees in the acceptable growing stock class in order to reach the target residual density.

In almost all cases, regardless of which tree classification system is used as the basis for the marking rules, some proportion of either the reserve growing stock class in the Putnam system or the acceptable growing stock class in the Meadows system will need to be cut to reach the target residual density.

Unfortunately, there are three critical problems associated with the use of stand density management as the basis for thinning prescriptions in young, oak-dominated plantations. First, it is difficult for the timber marker to visualize the target level of residual density as he/she marks the plantation for thinning. Even experienced timber markers potentially may miss the target residual density by a significant amount. Second, trees in young plantations, even those composed of a single species, exhibit a wide range of characteristics that influence their ability to produce high-quality sawtimber at some point in the future. They vary greatly in quality, value, and suitability to achieve landowner objectives. Consequently, the spatial distribution of suitable trees across most plantations is generally not very

uniform. Suitable trees may be clustered in some parts of the plantation, whereas in other areas, suitable trees may be so dispersed that small groups of unsuitable trees are scattered across the plantation. This irregular spatial distribution of suitable trees creates difficulties for the timber marker when the thinning prescription requires residual density to be spread uniformly across the plantation. Third, because thinning prescriptions in stand density management are based solely on residual stand density, the timber marker often is forced either to leave low-quality, low-value trees or to cut high-quality, high-value trees in order to maintain the target residual density uniformly across the plantation. Consequently, residual stand quality and value growth potential may be compromised to the extent that thinning prescriptions based on stand density management often produce residual plantations of less-than-optimum economic value.

Stand Quality Management

Stand quality management is a new silvicultural strategy designed to use intermediate cuttings to improve growth, quality, and value of residual trees through regulation of plantation quality. Consequently, all intermediate cuttings applied under the concept of stand quality management are classified as improvement cuttings.

The objective of stand quality management is to develop and maintain a high level of stand quality, with stand density relegated to a role of secondary importance. Demotion of stand density to a secondary role is justified because, in studies in natural stands, diameter growth response of residual dominant and codominant red oaks was very similar across a range of residual stand densities (about 60–90 square feet of basal area per acre) after application of several different thinning prescriptions based on stand density management (Meadows 2012, Meadows and Goelz 2002, Meadows and Skojac 2006). In other words, residual stand density is relatively unimportant to residual, upper-crown-class red oaks as long as it falls within these fairly broad limits.

Simply stated, the basic premise of stand quality management is “if it’s a good tree, leave it; if it’s a poor tree, cut it!” Under this premise, tree quality dictates which trees will be cut and which trees will be left in the plantation during an improvement cutting. As long as residual stand density falls within broad limits, improvement cutting prescriptions and marking rules established under stand quality management can be based on tree quality alone, with little or no regard for residual stand density.

The Meadows tree classification system (table 4) can be used to differentiate between “good” trees and “poor” trees. The tree classes in this system reflect the current quality and expected future sawtimber value of each tree. Each tree class represents a different level of tree quality and therefore also represents the suitability of each tree for achieving the landowner objective of

production of high-quality sawtimber. The preferred, desirable, and acceptable growing stock classes, as well as the superior poletimber stock class, consist of trees that have the capability to achieve this landowner objective; trees in these classes are considered to be “good” trees. In contrast, the cutting and cull stock classes, as well as the inferior poletimber stock class, consist of trees that do not have the capability to achieve this objective and, in fact, actually detract from the goals of management; trees in these classes are considered to be “poor” trees.

Although this tree classification system was designed to be used in sawtimber stands, Meadows and Skojac (2008) described how to modify the system for use in young stands, in which all or nearly all of the trees are below sawtimber size. The five sawtimber tree classes are used to classify upper-canopy trees in young stands. Log grade requirements for these tree classes are evaluated on the basis of the potential log grade that may be achieved once minimum diameter requirements are reached. All other requirements for these five classes remain the same. The two poletimber tree classes are used to classify lower-canopy trees in these young stands.

The Meadows tree classification system, with its collection of “good” tree classes and “poor” tree classes, is used to define the residual components for four different improvement cutting prescriptions based on stand quality management. The tree classes are used to identify which trees to leave and which trees to cut. Two of the improvement cutting prescriptions are appropriate only in older, late-rotation stands and will not

be described here. The other two prescriptions, illustrated in figure 20, are suitable for use in young plantations and are designated as Acceptable Growing Stock With Superior Poletimber (**AccSupP**) and Desirable Growing Stock With Superior Poletimber (**DesSupP**).

In the following discussion of each of these two improvement cutting prescriptions, we assume that the forest manager has conducted a recent inventory of the plantation and has used the inventory data to calculate stocking percent and to prepare the tree class distribution of the plantation (i.e., the percentage of total basal area in each of the seven tree classes). We further assume that the forest manager has concluded from these data that the plantation is suitable for continued management for high-quality sawtimber production. To reach this decision, the forest manager must evaluate both current stand density and current stand quality to ensure that they meet minimum acceptable requirements. Current stocking must not be significantly below the B-line, which represents minimum full stocking. A plantation with stocking well below the B-line is seriously understocked—there simply are not enough trees to justify continued management. For current stand quality to be judged as sufficient, the growing stock component (preferred, desirable, and acceptable growing stock classes and superior poletimber stock class, combined) of the plantation should account for at least 50 percent of total basal area. A plantation that does not meet this requirement does not contain enough trees of at least acceptable quality to justify continued management. Any plantation that fails to meet either of these two minimum requirements is not suitable for continued

Tree class	AccSupP	DesSupP
Preferred growing stock	✓	✓
Desirable growing stock	✓	✓
Acceptable growing stock	✓	
Cutting stock		
Cull stock		
Superior poletimber stock	✓	✓
Inferior poletimber stock		

Figure 20—Improvement cutting prescriptions based on stand quality management that are suitable for use in young, oak-dominated plantations. **AccSupP** = Acceptable Growing Stock With Superior Poletimber prescription; **DesSupP** = Desirable Growing Stock With Superior Poletimber prescription. Check marks indicate the tree classes to be retained in the plantation after each prescription is applied.

management for high-quality sawtimber production and should be regenerated as soon as possible.

Our second assumption relative to the following discussion is that the forest manager has decided, based on the inventory data, that an improvement cutting is necessary at the present time to improve the capability of the plantation to produce high-quality oak sawtimber in the future. To reach this decision, the forest manager must evaluate current stand density only. If current stocking is near, at, or above 100 percent (maximum full stocking), the plantation is overstocked, and an improvement cutting is needed. If current stocking is significantly less than 100 percent, the appropriate management decision is to do nothing and allow the plantation to grow and develop until stocking reaches the point at which an improvement cutting is required.

In some situations, the volume to be removed during the improvement cutting is too low to attract a logger to perform the harvest operation. As mentioned previously, there should be at least 10–15 tons of pulpwood per acre, or more, removed from the plantation to constitute a viable commercial harvest. If the volume to be removed is too low for a commercial harvest, the landowner has three options: (1) increase the volume to be removed until it is sufficient for a commercial harvest; (2) postpone the improvement cutting until the volume to be removed is great enough to attract a logger; or (3) perform the improvement cutting as a pre-commercial harvest operation. We do not recommend the first option because the only way to increase the volume to be removed is to include trees in the timber sale that should be retained in the plantation because they are expected to develop into high-quality sawtimber trees as they mature. Removal of some of these trees during the current improvement cutting will reduce the future value of the plantation. If current stocking of the plantation is near but not > 100 percent, postponement of the improvement cutting for a few years is an acceptable option. If current stocking is already > 100 percent, we recommend that the landowner conduct the improvement cutting as a pre-commercial operation as soon as possible. It will be a cost to the landowner, but the operation should be viewed as a necessary investment in the future value of the plantation.

Once the decision has been made that an improvement cutting is needed now, the forest manager must select the most appropriate prescription to apply. This decision will affect growth and value of the plantation for many years. Under the concept of stand-quality management, the choice between the two improvement cutting prescriptions suitable for use in young plantations (see fig. 20) is based solely on current stand quality, as reflected by the current tree class distribution of the plantation. The key indicator of the level of stand quality is the proportion of total basal area attributed to trees in the preferred and desirable growing stock classes, combined. Plantations in which these two tree classes combine for < 50 percent of total basal area are deemed to have medium stand quality.

The **AccSupP** prescription is the most appropriate one to use in medium-quality plantations. In contrast, plantations in which trees in the preferred and desirable growing stock classes account for at least 50 percent of total basal area are considered to have high stand quality. The **DesSupP** prescription is the most appropriate one to use in high-quality plantations.

Acceptable Growing Stock With Superior Poletimber (AccSupP)—By definition, medium-quality plantations generally are somewhat deficient in preferred and desirable growing stock trees. This situation is typical of plantations in which no previous cuttings have been made. In particular, it is the most common prescription used in younger plantations as the first cutting operation. When preferred and desirable growing stock trees together comprise < 50 percent of total basal area, the forest manager should select the **AccSupP** improvement cutting prescription. Marking rules for this prescription are:

1. Leave all trees in the preferred, desirable, and acceptable growing stock classes and in the superior poletimber stock class.
2. Cut all trees in the cutting, cull, and inferior poletimber stock classes.

Because there is a deficiency of preferred and desirable growing stock trees, the **AccSupP** prescription requires retention of all acceptable growing stock trees in order to maintain adequate residual stocking after improvement cutting. All superior poletimber stock trees are retained in young plantations because there is ample time remaining in the life of the plantation for these trees to grow and develop into high-quality sawtimber trees. The **AccSupP** improvement cutting prescription likely will produce a high-quality residual stand well within the fairly broad limits of acceptable residual stand density (fig. 21A).

