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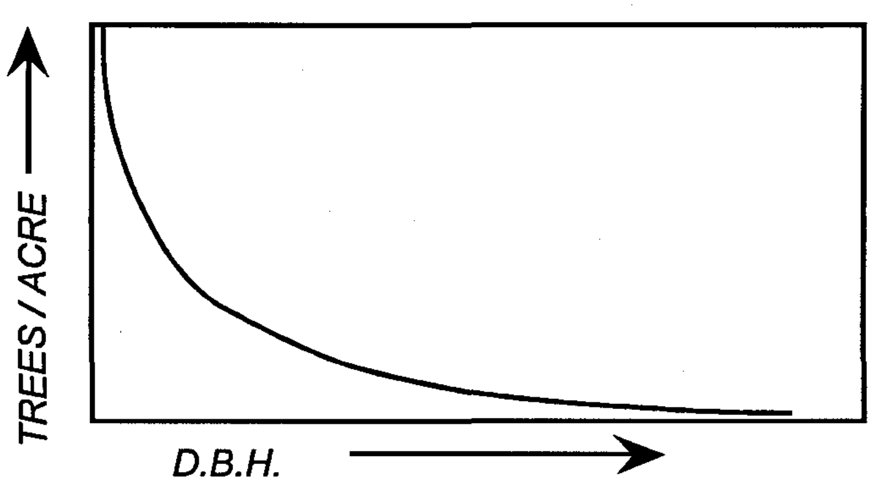

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PREFACE

In 1937, R.R. Reynolds of the USDA Forest Service established the "Good" and "Poor" Farm Forestry Forties on the Crossett Experimental Forest in Ashley County, Arkansas, in the first attempt to implement uneven-aged silviculture in shade-intolerant loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine stands. Interim results of these studies have been widely published over the years, and the Crossett Farm Forestry Forties have become a showcase for uneven-aged silviculture in the loblolly-shortleaf pine forest type in the Southern United States. With Reynolds' techniques as a basis, farm-forestry studies were established throughout the South to demonstrate the feasibility of selection silviculture on other sites and in other southern pine forest types.

A half-century of experience and research with uneven-aged silviculture in loblolly-shortleaf pine stands in the South are summarized in this publication, and silvicultural guidelines for developing and managing uneven-aged stands are provided. These results and guidelines are extremely pertinent today because selection silviculture can be used effectively to rehabilitate and manage thousands of acres of poorly stocked and previously unmanaged private, nonindustrial timberland in the South. Uneven-aged silviculture is also relevant to the Ecosystem Management philosophy adopted by the USDA Forest Service in 1992 for managing national forests throughout the United States. This publication should be useful to silviculturists, foresters, and other resource professionals in developing and managing uneven-aged pine stands. It can also serve as a teaching aid in forestry workshops, short courses, and university curricula.

The authors of this publication are listed alphabetically. Although all authors collaborated in preparing the manuscript, their principal contribution was as follows: Cain—introduction, glossary, and coordination; Guldin—chapter 1; Shelton—chapters 2 and 5; Baker—chapter 3, summary, and coordination; and Murphy—chapter 4.

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INTRODUCTION

The natural range of the two most important southern yellow pines—loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.)—extends throughout the Southeastern United States. Loblolly and shortleaf pines can occur as pure stands or as mixtures with other pine and hardwood species. Oaks (*Quercus* spp.), gums (*Liquidambar styraciflua* L. and *Nyssa sylvatica* Marsh.), and hickories (*Carya* spp.) are common hardwood associates (Baker and Balmer 1983).

Such wide dispersion of loblolly and shortleaf pines suggests that both are well adapted to an array of soil and site conditions. Perpetuation of these pines for timber production can be achieved by relying on natural pine seedfall under four reproduction cutting methods—clear-cutting, seed-tree, shelterwood, and selection (Smith 1986). The first three methods result in even-aged stands; the selection method (single-tree or group selection) is used to regenerate uneven-aged stands. Selection methods developed for loblolly and shortleaf pine stands during the past 50 years are described in this publication.

Exploitation of the virgin loblolly-shortleaf pine forests in southern Arkansas and northern Louisiana began in the 1890's, and these forests were exhausted by the late 1920's, leaving vast acreages of understocked, second-growth stands. Although some lumber companies abandoned their landholdings and moved west after the virgin southern pines were gone, others stayed in the region and began to manage their cutover forestland (Reynolds 1980). In the early 1930's, R.R. Reynolds and his associates pioneered the development of the uneven-aged silvicultural system in loblolly-shortleaf pine stands in southern Arkansas as a way to manage these cutover, understocked stands (Reynolds 1980).

The uneven-aged silvicultural system as developed by Reynolds consisted of the single-tree selection reproduction cutting method, stand structure regulation by volume control in the pine sawlog component, frequent harvests at 1- to 10-year intervals, and vigorous control of the hardwood component. Competition control is especially critical when applying uneven-aged silviculture to shade-intolerant species such as loblolly and shortleaf pines.

Ever since the development of uneven-aged silviculture for loblolly and shortleaf pines, this technique has been controversial. The debate over even-aged versus uneven-aged management of southern pines dates from the 1950's (Bond 1953, McCulley 1953), when the Society of American Foresters held a regional symposium on the subject. However, by the mid-1960's, the even-aged system, with clearcutting and artificial regeneration, was sweeping the country (Mustian 1978) and was being used on forest industry land and on the national forests. Differences of opinion about clearcutting reached a national scale with arguments and lawsuits over proposed cutting plans on national forests. This led to the passage of the Forest and Rangeland Renewable Resources Planning Act and the National Forest Management Act in the 1970's (USDA, FS 1989).

In the late 1980's, the pendulum began to swing away from clearcutting and plantation management on the national forests. Increasing non-timber use of national forest land resulted in pressures from public-interest groups urging the adoption of stand management alternatives that did not result in clearcuts. This, in turn, led to the socio-political concern that the public mandated the use of the uneven-aged system on national forests as the method of choice and as an aversive response to clearcutting (Hamilton 1991).

Ownership of forestland in the United States is not limited to Federal or State governments or to corporations. Private, nonindustrial landowners control about 70 percent of the commercial forestland in the South. Much of this land is producing timber at half its potential. The uneven-aged system requires little initial outlay of capital (Reynolds and others 1984), so it could be used to provide periodic income to private landowners while their understocked stands are rehabilitated. However, the choice of one silvicultural system over another depends on the land-owners' objectives and the condition of their timberland (McKee 1985).

The uneven-aged system is not a panacea because it requires some of the highest levels of skill and understanding of any forest management technique in use today (Hamilton 1991). Yet, it is a flexible system that can be adapted to fit various stand conditions. So it is appropriate to document the basic tenets of the uneven-aged silvicultural system for loblolly and shortleaf pines in a single publication.

Whether the uneven-aged system can provide non-commodity forest values such as wildlife habitat, recreational opportunities, biodiversity, and scenic beauty has yet to be established (Baker 1992). Existing knowledge about managing a forest to meet specified objectives of species composition, stand structure, stocking, growth, and yield of timber is much more voluminous and more scientifically based than our knowledge about developing a forest for any other purpose (Gibbs 1978). Consequently, our objective in this publication is to provide information about uneven-aged silviculture mainly for pine timber production. This information was synthesized from more than 50 years of experience and research with uneven-aged silviculture in loblolly-shortleaf pine stands on the Coastal Plain and Interior Highlands of Arkansas. Where appropriate, results from uneven-aged pine silvicultural research conducted throughout the Southeastern United States are included. Preliminary recommendations for hardwood retention in uneven-aged pine silviculture are also provided for readers who have management objectives beyond maximizing pine timber production.

Chapter 1

ECOLOGICAL BASIS OF UNEVEN-AGED SILVICULTURE

Silviculture is an ecological art and science subject to economic, social, and legal constraints. It is practiced at the stand level, which is the basic management unit of the forest. Forest management more properly deals with the forest as a whole rather than with individual stands.

Broadly speaking, nature provides two patterns for silviculturists to follow. The first is called **succession**—the normal growth and development of an existing forest or stand (Kimmins 1987). The second is known as **disturbance**—the partial or complete destruction of an existing forest or stand through natural events (Spurr and Barnes 1980). Ecologically, succession and disturbance combine to determine the development of the forest or stand. Silviculture, however, does not precisely mimic nature, because nature's ways are far more random and sometimes more catastrophic than silviculturists or society finds acceptable.

A silvicultural prescription is more predictable and more regulated than a corresponding set of natural disturbances to better achieve society's expectations or needs. Silviculture evolved as a modern, applied science when 18th-century foresters adapted natural patterns of succession and disturbance in managing forests to achieve the landowner's purpose. Today, foresters use silviculture to implement both disturbance and stand development in a stand in specific ways, which have varying degrees of "naturalness" about them. Uneven-aged silviculture offers some advantages over even-aged silviculture by emulating different stages of succession and different scales of disturbance.

Succession and disturbance are opposing yet complementary forces. Simply stated, under succession, a community progresses from early rapid changes in vegetation to later stages characterized by slow changes. Under disturbance, some or all of the vegetation is killed, setting succession back to an earlier stage. The actual interplay between succession and disturbance, however, is much more complex.

In this chapter, an overview of the ecological basis of succession and disturbance is presented, including some elements more appropriate to even-aged stands. After this overview, the discussion will emphasize the dynamics of stand development and disturbance that apply specifically to uneven-aged silviculture.

Succession

Succession—more specifically, secondary forest succession—is what we all think of as the normal growth and development of a forest stand. It begins immediately following disturbance when new trees start to grow and continues through distinct stages that, if unaffected by further large-scale disturbance, extend to old-growth.

Succession can be explained in terms of an idealized time continuum. Assume that, at some starting point called year zero, a major "catastrophe," such as a forest fire or windstorm, eliminates all the vegetation on a site. Secondary forest succession begins with this devegetated condition at year zero, just after the disturbance has occurred. From this point on, assuming no more catastrophic disturbances, the stand passes through four distinct stages of development. Two excellent summaries of these stages are presented by Bormann and Likens (1979) and Oliver (1981); a more indepth discussion of stand development is found in Oliver and Larson (1990). These four stages or phases of stand development can be summarized as follows.