Desirable Growing Stock With Superior Poletimber (DesSupP)—In contrast, high-quality plantations contain a relatively high proportion of preferred and desirable growing stock trees. This situation is most common in plantations in which previous improvement cuttings have been made. In particular, it is the most common prescription used in older plantations in which a previous improvement cutting was performed, usually at least 15–20 years ago. When preferred and desirable growing stock trees, combined, account for at least 50 percent of total basal area, the forest manager should select the **DesSupP** improvement cutting prescription. Marking rules for this prescription are:

1. Leave all trees in the preferred and desirable growing stock classes and in the superior poletimber stock class.
2. Cut all trees in the acceptable growing stock class and in the cutting, cull, and inferior poletimber stock classes.

(A) AccSupP improvement cutting



(B) DesSupP improvement cutting



Figure 21—Residual 35-year-old water oak plantation after (A) Acceptable Growing Stock With Superior Poletimber improvement cutting, and (B) Desirable Growing Stock With Superior Poletimber improvement cutting. (USDA Forest Service photo by James S. Meadows).

Silvicultural Options for Improved Acorn Production

In high-quality plantations, there is a sufficient number of valuable preferred and desirable growing stock trees to ensure adequate residual stocking after improvement cutting. Thus, there is no need to retain acceptable growing stock trees and, in fact, the **DesSupP** prescription requires removal of all trees in that tree class. As in the **AccSupP** prescription, all superior poletimber stock trees are retained in young plantations because there is enough time left in the rotation for these trees to develop into high-quality sawtimber trees. The **DesSupP** improvement cutting prescription likely will produce a very high-quality residual stand within the limits of acceptable residual stand density (fig. 21B).

Additional marking guidelines—No matter which of the two improvement cutting prescriptions based on stand quality management is selected to apply in a young oak plantation, there are three additional marking guidelines that the forest manager should follow. First, the plantation should be marked to remove trees only from those tree classes specified for removal in the selected prescription and to remove all trees in those tree classes. Second, once the appropriate improvement cutting prescription has been selected, there is no consideration for residual stand density or for spacing among residual trees. Third, the timber marker should evaluate the characteristics of each individual tree in order to assign the proper tree class to that tree, independently of all other trees in the plantation. The decision to cut or leave any given tree must be based solely on the tree class of that tree. It must not be influenced by the tree classes of neighboring trees. Adherence to these additional guidelines will ensure that the plantation is marked for the selected improvement cutting prescription in an unbiased and reliable manner that will uphold the basic premise of stand quality management.

Potential problems—Because marking rules in stand quality management do not allow residual stand density or spacing of residual trees to be considered, actual residual density likely will not be uniform across the plantation. The improvement cutting operation may leave small clusters of suitable residual trees, where few or no trees were removed, scattered across the plantation. Similarly, improvement cutting may create small, irregularly shaped gaps, where no suitable trees were present, dispersed throughout the plantation. When production of high-quality oak sawtimber is the sole or primary landowner objective, this irregular distribution of residual trees after improvement cutting may be viewed as a potential problem because it indicates a greater-than-desired level of competition in some parts of the plantation and an underutilization of the site in other parts of the plantation. However, to achieve a uniform distribution of residual trees after improvement cutting, the timber marker would have to cut some suitable trees to eliminate the clusters and would have to leave some unsuitable trees to avoid the creation of gaps. Both marking practices would compromise overall stand quality and would reduce the value growth potential of the plantation over the long term.

In this section, we present silvicultural options suitable for improved acorn production as the sole or primary landowner objective. As in the previous section, we assume that, based on a recent inventory of the plantation, the forest manager has decided that some type of intermediate silvicultural prescription is needed to improve stand structure for acorn production.

Key Concepts for Improved Acorn Production at the Stand Level

Information presented earlier on biological and environmental factors that control acorn production supports several principles that are key to improving acorn production in bottomland oak plantations:

1. Reproductive maturity in bottomland oaks generally is observed after the stand canopy differentiates into crown classes. This delay creates implications for the timing of intermediate cutting operations. Premature removal of trees in a cutting without knowledge of their potential for acorn production risks removal of genetically superior acorn producers.
2. Acorn production is maximized by trees that have a high percentage of their crown in full sunlight. Intermediate cutting operations should promote crown growth of trees classified as superior or fair for acorn production.
3. Bottomland oak species groups (white oaks and red oaks) have different initiation and completion rates for the various flowering and acorn maturation processes. These differences ultimately create variability in acorn production that limits annual consistency of crop size at the stand level. But, this variability also reduces the probability of an acorn crop failure in any given year. Forest managers should try to maintain an appropriate balance of white oaks and red oaks, where possible.
4. Within species groups, bottomland oaks are highly variable in annual acorn production and masting periodicity. Management for stand species compositions that reflect balanced proportions of site-appropriate bottomland oaks can minimize the occurrence of acorn crop failure.
5. Trees that exhibit genetically superior acorn production typically comprise less than one-third of the individual oaks in any given stand. Maximization of acorn production hinges on identifying these individuals and favoring them in intermediate cutting operations. Superior trees can be identified only after 3 or more years of observation of acorn production.
6. Environmental factors tied to weather events or climate can have strong impacts on annual acorn production. Although these factors cannot be controlled, management

that encourages stand structures of superior and fair trees of multiple oak species builds physiological resistance and resilience to environmental stress that will sustain reproductive processes, such as acorn production.

7. Mistakes in species-site assignments, which are common in bottomland oak plantations, should be corrected through an improvement cutting during the first stand entry. Bottomland oaks planted offsite, such as cherrybark oak on a Nuttall oak site, are inferior trees because they will lack sufficient vigor to develop into good acorn producers.
8. Intermediate cuttings will not mitigate active factors of site degradation. For example, bottomland oak plantations managed as greentree reservoirs should have appropriate infrastructure to control hydrologic regimes and should be monitored for signs of flooding stress on superior and fair trees.
9. Upon crown closure, acorn production of individual trees decreases as competition among neighboring crowns increases. Acorn production can be maximized if intermediate cutting operations create growing space for superior and fair trees while maintaining sufficient stand stocking. Cutting the stand too lightly will not initiate significant crown growth by superior and fair trees, while cutting the stand too heavily will reduce oak stocking such that stand-level acorn production is reduced. Consult figures 12 and 13 and appendix A for stand stocking levels that support maximum crown growth and acorn production.

Crop-Tree Release

Crop-tree release can be used to manage bottomland oak plantations for a range of management objectives but is ideally applicable as a silvicultural approach to improve stand-level acorn production. The approach simply involves (1) identification of trees judged most likely to contribute to the accomplishment of management objectives—crop trees; and (2) removal of crop-tree competitors—trees with a crown in the main canopy and in direct contact with a crop tree. It favors crop trees by releasing them from canopy competition (Miller and others 2007). Crop-tree release can be applied in plantations of any age but, if the primary objective is acorn production, it would be applied most effectively in stands that have begun crown differentiation. Expression of crown differentiation and acorn production are required for accurate identification of crop trees.

Crop trees are released by cutting or killing adjacent trees competing for canopy space. Competitors are defined as trees with dominant or codominant crowns touching the crop-tree

crown. Intensity of the release depends on the proportion of the crop-tree crown to be freed of competition (Miller and others 2007). In this respect, crop-tree release differs from other conventional intermediate cutting practices in that there is generally minimal concern with residual stand density. In other words, cutting is not applied to achieve a rigid stand density target. Still, the manager should define a target density for crop-tree retention because stand-level acorn production will depend on the amount of acorn-producing crown area per acre, which is dependent on stand stocking. The evaluation tool presented earlier provides a practical means of assessing the status of acorn production capacity of bottomland oak stands. Further development of equations published by Goelz (1996) allows for the calculation of stand stocking levels that are based on crown size and are relevant to management for acorn production through crop-tree release.

Figure 22 illustrates the relationships among quadratic mean diameter, stem density, and 100 percent crown cover for crop trees in stands of bottomland oaks. Evaluation of stand inventory data relative to these relationships would enable the forest manager to identify current stocking of crop trees in a stand and to set marking intensity for crop-tree release. In practice, all trees classified as superior should be retained as crop trees and trees classified as fair would be retained in sufficient number to achieve good distribution and a targeted crop-tree density. To assist in the development of prescriptions for crop-tree release, two additional lines of stocking were created (fig. 22). The additional lines represent crop-tree density given a 5-foot band of growing space around crop-tree crowns and given a 10-foot band of growing space around crop-tree crowns. We recommend that prescriptions for crop-tree release target a density that ranges within the values between the 5- and 10-foot bands. But because intensity of the release will be relative to crop-tree crown size, stand age and stage of development should be considered when targeting a residual crop-tree density. Younger stands that still are developing through canopy differentiation should be marked for residual crop-tree densities near the 5-foot band, whereas older plantations should be marked nearer to the 10-foot band to maximize acorn production. For example, a stand with a quadratic mean diameter of 16 inches for crop trees would be released to a target density of 11–22 trees per acre, but preferably closer to 11 trees per acre to maximize acorn production (fig. 22, app. D).