The **stand initiation stage** (reorganization phase) begins immediately after the disturbance in year zero. Removing the vegetation makes more water, nutrients, and sunlight available on the site. New species (herbs, shrubs, and trees) become established because of the moist, fertile, and open conditions. Many different species with various degrees of shade tolerance and different regeneration habits become established during this period. The species that grow best are generally intolerant of shade (herbaceous plants, shrubs, and some trees like pines and sweetgum) and those that reproduce by sprouting from existing rootstocks (oaks, maples [*Acer* spp.], and hickories).

The **stem exclusion stage** (aggradation phase) takes over when one or more of the resources of the newly exposed site become limiting, preventing the further establishment of new plants. Some herbaceous species disappear, while others dominate for various periods; eventually the main canopy is dominated by trees. The new stand occupies the site completely, and competition for nutrients, moisture, and light begins in earnest.

As this stage proceeds, tree growth and competition lead to recognizable and predictable patterns of stand development. The early successional herbaceous plants can no longer persist because the main canopy forms a continuous, dense layer. Intense competition results in a stratified canopy of vegetation. Shade-intolerant species must be strong competitors to retain rapid height growth and remain in the upper canopy. Otherwise, they will lag behind and probably succumb to suppressing competition. Shade-tolerant species seldom remain in the upper canopy, but can persist in the shaded conditions found in the lower canopy. Over time, a prominent layer of shade-tolerant species, such as flowering dogwood (*Cornus florida* L.), maples, American hornbeam (*Carpinus caroliniana* Walt.), and eastern hophornbeam (*Ostrya virginiana* [Mill.] K. Koch) may develop in the lower portions of the main canopy.

The **understory reinitiation stage** (transition phase) begins when trees in the main canopy begin to succumb, either singly or in small groups, to natural mortality caused by lightning, wind-throw, or insects and disease. The gap in the canopy that results is ecologically significant in that resources formerly used by the dead tree are reallocated to the surviving vegetation. If there is a closed mid-canopy beneath the overstory, shade-tolerant species may respond to release and ascend to the overstory. If there is not a closed mid-canopy, enough sunlight may penetrate to the forest floor to support the establishment of new trees. As overstory trees next to the opening also succumb, the opening expands, allowing even more light, nutrients, and moisture to be used by the new plants. These regeneration processes, called "gap-phase regeneration dynamics" (Bray 1956, Pickett and White 1985, Runkle 1982, Runkle and Yetter 1987), are similar to those that occurred during stand initiation, only at a smaller scale. This difference in scale, however, is of ecological significance because the gaps are small enough to be influenced by adjacent overstory vegetation.

The **old-growth stage** (steady-state phase) is distinguished from the understory reinitiation and stem exclusion stages in that the old-growth stage tends toward greater stability in biomass and productivity. Regeneration dynamics continue through the gap-phase regeneration process described in the transition period. Theoretically, a series of gaps created over time will result in a stable balance of trees of different species, sizes, and ages. An observer in the stand during this stage has difficulty seeing for great distances because of the overlapped screening effect of foliage from overstory, midstory, and understory trees.

Again, under ideal circumstances, this period is indeterminate. The coexistence of young and old trees, the dynamics of development within gaps and between gaps, and the relatively stable biomass and productivity levels continue over the long term. Vegetation changes slowly in this stage because changes in soil, weather or climate, competition, diseases, and insect pests also occur gradually.

Disturbance

Natural disturbance is the ecological counterpoint to succession. Through succession, plant communities develop; through disturbance, that development is altered. Some disturbances are severe enough to set a plant community back to the beginning of the stand initiation stage. Others are so minor that only one tree is affected, thereby advancing development during the stem exclusion, understory reinitiation, and old-growth stages.

When judged by ecological time scales, the proportion of time that disturbances affect a stand is infinitesimal. But these periods are extremely important ecologically because they allow new generations of vegetation to become established and develop. By their very rarity, disturbances are of keen interest to ecologists and foresters as physical phenomena; by their occurrence, they establish ecological conditions within which new plant communities are created.

Disturbances vary according to three dimensions (White 1979). **Frequency** is the rate at which existing disturbances recur or is the mean number of recurrences over time. Frequent disturbances occur every few years, whereas infrequent disturbances occur once every few centuries. **Predictability** describes the regularity of occurrence of the disturbances; i.e., how predictable the recurrence of a disturbance is. **Magnitude** is the duration of the disturbance and varies from a few seconds or minutes (such as during a wildfire) to several years (such as a drought). Reckoned by human time scales, disturbances vary from being somewhat to exceedingly rare; however, this does not make them any less essential to a holistic view of forest ecology.

Disturbance frequency is generally inversely correlated with severity. In nature, a catastrophic disturbance that sets succession back to the stand initiation stage is exceedingly rare. The concept of disturbance cannot be restricted to large, catastrophic events, such as the volcanic eruption of Mt. St. Helens in 1980, the wildfires in Yellowstone National Park in 1988, or Hurricane Hugo in 1989, spectacular though they may be.

The severe, partial disturbance in which most of a stand is destroyed but part of the overstory and midstory survives is more common, but still rare. Stand development after such a disturbance is affected by competition not only within the newly developing reproduction but also between the reproduction and the scattered overstory trees that survived the disturbance. The resulting stand is much more variable in structure and species composition than a stand that follows a complete disturbance.

Small disturbances that affect one to a few trees are the most common, occurring far more frequently than stand-replacing disturbances. This solitary mortality is a basic element of stand development throughout succession and influences the formation of canopy layers, depending on the size of the tree that succumbs. During the early stages of stand development, the death of an individual tree usually improves conditions for its neighbors—in silvicultural terms, density-dependent mortality similar to thinning.

But during the last two stages of stand development, the death of a tree in the overstory provides growing space for reproduction and development of the understory. At this stage, if a tree in the main canopy succumbs, the crowns of the neighboring overstory trees may not expand fast enough to occupy the resulting canopy opening. Unless there is a closed mid-canopy, this disturbance fosters new reproduction or releases advance growth.

Thus, in late successional stages, the regeneration process depends on whether overstory crown expansion closes the gap before the understory trees fill the gap from below. Understory trees are more likely to make it to the overstory if: (1) the gap is large, (2) the trees adjacent to the gap do not respond vigorously in lateral crown growth, and (3) the gap is enlarged by the death of trees that border it.

Applying Ecological Principles to Silvicultural Practice

Foresters use silviculture to impose disturbance and modify successional development in a stand. Some trees (or other plants) are removed so others can develop better. The degree to which these prescribed actions "imitate" nature depends on how they are implemented.

The first alternative of the forester is that of no treatment. But subsequent alternatives involve removing increasing proportions of the vegetation. The choice of alternatives must be consistent with the ecology of the species that comprise the stand, the existing condition of the stand, and the future condition desired by the forest owner.

Silviculture and Stand Development

The stages of stand development and gradients of disturbance reflect the ecological basis within which silviculturists operate. The early stages of stand development set the stage for even-aged silviculture. By imposing disturbances severe enough to promote regeneration across the entire stand, the forester can encourage the development of intolerant and mid-tolerant species as one or two age classes distributed uniformly across the stand.

The later stages of succession, primarily the understory reinitiation stage, provide the ecological basis for uneven-aged silviculture. A silvicultural prescription that imitates scattered natural mortality in the upper crown classes can promote development of reproduction continuously over time. The goal of uneven-aged silviculture is to stabilize stand structure and biomass (volume) over the long term, thus emulating the old-growth stage. But other desirable ecological attributes of the old-growth stage (such as downed woody debris and low net growth) are less likely to be achieved in uneven-aged silviculture.

Silviculture and Disturbance

Ecologically, silviculture is simply an effort by the forester to imitate succession and disturbance. Reproduction cutting imitates disturbance; stand management after reproduction cutting imitates stand development. The decision to practice even-aged or uneven-aged silviculture depends upon many things, of which the most important is the landowner's objectives. The next step is to evaluate the ecological situation considering those objectives and regarding the silvicultural options.

Even-aged reproduction cutting methods imitate disturbances that affect an entire stand; uneven-aged reproduction cutting methods imitate disturbances that affect only part of a stand. By choosing to pursue uneven-aged silviculture, the forester is opting to work with various small-scale disturbances that disturb only part of the stand and promote the later stages of development, especially the understory reinitiation stage.

The most intensive small-scale disturbances do not affect an entire stand, but can create large openings within a stand. Natural examples include a localized insect infestation such as southern pine beetle (*Dendroctonus frontalis* Zimmermann), a locally severe wind, or the flareup of a surface fire. Such a disturbance creates a gap in the canopy of the stand; reproduction becomes established and develops within this opening. Ecological conditions within the gap are affected by bordering trees, depending on opening size and shape. **Group selection** is used by foresters to approximate these conditions.

The least-intensive, small-scale disturbance likely to occur in a stand is a single tree falling, or dying while standing, in the woods. Causes of such individual tree mortality include disease, insects, lightning, windthrow, or some combination of these. If the dying tree had a large crown, reproduction will become established in the gap created in the canopy. In the smallest gaps, the opening may close before the reproduction can grow into the main canopy, and the reproduction may then persist without further growth or may even become suppressed and die. The occurrence of multiple gaps (where trees next to a recently created gap succumb due to some cause linked to their proximity to the gap) or the concurrent creation of several small gaps within the same area can tip this ecological balance in favor of reproduction survival and development. **Single-tree selection** is used by foresters to approximate these conditions.

Key Ecological Elements of Uneven-Aged Silviculture

Gap-phase regeneration dynamics.—Opening size greatly influences understory development. It affects species composition and growth of reproduction. Understanding the interplay involved is critical to the forester's ability to apply the concepts silviculturally.

The primary factor to consider is gap size relative to the shade tolerance of the desired species or mixture of species. Generally, large gaps favor shade-intolerant species, and small gaps favor shade-tolerant species. As gap size decreases, the adjacent trees increasingly constrain the development of reproduction within the gap until, in the smallest gaps, the reproduction is suppressed. In addition, advance reproduction in place before the gap occurs also influences the species composition of reproduction after the gap has been created.

The foregoing applies to circular gaps in flat terrain. The situation becomes more complicated where gaps are irregular in shape and where terrain is hilly. The less direct the exposure to sunlight and the less circular the gap, the greater the influence of adjacent vegetation within the gap.