Note that the target prescription is to identify and retain a recommended density of trees rated as superior or fair for acorn production, not to create a 5- or 10-foot band of open space around each crop tree. The 5- and 10-foot bands represent average levels of release around residual crop trees—they do not represent absolute levels of release necessary around each residual crop tree. Accordingly, the

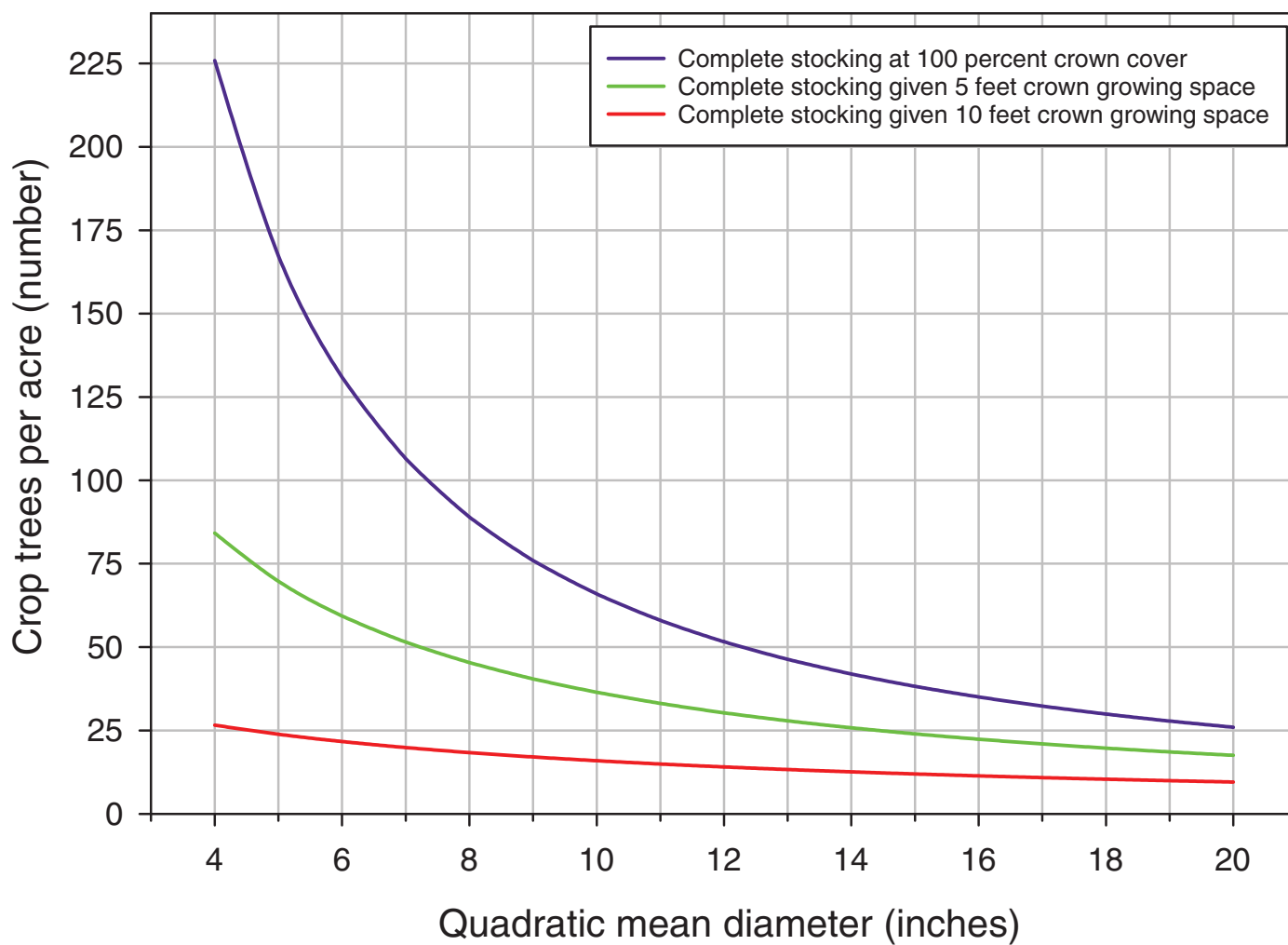


Figure 22—Stocking curves applicable to crop-tree release for improved acorn production in bottomland oak plantations.

prescription will produce stands of irregularly distributed crop trees that may or may not be released on all sides and that likely will have different amounts of open space around the crown. Residual crop trees may show a clumped distribution across the stand, with some areas within the stand void of suitable trees to retain.

While it is not necessary for effective crop-tree release, the manager could apply a variant of this approach that would result in an orchard-like stand. In this variant, identification and marking of crop trees is accompanied by the removal of all other planted and volunteer trees in the plantation, not just those trees immediately adjacent to the crop tree. This variant maximizes acorn production capacity of the stand while opening the stand for other objectives, such as browse production. Stump sprouting by cut trees will occur and may have an effect on stand-level acorn production in the future.

Additionally, crop trees can be pruned to improve crown vigor and acorn production. Pruning transfers crown growth to branches receiving the greatest amount of sunlight, but it can reduce tree growth if too many branches are removed. If pruning is implemented to promote crown vigor and development, the manager should (1) prune branches before their basal diameter exceeds 1.5 inches, (2) retain about two-thirds to one-half of tree height in crown—younger trees should retain a higher proportion of crown relative to tree height than older trees, (3) cut branches past the apparent branch collar (the enlarged zone around the connection to the bole), and (4) conduct pruning operations during the dormant season. When pruning is conducted in conjunction with crop-tree release, it will encourage rapid branch growth into canopy space made available by the release.

Selective Thinning

Accurate identification and mapping of trees that are superior acorn producers are the greatest challenges to managing bottomland oak plantations for improved acorn production. These tasks cannot be completed until stands begin to produce acorn crops. Selective thinning can provide an acceptable option for improving stand structure of bottomland oak plantations that have not developed to reproductive maturity. In this situation, proper application of selective thinning for improved acorn production requires (1) tree classification to identify individuals least likely to contribute to future acorn production, and (2) removal of trees with the lowest potential for acorn production to achieve a targeted stand density across the plantation. Accordingly, young dense stands in which the oak component is under severe competition are most suited for selective thinning. In such stands, competition among residual trees can be reduced with minimal risk of jeopardizing future acorn production if the manager targets a relatively high stand density that favors the oak component.

Tree classification for acorn production is problematic in young stands because acorn production potential cannot be assessed. It is unlikely that this issue can be resolved by substituting acorn production capacity for acorn production potential, as presented in figure 11, because diameter distributions of young stands typically range below a sufficient size for predicting acorn production capacity (< 6 inches d.b.h.). Given this issue of unknown acorn production potential, managers should classify trees for retention or removal based on factors that obviously would impact future acorn production. As previously described in the tree classification system, oak species planted offsite, oaks with declining health or vigor, and non-oak species will not contribute to future stand-level acorn production. These trees should be the first ones marked for removal. If the targeted stand density cannot be achieved by removing obviously inferior and non-oak trees, the manager will have to revise the targeted stand density or sacrifice an unknown amount of acorn production potential. In the case of the latter, the weakest competitors where oak density is highest should be marked for removal (i.e., oaks that are not likely to compete for an upper canopy position).

For purposes of crown development and acorn production, complete stocking for bottomland oak plantations is referenced to figure 9 which illustrates the relationships among quadratic mean diameter, stem density, and 100 percent crown cover. Stand inventory data can be evaluated relative to this illustration (or to figure 10) to gauge current stand stocking and to index marking intensity for selective thinning. If it is determined that the plantation would benefit from thinning, a sufficient number of trees classified as inferior or non-oaks would be cut to achieve the targeted density across the stand. Figure 23 presents the relationship introduced in figure 9 along with two additional lines of stocking that were developed to assist the manager with identifying reasonable stand density targets to improve stand structure for acorn production through selective thinning. These lines represent tree densities needed to retain 75 percent and 50 percent crown cover relative to quadratic mean diameter of the stand. We recommend that thinning prescriptions target a density that ranges among the values between the 75 percent and 50 percent crown cover lines. Young stands that have not reached reproductive maturity should be marked for residual stand densities near the 75 percent crown cover line. Older plantations in which superior acorn producers have been identified and mapped could be marked for residual stand densities near the 50 percent crown cover line. A stand with a quadratic mean diameter near 5 inches, for example, would be thinned to between 126 and 84 trees per acre, but preferably closer to 126 trees per acre to minimize loss of unknown acorn production potential (fig. 23, app. D).