However, gaps may not be necessary for adequate reproduction. Simply reducing the overstory stocking to levels that would be considered "understocked" under even-aged management can allow sufficient diffuse sunlight to penetrate to the forest floor, if the midstory is also understocked. Repeated disturbances to maintain this understocked condition can successfully regenerate a stand over time.

Thus, the interplay of ecological condition, gap size, competition, and physical resources is the key to understanding regeneration dynamics in the last two stages of succession. These patterns can provide an ecological basis for practicing either group selection or single-tree selection, although the ecological distinctions between these two methods of selection are often fuzzy.

Canopy dynamics and shade management.—The silviculturist applies these concepts of small-scale disturbances and gap dynamics by means of shade management. The position and shape of a tree's crown determine how much solar radiation it can intercept. The decision of whether to cut a tree can be linked to the size and vigor of a tree's crown, which reflect its demands on soil nutrient and moisture resources. As this decision is made for each tree in the stand, the degree of shade retained across the entire stand is determined. Thus, by managing the shade in the stand, the forester directly affects the future development of both overstory and reproduction.

The result of shade management properly applied in uneven-aged silviculture is easily seen by the forester in the canopy profile. The desired species will be present in all expected levels of the canopy profile, depending on the number and frequency of cutting-cycle harvests. For stands that have been under regular cutting-cycle harvests for an extended period, the desired species will exist in all levels of the canopy. For stands under uneven-aged silviculture for only one or two cutting cycles, the desired species will be apparent in only the upper and lower layers of the canopy.

One should expect each cutting-cycle harvest to contribute some reproduction to the stand, and this should be apparent from both a range of tree sizes and the presence of the desired species in the appropriate canopy levels. In stands with frequent cutting cycles and prolific reproduction, new reproduction need not be obtained after every harvest. Even so, reproduction should follow at least every other harvest. As the cutting cycle lengthens or as the desired species becomes more difficult to regenerate, reproduction should be obtained after each cutting-cycle harvest. In both examples, the presence of different size classes of desired species should be clearly seen, not only in the diameter distribution but also in the canopy profile.

Gap-phase dynamics and shade management can also sustain the development of intolerant species in uneven-aged stands. The key is to ensure that there is always adequate light for desired species to persist and, if possible, to grow into the understory and lower layers of the canopy. This is done by controlling average stand stocking (basal area) and average gap size. An estimate for the desired basal area for a given species is the overstory basal area that marginally suppresses height growth of the reproduction if overstory trees are distributed uniformly across the stand. The goal should be to attain this basal area at the end of the cutting cycle. Then, the gaps normally created by "cutting the worst and leaving the best" are where the establishment and development of reproduction will be most vigorous. The stand as a whole, both overstory and the sparsely stocked understory, will develop throughout the cutting cycle, but the more densely stocked portions of the stand will support only overstory development. Essentially, this process ensures a continuous development of new gaps and expansion of old gaps.

However, once this balance between stand stocking and cutting-cycle length is established, it can be maintained only by harvesting at fairly regular intervals. Excessive delays in cutting-cycle harvests will alter stand structure because the overstory stocking will increase and understory development will slow dramatically under over-stocked conditions. In essence, the stand reverts to a more even-aged character, and the process of building good uneven-aged stand structure must be restarted.

Traits of Loblolly and Shortleaf Pines that Influence Silvicultural Options

Loblolly pine in the West Gulf Coastal Plain lends itself, perhaps more than any other species in the world, to silvicultural flexibility. It is a medium-lived tree with rapid juvenile growth and a prolific seed producer in this part of its natural range (Baker and Langdon 1990). It can withstand some overstory shading when young, but the height growth of reproduction decreases and mortality increases with excessive shade, especially from overtopping hardwoods. However, if loblolly pine seedlings growing with hardwood sprouts survive their third year, they will successfully compete with the hardwoods in open conditions (Baker and Langdon 1990). Shade management becomes important in such circumstances. Uneven-aged methods that enlarge existing regenerated gaps or that further remove residual overstory trees within gaps will promote successful uneven-aged silviculture with the species.

Shortleaf pine tolerates wide extremes in temperature and moisture and is the most broadly distributed of all the southern pines. It produces good to excellent cone crops every 3 to 6 years (Lawson 1990). Seedlings grow slowly for the first several years as their root systems expand. The species has unique seedling characteristics of ecological and, perhaps, silvicultural interest—they develop a sharp J-shaped crook at the ground line. Associated with this crook are axillary and other buds that develop into sprouts if the above-ground portion of the seedling is killed. This trait persists through roughly the first decade, a likely adaptation to fire (Mattoon 1915).

Shortleaf pine is considered intolerant of shade, and does not grow well when suppressed (Lawson 1990).

However, it can survive suppression for extended periods and still respond to release (Mattoon 1915). Shade management becomes important in such circumstances. As with loblolly pine, uneven-aged methods that enlarge existing regenerated gaps or that further remove residual overstory trees within gaps will help uneven-aged silviculture succeed with shortleaf pine. Its sprouting ability, rarity of adequate seed crops, and ability to persist beneath shade until released, all suggest a silvicultural strategy based on advance reproduction, perhaps established with prescribed fire and linked with the selection method.

In addition to the silvical traits of loblolly and shortleaf pines, silviculturists must also be aware of the characteristics of their competitors. Loblolly and shortleaf pines are commonly associated with a variety of southern hardwoods, many of which are more shade tolerant than the pines. Therefore, lacking periodic disturbances, a loblolly-shortleaf pine stand will eventually be dominated by hardwoods (Cain and Shelton 1994, Cain and Yaussy 1984, Switzer and others 1979). Persistent silvicultural effort must be expended in uneven-aged pine stands to prevent this shift in species composition.

Chapter 2

CONCEPTS AND DEFINITIONS

Precise principles and terminology are essential for any profession. Therefore, some basic concepts used in uneven-aged silviculture are defined in this chapter. In addition, a glossary is provided in the appendix.

Silviculture Versus Forest Management

Silviculture is the art, science, and practice of establishing and maintaining the types of stands and forests that will meet landowner and society needs on a sustainable basis. There is a subtle but clear distinction between silviculture and forest management. Silviculture is principally applied in **stands**. A stand is a contiguous group of trees that can be considered a distinguishable unit; the trees are similar in species composition, age- or size-class distribution, and condition and are growing on a site of uniform quality. By contrast, a forest is a collection of stands. **Forest management** is implemented at the forest level and encompasses economics, silviculture, politics, laws, societal preferences, protection, roads, and other factors that affect the stewardship of a forest. For some landowners, the stand and the forest may coincide.

Even-Aged Versus Uneven-Aged Silviculture

A **silvicultural system** is the planned program of treatments applied during the entire life of a stand. Treatments are formulated to meet the ecological requirements of the species under management and the objectives of the landowner. When the two do not coincide, ecological principles will set the limits of the silvicultural system unless the landowner is willing to expend large amounts of capital to overwhelm nature. A silvicultural system includes reproduction cuttings, site preparation, competition control, and tending operations, such as thinning. Such activities are intended to promote development of the best trees through maturity by removing cull, diseased, and undesirable trees, consistent with the landowner's objectives.

Maturity is the stage when a tree best meets the objectives of the landowner. For timber production, it is important in deciding when to harvest a tree or group of trees and to secure their replacements through regeneration. Maturity can be evaluated in several ways. **Financial maturity** occurs when a tree ceases to return an acceptable compound interest rate on the investment that it represents. **Physiological maturity** occurs when a tree attains its full size, and **overmaturity** occurs when health and vigor decline enough to increase the risk of mortality.

Reproduction cutting method refers to the way that mature trees in a stand are removed and the new stand is established. The goal is to create the environmental conditions needed to establish and develop the new stand by harvesting and site preparation. The reproduction cutting method is perhaps the key element in a silvicultural system because it strongly influences the character of the new stand and subsequent silvicultural treatments. Thus, regenerated stands and silvicultural systems are generally named for their reproductive cutting method. Uneven-aged reproduction cutting methods (**single-tree selection** and **group selection**) generally retain more trees than even-aged methods (**clearcutting**, **seed-tree**, and **shelterwood**), and the trees are usually more varied in size and spacing. In even-aged reproduction methods, trees retained for seed production may be completely removed once the stand has successfully regenerated, unless they are retained for other purposes, such as visual and wildlife habitat enhancement. These cutting methods create an array of environmental conditions for reproduction, ranging from the open areas resulting from clearcutting to the partially shaded understories of single-tree selection.

Choosing a reproduction cutting method is based on the existing stand conditions, silvical characteristics of the desired species, landowner objectives, desired future conditions, local timber markets, and economic considerations. Although by definition these cutting methods are distinctively different, one method may overlap another, resulting in similar stand conditions. For example: (1) small, patch clearcuts may appear to be the larger openings created in group selection, (2) stands with small, group-selection openings may appear to be under single-tree selection, and (3) shelterwood stands with trees retained after regeneration may produce stands similar to those under single-tree selection.

Even-aged silviculture is based on a **rotation**, defined as the length of time between reproduction cuttings. Rotation length, typically 25 to 100+ years in the Southern United States, is affected by many factors, including landowner goals, timber markets, economics, growth rates, and site productivity. Treatments such as site preparation, release, thinning, and the final harvest are usually applied over the entire stand and are independent of each other. The maturity of trees is determined by the collective traits of the entire stand. Of course, the final harvest is not the only cutting done in even-aged stands; thinning is done periodically to control stocking, capture anticipated mortality, and improve stand vigor and quality. The **thinning interval** is the length of time between thinnings.

Conversely, harvesting in uneven-aged stands is based on the **cutting cycle**, defined as the number of years between successive cuttings in the stand. The cutting cycle is usually constant, but it can be adjusted to take advantage of seed production, market variability, or landowner needs. In the Southern United States, cutting cycles generally range from 3 to 20 years and are affected by the same factors that determine even-aged rotations. Within each cutting cycle, all silvicultural treatments common to an even-aged rotation, such as site preparation, release, thinnings, and reproduction cutting, may be applied. However, treatments are usually restricted to only those portions of the stand where needed. Tree maturity is evaluated on the merits of the individual tree or small groups of trees.