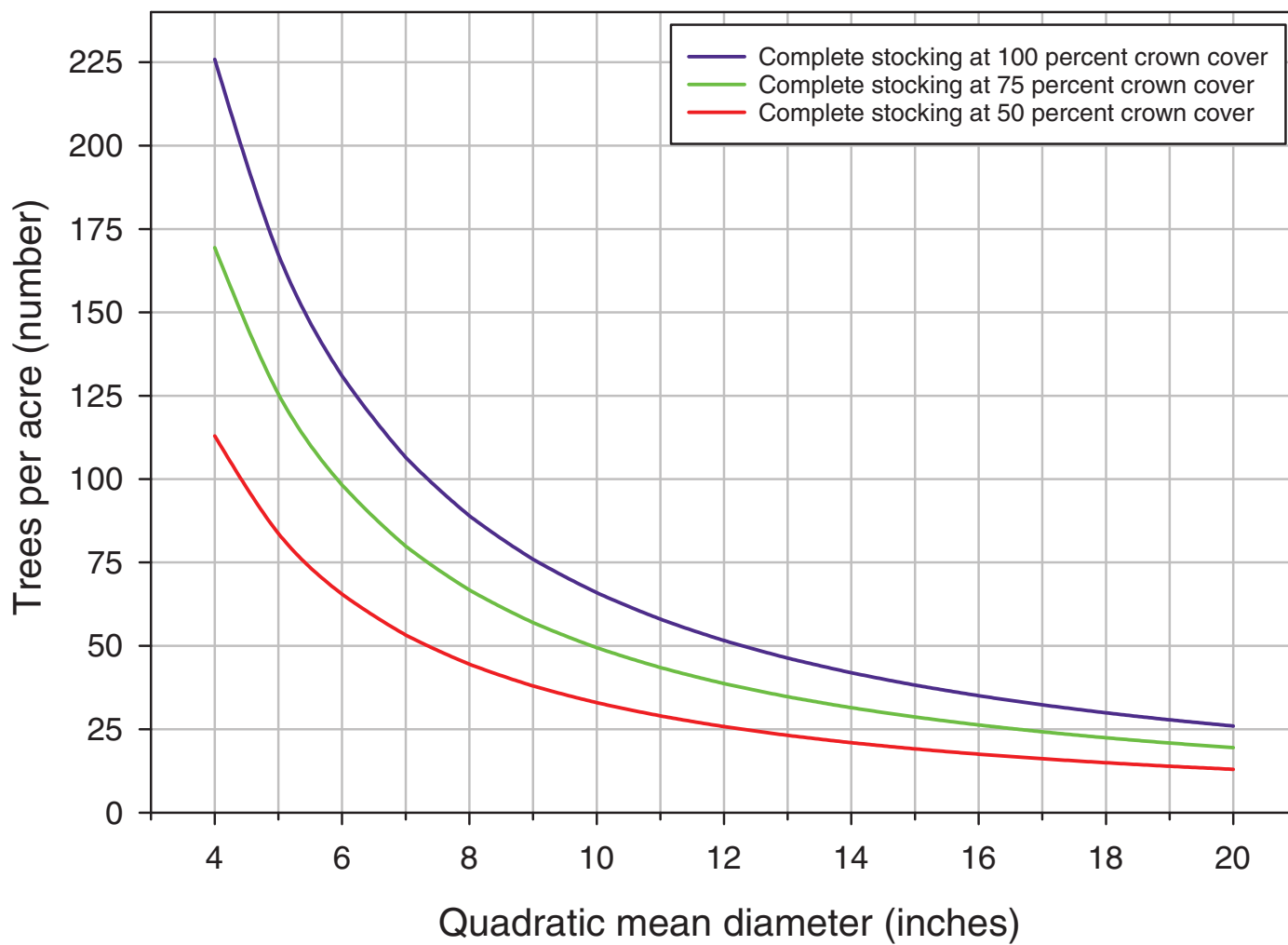


Figure 23—Stocking curves applicable to selective thinning for improved acorn production in bottomland oak plantations.

Silvicultural Options for Integrated Timber/Wildlife Management

In this section, we present silvicultural options suitable to integrated management for both high-quality oak sawtimber and improved wildlife habitat through improved acorn production as multiple objectives of roughly equal importance and priority to the landowner. As in the previous two sections, we assume that, based on a recent inventory of the plantation, the forest manager has decided that some type of intermediate silvicultural prescription is currently necessary to improve the capability of the plantation to achieve these multiple landowner objectives.

There is no need to create entirely new silvicultural options to implement integrated management of young, bottomland oak-dominated plantations. Rather, we can select appropriate prescriptions from the previous two sections and combine them to form a “hybrid” prescription suitable for integrated management of these plantations for multiple objectives. Our discussion in this section will focus on the situation in which the timber and wildlife objectives have roughly equal importance and priority to the landowner. However, there are other situations in which both objectives are desired by the landowner, but one takes priority over the other. For example, the landowner primarily wants to grow high-quality oak sawtimber but also wants to improve wildlife habitat across the plantation. Conversely, the landowner primarily wants to increase acorn production and thus improve hunting success but also wants to generate revenue from high-quality oak sawtimber across the plantation. Consequently, it is imperative that, before any silvicultural prescriptions are developed or implemented, the landowner and the forest manager finalize the ownership objectives and the proportions in which those objectives are prioritized. Prescriptions must be based on the combination of those objectives specific to that landowner.

In the previous section on silvicultural options for high-quality sawtimber production, we presented and described two management strategies: (1) stand density management, and (2) stand quality management. We discussed the disadvantages of stand density management as a suitable strategy to achieve the sole objective of production of high-quality sawtimber in young oak-dominated plantations. We concluded that residual stand quality and value growth potential often are compromised to the extent that prescriptions based on stand density management likely will produce residual plantations of less-than-optimum economic value. Consequently, we believe that stand density management should not be included as part of our hybrid prescription for integrated timber/wildlife management.

Likewise, in the previous section on improved acorn production, we presented and described two silvicultural options: (1) crop-tree release, and (2) selective thinning. We discussed the disadvantages of selective thinning as an appropriate option

to achieve the sole objective of improved acorn production in young oak-dominated plantations. Because selective thinning is more suitable for improving stand structure in young, dense plantations that have not developed to reproductive maturity, we concluded that selective thinning should not be included as part of our hybrid prescription for integrated timber/wildlife management.

Recommended Silvicultural Option for Integrated Management

We recommend that a hybrid combination of the stand quality management strategy for sawtimber production and the crop-tree release option for improved acorn production be used to achieve these two co-equal landowner objectives. The focus of the stand quality management strategy is on timber quality and value. The focus of the crop-tree release option is on crown growth and expansion of those trees that are either proven or suspected good acorn producers. Consequently, we believe that a combination of these two silvicultural options provides the landowner with the best opportunity to achieve integrated timber/wildlife management of young oak-dominated plantations. Because there likely will be tradeoffs in sawtimber production and/or acorn production as a result of the desire to achieve multiple landowner objectives within an individual oak plantation, the goal of the hybrid prescription necessarily is to optimize, rather than maximize, these two objectives.

Marking rules for both silvicultural options utilize tree classification systems to identify “good” trees—those trees that are capable of fulfilling the management objective—and “poor” trees—those trees that are not capable of fulfilling the management objective. Further, the marking rules specify that trees classified within “good” tree classes should be retained and that trees classified within “poor” tree classes should be removed. The hybrid prescription designed to achieve integrated timber/wildlife management of young oak-dominated plantations adheres to this marking strategy.

If the goal of the landowner is to produce high-quality oak sawtimber and to improve acorn production for wildlife habitat as multiple management objectives with equal priority, then it is clear that the hybrid prescription should retain the best timber trees regardless of their suitability for acorn production and the best acorn-producing trees regardless of their suitability for timber production. According to the tree classification system designed for timber production (Meadows and Skojac 2008), our best timber trees are assigned either the Preferred or the Desirable tree class. Likewise, according to the tree classification system designed for acorn production (described earlier in this handbook), our best acorn-producing trees are assigned the Superior tree class or are those trees in the intermediate crown class that are assigned the Fair tree class because they have demonstrated superior acorn production.

An Applied Example

Retention of the trees just described allows the landowner to keep all of the trees that have the greatest capability to fulfill each of the individual landowner objectives and to provide the greatest benefit to integrated timber/wildlife management. Consequently, our marking rules for the hybrid prescription are as follows:

1. Retain all trees in the Preferred and Desirable timber tree classes regardless of their acorn production tree class.
2. Retain all trees in the Superior acorn production tree class regardless of their timber tree class.
3. Retain all trees in the intermediate crown class in the Fair acorn production tree class regardless of their timber tree class.

There will be some situations in which there may be few Preferred or Desirable timber trees and/or few Superior acorn-producing trees. In these stands, adherence to the marking rules listed earlier will produce an under-stocked residual stand that will likely fail to fulfill landowner objectives at the stand level. An additional marking rule will be required: Retain all or some proportion of the trees classified as both Acceptable timber trees and Fair acorn production trees not in the intermediate crown class (intermediate Fair trees are retained under marking rule 3 earlier). These trees are not the best timber trees and are not the best acorn-producing trees, but they are capable of satisfactorily fulfilling both management objectives. Their retention will improve residual stand stocking and will provide a greater benefit to integrated timber/wildlife management.

As mentioned previously, there likely will be tradeoffs in sawtimber production and/or acorn production as a result of integrated management to achieve multiple landowner objectives. There are two types of tradeoffs: (1) trees that would have been retained under single-objective management but are removed under multiple-objective management; and (2) trees that would have been removed under single-objective management but are retained under multiple-objective management. Both sawtimber production and acorn production objectives likely will experience both types of tradeoffs. For example, trees in the Acceptable timber tree class and in either the Fair or Inferior acorn production tree class would be retained in the residual stand under management solely for sawtimber production but are removed from the stand under multiple-objective management. Similarly, trees in the Inferior acorn production tree class and in either the Preferred or Desirable timber tree class would be removed from the stand under management solely for acorn production but are retained in the residual stand under multiple-objective management. A stand inventory that assigns both timber tree class and acorn production tree class to individual trees allows the forest manager and landowner to quantify these tradeoffs.

To illustrate both differences and similarities among the silvicultural options described in the three previous sections, we present a realistic example to compare the structure and appearance of the residual stands that would result from the application of an appropriate silvicultural prescription for each of the three management objectives addressed in this handbook. The example is based on data collected from an existing plantation in the LMAV. For each of the three management objectives, we simulated the application of a silvicultural prescription designed to achieve that particular objective.

We collected data from an undisturbed, 25-year-old Nuttall oak plantation in Sharkey County, Mississippi. Soils at the site are a mixture of Alligator clay and Forestdale silty clay loam. Both soils originate from clayey alluvium and are poorly drained. Site index for Nuttall oak on both soils averages about 88–89 feet at 50 years (Broadfoot 1976). Nuttall oak is a desirable species and grows well on both soils (Broadfoot 1976). Trees were planted on a 12- by 12-foot spacing. We collected data on surviving trees from a 0.5-acre plot that consisted of 10 rows with 15 planting spots per row.

At age 25 years, the undisturbed plantation contained 258 trees per acre with a basal area of 93 square feet per acre and a quadratic mean diameter of 8.1 inches. Survival was 86 percent and stocking 88 percent, an indication that the plantation was approaching maximum full stocking. Estimated volume was 1,322 cubic feet per acre, or about 44 tons of pulpwood per acre. There were several natural gaps scattered throughout the plantation, but, in general, the plantation was fully stocked (fig. 24A).

Objective 1: High-Quality Oak Sawtimber

We selected the stand quality management strategy as the most appropriate silvicultural option to achieve the sole management objective of production of high-quality oak sawtimber in this particular plantation. It has advantages over stand density management, as previously discussed, and is more appropriate than any of the variations of row thinning because individual trees in this plantation have differentiated into crown classes and, therefore, are more suited to management by selective cutting.