Stand Structure

Structure refers to the age- or size-class distribution of the trees making up a stand. This information hints at the stand's origin and reveals the form of its canopy. A stand's age structure is classified according to the number of distinctive age classes that are present. An **even-aged stand** is composed of a single age class, where the range of tree ages does not exceed 20 percent of the rotation length. A **two-aged stand** contains two distinctive age classes and results from even-aged reproduction cutting, such as the seed-tree and shelterwood methods, where the residual trees are retained well beyond the normal period needed for regeneration.

Uneven-aged stands are composed of three or more age classes that are spatially intermingled. Each class makes up a significant portion of the stand's stocking and contains the desired species. Thus, an even-aged pine stand with understory and mid-canopy hardwoods cannot be classified as an uneven-aged stand if only the pine component is being managed.

Although silviculturists often talk about a stand's age structure, rarely do we know what it is—determining age of many trees is simply too time consuming. Thus, the size-class distribution within a stand, most commonly expressed in **d.b.h.** (diameter at breast height taken at 4.5 ft above ground), is typically used instead of age, especially if it is combined with some evaluation of tree vigor and crown features. Moreover, a tree's age is of less concern than its ability to respond at an acceptable growth rate when released.

Tree age and size are usually not highly correlated within an even-aged stand because all the trees are similar in age. Tree sizes, however, can vary due to differences in genetics, microsites, spacing, and other factors. Trees that do not keep pace become suppressed and die, or they may be removed in thinning. Thus, an even-aged stand has a **bell-shaped** d.b.h.-class distribution, is characterized by a high degree of uniformity, and has a single canopy (fig. 2.1). A two-aged stand has a binomial d.b.h.-class distribution and two distinct canopy layers of the species being managed (fig. 2.1).

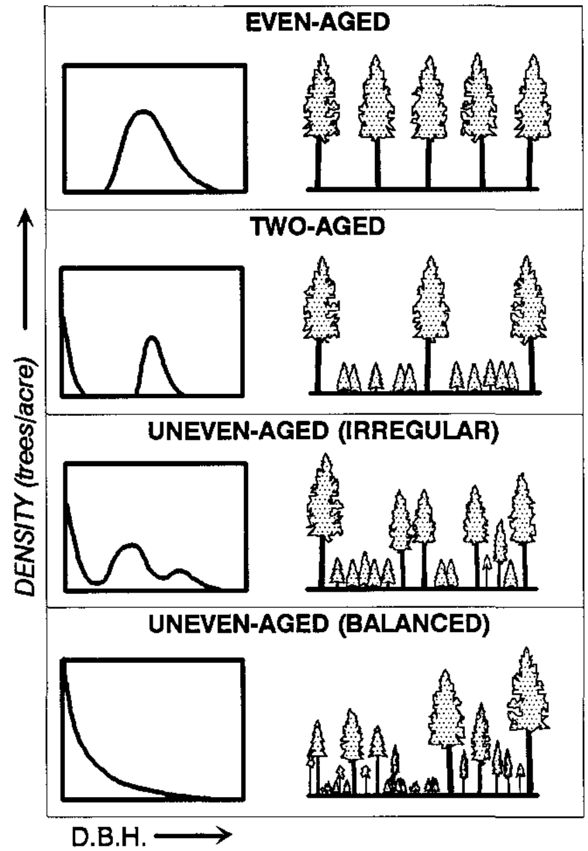

Figure 2.1.—*Diameter distributions and canopy profiles occurring in stands with different types of age structure.*

The multiple ages of an uneven-aged stand result in a wide range of size classes. Uneven-aged stands typically have a **reverse J-shaped** d.b.h.-class distribution (fig. 2.1). There are many small trees, some medium trees, and a few large trees of the species being managed. Within an uneven-aged stand, tree age is reflected in tree size, with small trees tending to be young and large trees tending to be old (Shelton and Murphy 1991). However, this relationship is also affected by variation in genetics, microsites, and competition from larger trees.

The ideal d.b.h.-class distribution in uneven-aged stands is a **balanced** reverse-J curve (fig. 2.1). It represents a compilation of many overlapping bell-shaped curves, each curve depicting an age class (Smith 1986). This balanced curve can also be called a negative exponential distribution. The wide range in size results in an irregular canopy structure with multiple layers (Shelton and Murphy 1993).

Age classes in some uneven-aged stands may not be established frequently or at regular intervals because of the irregular timing of such events as harvests, fires, competition control, seed crops, weather, and insect and disease attacks. The resulting distribution represents an **irregular** uneven-aged stand (fig. 2.1). For most shade-intolerant species, the irregular distribution is probably more common than the balanced one. The irregular, uneven-aged distribution is similar to the binomial, even-aged distribution. This illustrates that a stand can occur anywhere along a continuum of possible age structures, ranging from the simplest (an even-aged stand) to the most complex (a balanced, uneven-aged stand). In reality, no clear distinction may exist between even-aged and uneven-aged structure under certain stand conditions.