Based on the inventory of our 25-year-old Nuttall oak plantation, the current stocking level of 88 percent is approaching maximum full stocking of 100 percent, such that an intermediate cutting is warranted. The tree class distribution of the plantation, calculated from data collected during our inventory, reveals that our highest quality trees (preferred and desirable growing stock) account for only 25 percent of total stand basal area. Plantations in which these two tree classes combine for < 50 percent of total basal area are deemed to have medium stand quality. The Acceptable Growing Stock

With Superior Poletimber (**AccSupP**) prescription is the most appropriate stand quality management prescription to use in medium-quality plantations. The marking rules for the **AccSupP** prescription are (1) to leave all trees in the preferred, desirable, and acceptable growing stock classes and in the superior poletimber stock class; and (2) to cut all other trees.

After application of the **AccSupP** prescription, the residual plantation in this example contains 130 trees per acre with a basal area of 59 square feet per acre and a quadratic mean diameter of 9.0 inches. Residual volume is 968 cubic feet per acre. The cutting operation removed about 50 percent of the trees, 36 percent of the basal area, and 27 percent of the volume. It also increased quadratic mean diameter to 9.0 inches and thus moved the plantation further down the path of stand development. Some of the small gaps that existed in the undisturbed plantation are now larger and new gaps have been created (fig. 24B).

According to the **AccSupP** prescription, there are approximately 12 tons of pulpwood per acre marked to be removed from the plantation. This volume may or may not be enough to attract a logger to conduct the improvement cutting operation. If it is enough volume for a commercial operation, the landowner should proceed with the improvement cutting. If the volume is too low to attract a logger, the landowner may elect to postpone the improvement cutting for a few years because current stocking of the plantation is 88 percent, still below maximum full stocking of 100 percent. However, the forest manager and landowner should plan to conduct a new inventory of the plantation at that time.

The **AccSupP** prescription has created a residual stand that has a strong potential to achieve the management objective of high-quality oak sawtimber production in the future. All of the trees left in the plantation are “good” trees that are likely to achieve the management objective. No “good” trees were cut and no “poor” trees were left in the stand. Application of the **AccSupP** prescription has given us the best opportunity to achieve our objective.

Objective 2: Improved Acorn Production

Our inventory of the Nuttall oak plantation indicates survival is acceptable and crown differentiation along with acorn production are sufficiently advanced to allow classification of trees for acorn production. But, the plantation is poorly structured for optimizing stand-level acorn production because competition among canopy trees has limited crown growth—crown area relative to d.b.h. of individual trees is considerably below the maximum. Yet, an earlier stand entry to encourage crown growth would not have been advised because entries made prior to initiation and assessment

of acorn production carry a high risk of removing trees that would express genetically superior acorn production in the future. We selected crop-tree release as the most appropriate silvicultural practice for transitioning structure of the plantation to one optimally suited to meet the primary objective of improved acorn production. We suggest crop-tree release is the most appropriate practice in this plantation because trees with inherently superior acorn production have been identified and mapped, and the relatively heavy release treatment will encourage maximum crown expansion by the residual crop trees. Selective thinning is less appropriate in this plantation because trees are expressing acorn production and maintaining a targeted residual stand density will not benefit acorn production to the same extent as providing ample growing space for crown development of crop trees.

All trees were classified according to variables of crown class and visual crown surveys as described earlier. We classified 34 trees per acre as Superior, 84 trees per acre as Fair, and the remaining 140 trees per acre as Inferior. Superior trees averaged 9.6 inches d.b.h., Fair trees averaged 8.7 inches d.b.h., and Inferior trees averaged 6.9 inches d.b.h. Superior and Fair trees comprise about 46 percent of the trees in the stand but contain about 53 percent of the basal area. Of the trees classified as Fair, 26 trees per acre show superior acorn production but hold an intermediate crown position. These trees, together with the 34 trees per acre classed as Superior, represent 23 percent of the trees in the stand. Application of stand inventory data indicates that current crop-tree stocking based on Goelz (1996) is substantially above 100 percent (fig. 9); an indication that crown development for acorn production is severely limited.

Our crop-tree release marking rules suggest that we should (1) retain all trees classed as Superior, and (2) retain a sufficient number of trees classed as Fair to achieve good distribution and a targeted crop-tree density. Crop-tree stocking of Superior trees in the current stand is about 49 percent while crop-tree stocking of Fair trees is over 100 percent. So, retention of all Superior and all Fair trees would not be a sufficient crop-tree release. Retention of all Superior trees and only those Fair trees with demonstrated superior acorn production, i.e., trees with dominant, codominant, or intermediate crowns and superior acorn production, would be a more appropriate crop-tree release. Application of these marking rules to the current example leaves a stand with 60 trees per acre, 22 square feet of basal area per acre, a quadratic mean diameter of 8.2 inches, residual crop-tree stocking of about 70 percent, and an acorn production capacity of about 17 percent (fig. 24C; figs. 10, 12, and 13). Approximately 31 tons of pulpwood per acre were removed from the plantation during the crop-tree release, a volume more than sufficient to make a commercial harvest operation.

(A)

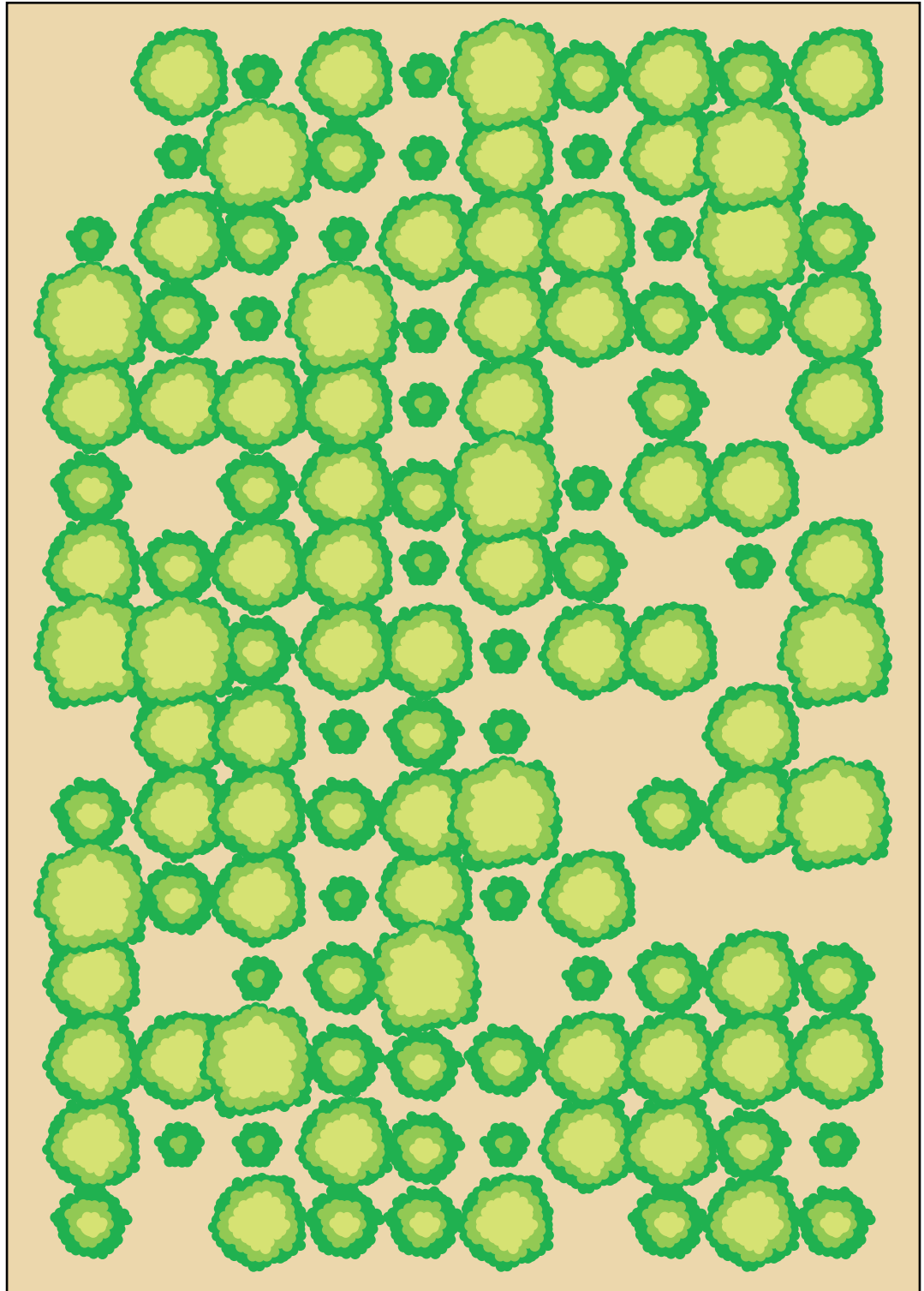


Figure 24(A)—Example of the spatial distribution of trees across a 0.5-acre plot in a 25-year-old Nuttall oak plantation before cutting. Size of trees in each figure indicate crown class.

(B)

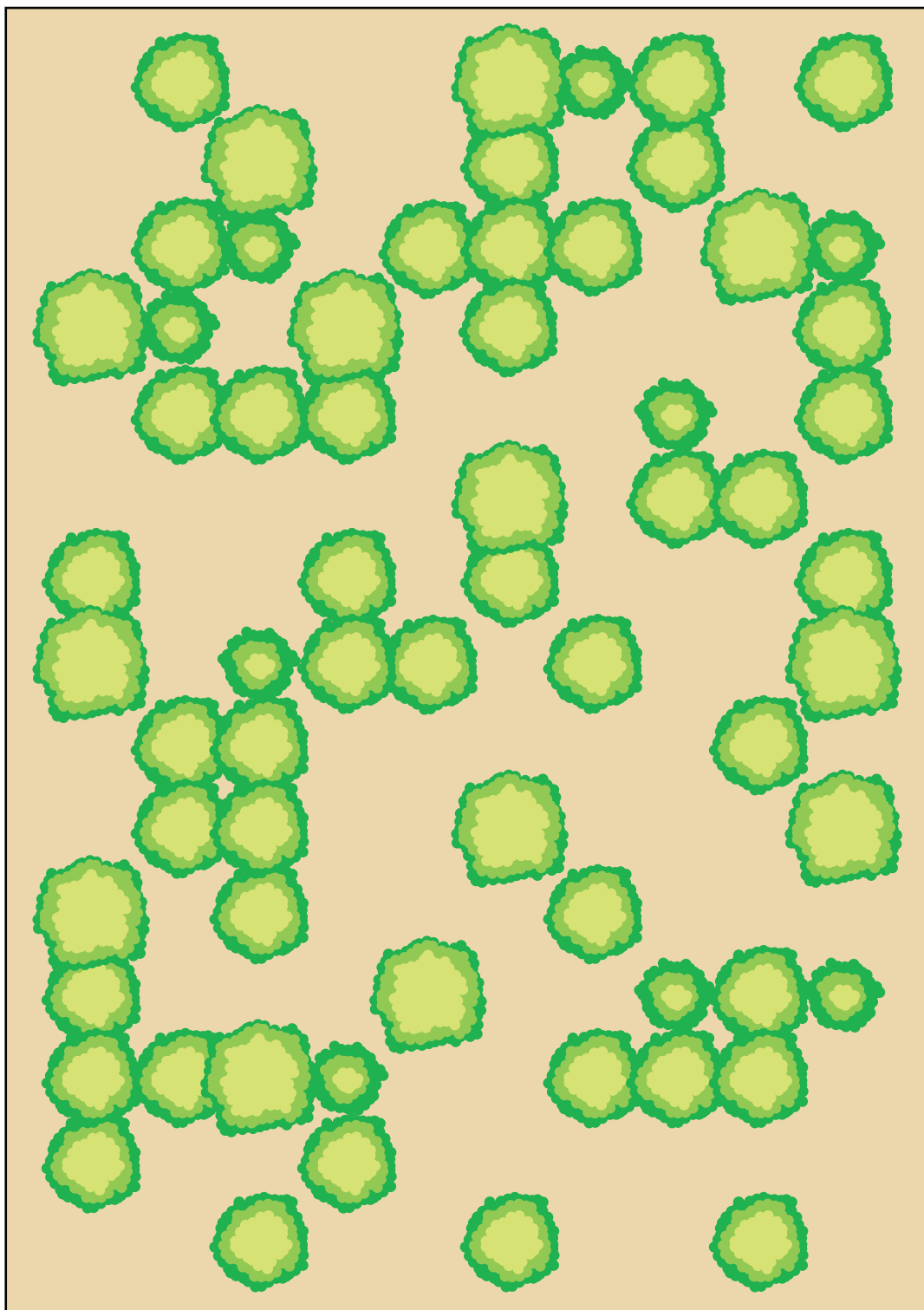


Figure 24(B)—Example of the spatial distribution of trees across a 0.5-acre plot in a 25-year-old Nuttall oak plantation after stand quality management improvement cutting for high-quality oak sawtimber production. Size of trees in each figure indicate crown class.

(C)

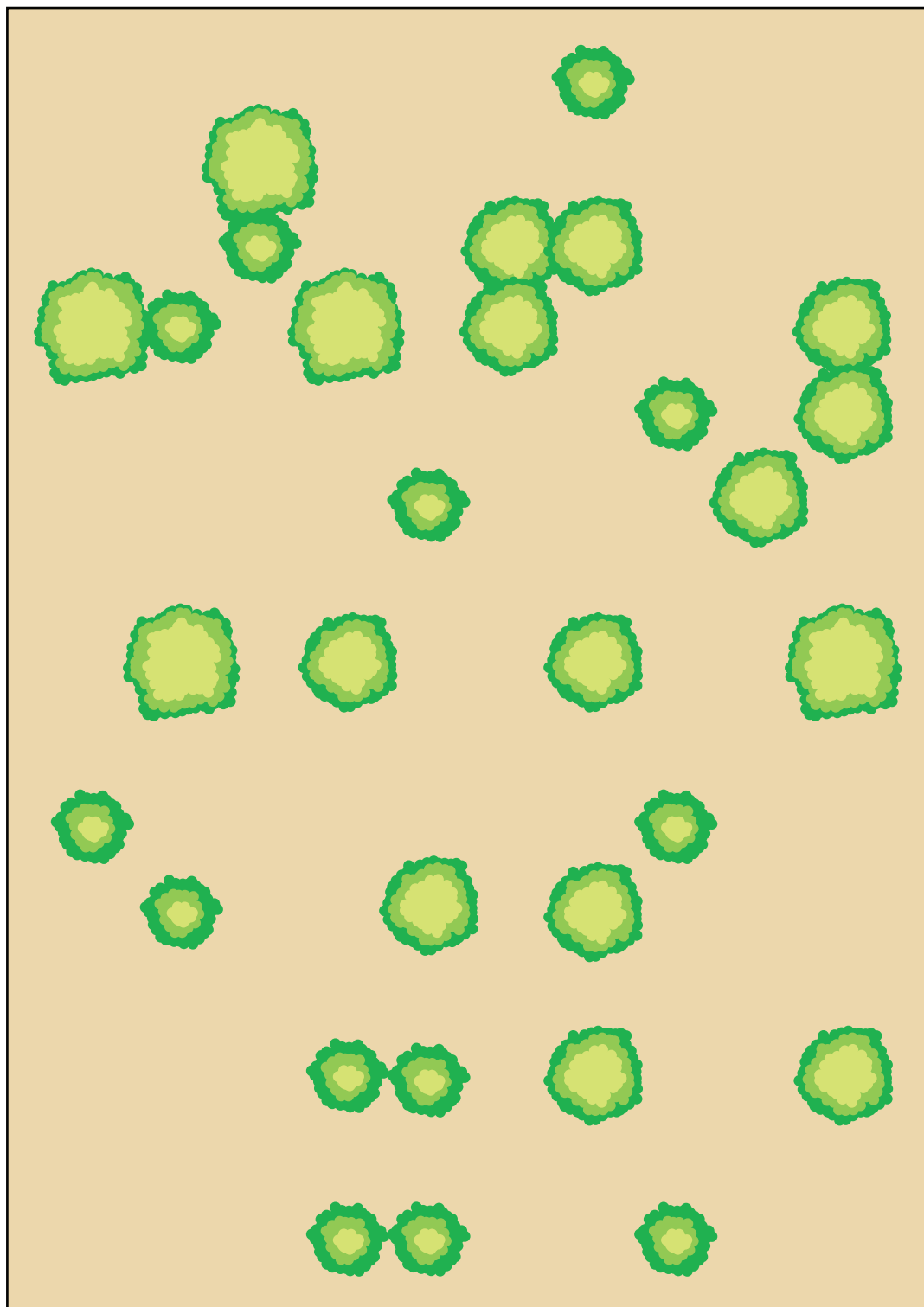


Figure 24(C)—Example of the spatial distribution of trees across a 0.5-acre plot in a 25-year-old Nuttall oak plantation after crop-tree release for improved acorn production. Size of trees in each figure indicate crown class.

(D)

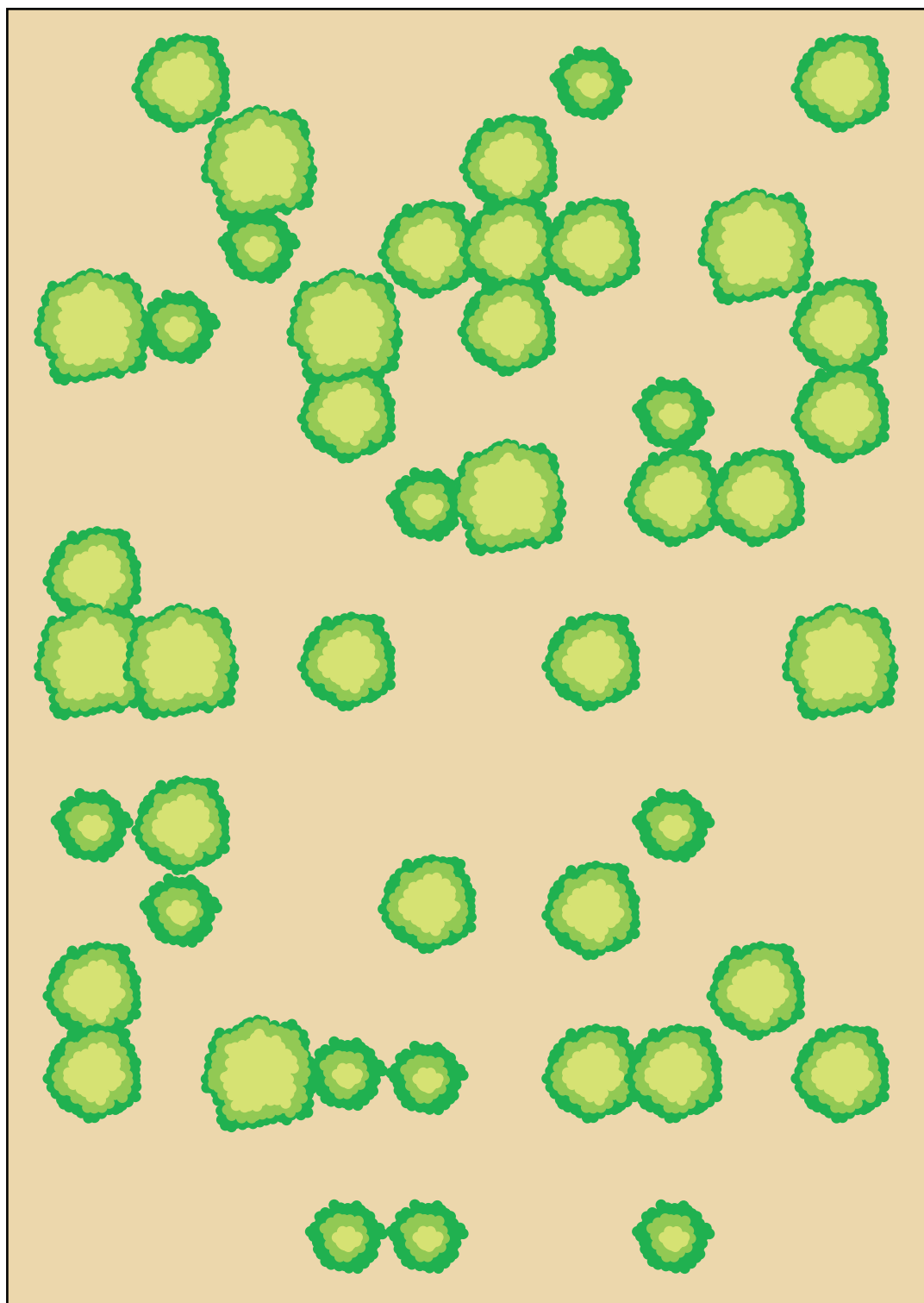


Figure 24(D)—Example of the spatial distribution of trees across a 0.5-acre plot in a 25-year-old Nuttall oak plantation after a hybrid combination of stand quality management and crop-tree release for integrated timber/wildlife management. Size of trees in each figure indicate crown class.

Structure of the residual stand shows good conformance with the suggested stocking curves for crop-tree release in figure 22 because crop-tree stocking falls below the blue and above the green lines in the figure. This release appears appropriate for a first entry in a plantation where transforming stand structure for improved acorn production is the primary objective. All growing space in the canopy has been allocated to trees with superior acorn production, which will encourage rapid growth and expansion of crop-tree crowns. The effect of the release on crown area growth will lead to a concurrent and sustained rise in acorn production capacity of the stand.

Objective 3: Integrated Management for High-Quality Sawtimber and Improved Acorn Production

We selected the hybrid combination of the stand quality management strategy and the crop-tree release option as the most appropriate silvicultural option to achieve the integrated timber/wildlife management objectives of high-quality oak sawtimber production and improved acorn production in

our example Nuttall oak plantation. The hybrid prescription optimizes these two co-equal objectives and gives the landowner the desired benefits without excessive tradeoffs.

Our inventory of this plantation included assessment of both timber tree class and acorn production tree class on every tree. The combined tree class distribution is presented in table 5. Preferred and Desirable timber trees combined constituted 48 trees per acre (19 percent of the total), whereas Superior acorn-producing trees and those intermediate trees with demonstrated superior acorn production (classified as Fair) accounted for 60 trees per acre (23 percent of the total). There were 16 trees per acre that were classified as both Preferred/Desirable and Superior. Consequently, there were 92 trees per acre (36 percent of the total) that, by the definitions associated with the two tree classification systems, are the best trees in the plantation for these two landowner objectives. There seems to be no need to retain the additional 26 trees per acre in both the Acceptable timber tree class and the Fair acorn production tree class.

Table 5—Tree class distribution in a 25-year-old Nuttall oak example plantation

Timber tree class	Acorn production tree class	Trees	Basal area
		<i>number per acre</i>	<i>square feet per acre</i>
To be retained:			
Preferred/Desirable	Superior	16	7
Preferred/Desirable	Fair	22	11
Preferred/Desirable	Inferior	10	5
Acceptable	Superior	12	7
Cutting Stock/Cull	Superior	6	3
Superior Poletimber	Fair	10	3
Inferior Poletimber	Fair	16	5
LEAVE		92	41
To be removed:			
Acceptable	Fair	26	12
Acceptable	Inferior	26	13
Cutting Stock/Cull	Fair	10	5
Cutting Stock/Cull	Inferior	14	6
Superior Poletimber	Inferior	8	2
Inferior Poletimber	Inferior	82	14
CUT		166	52

Conclusions

Because there was a satisfactory number of “best” trees in the plantation, we applied the version of the hybrid prescription that calls for retention of all Preferred and Desirable timber trees, all Superior acorn-producing trees, and all intermediate trees classified as Fair acorn producers and removal of all other trees, including Acceptable timber trees. This prescription removed 64 percent of the trees and 56 percent of the basal area from the plantation. It created a residual stand that contains 92 trees per acre and 41 square feet of basal area per acre, with a quadratic mean diameter of 9.0 inches. The residual stand contains 675 cubic feet of pulpwood volume per acre. There were approximately 22 tons of pulpwood per acre removed from the plantation, a volume likely to be enough to make a commercial harvest. The cutting operation created some moderately large gaps that should encourage production of browse across the plantation (fig. 24D).

As described in the previous section, there are tradeoffs associated with integrated management of the plantation for multiple objectives. If the plantation had been managed solely for the production of high-quality oak sawtimber, there are 60 trees and 26 square feet of basal area per acre that would have been retained as satisfactory timber trees but were removed because they are not superior acorn producers. These totals represent (1) Acceptable timber trees classified as either Fair or Inferior acorn-producing trees, and (2) Superior Poletimber trees classified as Inferior acorn-producing trees (table 5). There are also 22 trees and 8 square feet of basal area per acre that would have been removed because they are poor timber trees but were retained because they are superior acorn producers. These totals represent (1) Cutting Stock/Cull timber trees classified as Superior acorn-producing trees, and (2) Inferior Poletimber trees classified as Fair acorn-producing trees (table 5). Conversely, if the plantation had been managed solely for improved acorn production, the only tradeoff would be the 32 trees and 16 square feet of basal area per acre that would have been removed because they are not superior acorn producers but were retained because they are good timber trees. These totals represent Fair or Inferior acorn-producing trees classified as either Preferred or Desirable timber trees (table 5). None of the trees that would have been retained for improved acorn production were removed from the plantation. All of the tradeoffs just described illustrate the fact that the goal of integrated management is to optimize, rather than maximize, each of the landowner objectives. The hybrid prescription applied in this example plantation accomplished that goal because all of the best trees for each objective were retained and remain in the stand to continue to fulfill both landowner objectives.

To be successful, the landowner and forest manager must work together to develop a silvicultural strategy designed to manage young oak plantations in an orderly process to achieve landowner objectives, whatever those objectives may be. This strategy consists of a series of coordinated silvicultural actions taken over a period of time, all designed to steer the plantation from its current condition to the target condition at final harvest that is most optimum for achieving landowner objectives.

A well-designed silvicultural strategy must consider: (1) the species or mixture of species planted, (2) the site types and level of site quality that supports the plantation, and (3) the specific landowner objectives to be achieved. First, the seven oak species most commonly planted in the LMAV are planted typically in pure plantations, but sometimes are planted in mixtures with other oak species or with various non-oak species such as sweetgum. Each of these single-species and mixed-species possibilities vary considerably in terms of growth rate, site requirements, rate of plantation development, quality, value, and ability to achieve landowner objectives. Second, the different site types found within the LMAV—ridges, high flats, low flats, sloughs—span a wide range of levels of site quality. Consequently, site quality may vary significantly from one plantation to another and even within any given plantation. Finally, we addressed three common landowner objectives in this handbook, but landowners across the LMAV own forest land to achieve a wide variety of objectives, sometimes as single objectives and sometimes as multiple objectives that reflect a wide range of priorities placed on each objective. Consequently, the combination of numerous oak species and species mixtures, several site types and degrees of site quality, and many different landowner objectives and blends of objectives creates a seemingly endless number of unique situations faced by the landowner and forest manager.

Clearly, a single set of recommendations and silvicultural guidelines simply cannot address all possible situations adequately. Reliance on a one-size-fits-all silvicultural strategy to manage all young oak plantations throughout the LMAV will not be successful. Unfortunately, there is no magic cookbook. In this handbook, we present several silvicultural options suitable for achieving three common landowner objectives. But, our efforts address only a small portion of the many possible combinations of species, site, and landowner objectives found across the LMAV. Hopefully, each landowner and forest manager can use this handbook as a starting point to create and design the silvicultural strategy best suited for their specific situation.

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Appendix A—Calculation of Tree Density by Diameter Class For Bottomland Oak Plantations at 100 Percent Crown Cover and Population of a Stand Stocking Chart for Bottomland Oaks

Data for stem density relative to quadratic mean diameter of plantations at 100 percent crown cover were generated according to the following described methods. These methods are based on an equation published by Goelz (1996) that defines the relationship between d.b.h. and crown radius for bottomland oaks. The methods also include procedures for estimating stocking level relative to crown area (Goelz 1996).

1. Bottomland oak crown radius, in feet, for a given d.b.h. ($i = 4$ inches through 20 inches) is estimated with the following equation (see table A.1):

$$\text{Crown Radius}_i = (2.718)^{1.127} \times (\text{d.b.h.}_i)^{0.672}$$

2. Bottomland oak crown area, in square feet, for a given d.b.h. is calculated with the following equation (see table A.1):

$$\text{Crown Area}_i = 3.142 \times (\text{crown radius}_i)^2$$

3. Maximum number of trees per acre at 100 percent crown cover for a given d.b.h. is calculated with the following equation (see table A.1 and fig. 9):

$$\text{Maximum Trees per Acre}_i = 43,560 \div \text{crown area}_i$$

4. Stand basal area, in square feet per acre, at 100 percent crown cover for a given d.b.h. is calculated with the following equation. Basal area per acre and trees per acre data by d.b.h. are used to populate the stand stocking chart for bottomland oaks presented in figure 10.

$$\text{Basal Area}_i = 0.005454 \times (\text{d.b.h.}_i)^2 \times \text{maximum trees per acre}_i$$

Table A.1—Bottomland oak crown size estimates relative to d.b.h. and corresponding stand densities at 100 percent crown cover

D.B.H.	Crown radius	Crown area	Maximum trees per acre
	<i>feet</i>	<i>square feet</i>	<i>number</i>
4	7.8	192.8	226
5	9.1	260.3	167
6	10.3	332.6	131
7	11.4	409.1	106
8	12.5	489.6	89
9	13.5	573.5	76
10	14.5	660.8	66
11	15.5	751.1	58
12	16.4	844.2	52
13	17.3	940.1	46
14	18.2	1038.6	42
15	19.0	1139.5	38
16	19.9	1242.8	35
17	20.7	1348.3	32
18	21.5	1455.9	30
19	22.3	1565.6	28
20	23.1	1677.4	26

Appendix B—Estimation of Acorn Production Capacity for Bottomland Oak Plantations

Modeling acorn production capacity for bottomland oak plantations requires two components. The first component is a mathematical function of oak plantation stocking. Goelz (1996) provided a function suitable to this application as described in appendix A. The second component is a mathematical function that estimates acorn production capacity of a tree based on a quantifiable tree characteristic. Goodrum and others (1971) published equations to predict water oak and white oak acorn production from crown measurements. These equations are suitable for developing a general “trend-line” of acorn production capacity for bottomland oaks. Methods used to assemble an estimator of acorn production capacity for bottomland oak plantations are described as follows:

1. Estimation of crown radius relative to tree d.b.h. (table A.1) and data used to populate a stand stocking chart applicable to bottomland oak plantations (fig. 10) were generated according to methods and equations outlined in appendix A.
2. Individual tree acorn production, in pounds, relative to estimated crown size for a given diameter class was predicted for water oak and white oak with the following equations from Goodrum and others (1971):

$$\text{Water oak acorn production}_i = 20.1896 - 3.8293 \times (\text{crown radius}_i) + 0.1819 \times (\text{crown radius}_i)^2$$

$$\text{White oak acorn production}_i = 14.5078 - 3.5305 \times (\text{crown radius}_i) + 0.2071 \times (\text{crown radius}_i)^2$$

3. Individual tree acorn production was scaled up to the stand level, in pounds per acre, by multiplying estimates generated in step 2 with the corresponding maximum number of trees per acre for respective diameter classes (table A.1).
4. Stand-level estimates of acorn production generated in step 3 were averaged for water oak and white oak to produce a general “bottomland oaks” estimate of acorn production for each diameter class.
5. Data generated in step 4 were converted to a relative scale of acorn production capacity by transforming pounds-per-acre values to percentages of the 20-inch diameter class (the diameter class assumed to represent maximum acorn production for bottomland oak plantations in the scope of this handbook). This relative scale of acorn production capacity is suitable for individual tree and stand-level application. The relative acorn production capacity of an individual bottomland oak is indexed to d.b.h. in figure 11.
6. Data for acorn production capacity generated in step 5 (fig. 11) were coupled with the range of data for stand stocking in step 1 to produce the indices of acorn production capacity presented in figures 12 and 13—stand-level estimators of acorn production capacity for bottomland oak plantations indexed to quadratic mean diameter, stand density, and stocking percentage.

Appendix C—Protocol to Conduct a Visual Crown Survey to Document Bottomland Oak Acorn Production

Steps for conducting a basic visual crown survey are charted in table C.1. These steps are adapted from sampling procedures outlined in Koenig and others (1994). Implementation of this protocol over several growing seasons will enable the manager to identify individual trees that demonstrate superior acorn production, which is information critical to managing stands for improved acorn production. The basic method outlined in table C.1 can be modified to accommodate local stand conditions, but the practitioner should strive to adhere to a survey protocol that remains consistent within a stand over subsequent sample years to minimize survey bias.

The following tips should be considered when planning to conduct visual crown surveys in bottomland oak plantations:

- Mapping individual trees with a Global Positioning System (GPS) receiver will benefit long-term monitoring by minimizing tree re-location errors as plantations self-thin or receive a partial cutting operation.
- Surveys ideally should be conducted in the early fall as acorns approach maturation and before arboreal feeders remove a significant portion of the crop (fig. C.1A). If surveys are conducted later in the fall or into the winter, empty acorn caps should be included in counts (fig. C.1B).
- It is not necessary to survey trees with an overtopped crown because they do not have the capacity to contribute significant acorn production.
- Searches in white oak crowns should concentrate on branch sections that hold current year shoots, while those in red oak crowns should concentrate on branch sections of previous year shoots.
- Performing timed search intervals can be expedited with an easy-to-program timer that has an audible alarm.
- A stand should receive at least three visual crown surveys (three different years) for accurate identification of individual oaks that are superior acorn producers.

Table C.1—Steps necessary to conduct a visual crown survey for purposes of identifying bottomland oaks that demonstrate superior acorn production

Steps	Description
1	Map location and crown class of the subject tree.
2	Fix binoculars on a predetermined section of the upper 1/3 of the crown.
3	Search for and count acorns in the predetermined section of the crown for 15 seconds.
4	Tally the number of acorns counted.
5	Fix binoculars on another predetermined section of the upper 1/3 of the crown (typically 180 degrees from the first).
6	Search for and count acorns in the predetermined section of the crown for 15 seconds.
7	Tally the number of acorns counted.
8	Calculate a total for the tree by summing the two counts.
9	Repeat the visual crown survey in the stand for at least 3 subsequent years.



Figure C.1—(A) Late summer to early fall development of acorns in a Nuttall oak crown; (B) acorns and acorn caps remaining in a Nuttall oak crown during early winter. (photos by Emile S. Gardiner, U.S. Forest Service)

Appendix D—Crop-Tree Release and Selective Thinning Scenarios for Improving Acorn Production in Bottomland Oak Plantations

Crop-tree release scenarios aimed at improving acorn production in bottomland oak plantations are based on manipulating crown growing space available to crop trees. Two scenarios, developed from the relationship between d.b.h. and crown area as published by Goelz (1996), are presented (table D.1 and fig. 22). Application of the first scenario would create an average of 5 feet of growing space around crowns of residual crop trees. The second scenario would create an average of 10 feet of growing space around crowns of residual crop trees.

Selective thinning scenarios for improving acorn production in bottomland oak plantations are based on manipulating crown coverage in the stand canopy. Application of the first scenario would impose a reduction in stand density that decreases crown cover to 75 percent of complete, while the second scenario would impose a reduction in stand density that decreases crown cover to 50 percent of complete (table D.2 and fig. 23).

Table D.1—Bottomland oak stand densities relative to d.b.h. at 100 percent crown cover and for two crop-tree release scenarios that are based on crown growing space^a

D.B.H.	Trees per acre at 100 percent crown cover	Trees per acre given 5 feet crown growing space	Trees per acre given 10 feet crown growing space
	<i>number</i>	<i>number</i>	<i>number</i>
4	226	84	27
5	167	70	24
6	131	59	22
7	106	51	20
8	89	45	18
9	76	40	17
10	66	36	16
11	58	33	15
12	52	30	14
13	46	28	13
14	42	26	13
15	38	24	12
16	35	22	11
17	32	21	11
18	30	20	10
19	28	19	10
20	26	18	10

^aData presented in this table were used to populate figure 22.

Table D.2—Bottomland oak stand densities relative to d.b.h. at 100 percent crown cover and for two selective thinning scenarios that are based on crown cover of the stand^a

D.B.H.	Trees per acre at 100 percent crown cover	Trees per acre at 75 percent crown cover	Trees per acre at 50 percent crown cover
	<i>number</i>	<i>number</i>	<i>number</i>
4	226	169	113
5	167	126	84
6	131	98	65
7	106	80	53
8	89	67	44
9	76	57	38
10	66	49	33
11	58	43	29
12	52	39	26
13	46	35	23
14	42	31	21
15	38	29	19
16	35	26	18
17	32	24	16
18	30	22	15
19	28	21	14
20	26	19	13

^aData presented in this table were used to populate figure 23.

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This handbook presents several arrays of practical silvicultural options to landowners and forest managers of young, bottomland oak-dominated plantations. Each array of options is designed specifically to achieve one of three common landowner objectives: (1) production of high-quality oak sawtimber as the sole or primary objective; (2) creation of improved habitat for wildlife as the sole or primary objective, primarily through improved acorn production; and (3) integrated management for both oak sawtimber and improved wildlife habitat as multiple objectives of roughly equal importance and priority to the landowner. The handbook is divided into eight major sections: (1) patterns of stand development and acorn production over time in young, oak-dominated plantations; (2) silvicultural tools used for site, tree, and stand assessment, and for evaluation of acorn crops; (3) generalized decision-making process for initial management of young, oak-dominated plantations; (4) types of intermediate stand practices and their objectives; (5) possible detrimental effects of intermediate cuttings; (6) important factors to consider in the development of silvicultural options; (7) appropriateness of systematic cutting in young, oak-dominated plantations; and (8) silvicultural options suitable for attaining each of the three landowner objectives. To illustrate differences and similarities among the silvicultural options, we present an example based on data collected from an existing oak plantation to compare the structure and appearance of the residual stands that would result from the application of an appropriate silvicultural prescription for each of the three management objectives. For each management objective, we simulate the application of a silvicultural prescription designed to achieve that objective.

Keywords: Acorn production, bottomland oaks, integrated management, intermediate cuttings, plantations, *Quercus*, sawtimber production.



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