In balanced, reverse-J distributions, a constant ratio exists between successive d.b.h. classes. This relationship defines the curve's shape (steepness or flatness) and is called the **quotient** or q. The calculation is as follows:

$$q = N_i / N_{i+1}$$

where N_i is the number of trees in the ith diameter class and N_{i+1} is the number of trees in the next largest class. For example, q would be 1.2 if there were 12 trees in the 15-inch d.b.h. class and 10 trees in the 16-inch d.b.h. class. Note that a q of 1.0 results in a flat distribution because the number of trees is equal for all classes; a q of 2.0 produces a very steep curve because the number of trees in successive d.b.h. classes is halved. Class width affects the number of trees in the class and therefore the value of q (Murphy and Farrar 1988). The q for a distribution with 1-inch d.b.h. classes is squared to give the same distribution for 2-inch classes (for example, a q of 1.2 for 1-inch classes would be 1.44 [1.2 × 1.2] for 2-inch classes). The q is central to discussing the finer points of uneven-aged silviculture because it affects sustainable yields. Logically, no constant ratio exists between successive d.b.h. classes for irregular, uneven-aged stands; this complicates developing marking guides and obtaining a sustained yield of timber products.

The Uneven-Aged Silvicultural System

The **uneven-aged** or **selection system** is the principal means for creating and maintaining uneven-aged stands. The selection system should not, however, be confused with **selective cutting**, a term so corrupted that it is often applied to any type of partial cutting, whether it is a reproduction cut or an intermediate thinning. In fact, the meaning of selective cutting is so vague that it is not accepted in forestry terminology (Wenger 1984). The negative connotation of selective cutting originated in the unsavory practice of "high-grading," where only the best trees in a stand were harvested without providing for stand regeneration. Because of the similarity of the words selection and selective, the alternative term, **uneven-aged system**, which emphasizes the multiple-age classes necessary to sustain these stands is preferred.

Stands under the uneven-aged system have a continuous, irregular forest cover, recurring regeneration of desired species, and the orderly development of trees through a wide range of sizes. In the uneven-aged system, a balanced or irregular structure is maintained through frequent reproduction cuttings. **Single-tree selection** and **group selection** are the two recognized reproduction cutting methods. In single-tree selection, trees are selected for harvest based on their individual merits, such as form, quality, growth rate, financial maturity, competition with younger more vigorous crop trees, and mortality risk. By contrast, group selection focuses on the aggregate condition of small groups of trees. Group selection generally produces larger openings than does single-tree selection, which sometimes favors the regeneration of shade-intolerant species. However, group selection does not allow as much flexibility in nurturing individual trees as does single-tree selection.

Diameter-limit cutting, which removes trees above a specified diameter, generally has a bad reputation because low-quality trees that are above the limit are commonly left. Diameter-limit cutting often results in regeneration although it is technically not a reproduction cutting method. However, it may simulate the uneven-aged system if: (1) all trees above the diameter limit are cut, (2) the diameter limit is set to retain some trees of seed-producing size, and (3) competing vegetation is periodically controlled. A disadvantage of diameter-limit cutting is that yields widely fluctuate because residual stocking is not regulated (Murphy and Shelton 1991). The method also does not remove trees of low quality and vigor that are below the diameter limit.

Stocking

Stocking is a relative term comparing the existing stand with the optimum for landowner objectives. In even-aged stands, stocking is maintained by thinning to enable crop trees to fully use the site's potential. By contrast, stocking in the merchantable portion of an uneven-aged stand is maintained at less than full occupancy so that some of the site's resources (light, water, and nutrients) are available to reproduction. Thus, acceptable stocking in uneven-aged stands has both lower and upper limits; this allows meeting the combined objectives of obtaining acceptable growth rates for the merchantable trees and acceptable density and development of reproduction. The lower limit occurs when low stocking causes a growth loss, and the upper limit occurs when merchantable trees adversely affect the development of reproduction (table 2.1).

In uneven-aged stands, stocking is commonly measured separately for the merchantable and submerchantable stand components. Volume and basal area are usually used to evaluate the stocking of the merchantable portion of the stand. Stocking in the submerchantable portion is usually expressed as the number of seedlings and saplings per acre and includes some measure of their spatial distribution, such as **milacre stocking** (the percentage of 0.001-acre plots containing at least one seedling or sapling).

Table 2.1.—*Acceptable stocking in uneven-aged loblolly-shortleaf pine stands on good sites*[*]

Measurement[†]	Limit[‡]	
	Lower	Upper
Merchantable basal area (*Ft²/acre*)	45	75
Sawtimber basal area (*Percent of merchantable*)	60	80
Merchantable volume (*Ft³/acre*)	1,000	2,000
Sawtimber volume (*Ft³/acre*)	500	1,500
Sawtimber Doyle volume (*Fbm/acre*)	2,500	7,000
Sawtimber International volume (*Fbm/acre*)	4,000	10,000
Sawtimber Scribner volume (*Fbm/acre*)	3,000	8,500

[*] Site index >85 ft at 50 years for loblolly pine. Early results from several studies (Murphy and Farrar 1985, Murphy and others 1991, Shelton and Baker 1992a) suggest that similar stocking limits are applicable to shortleaf pine stands on poor sites (site index of <65 ft at 50 years).

[†] Merchantable trees are 4 inches in d.b.h. and larger; sawtimber trees are 10 inches in d.b.h. and larger. Cubic foot volumes are inside bark.

[‡] Lower limits are for a stand with a basal area of 45 ft²/acre, a maximum d.b.h. of 16 inches, and a *q* of 1.22 for 1-inch d.b.h. classes and using local-volume equations for the Crossett Experimental Forest (Farrar and others 1984b). Upper limits are for the target stand existing at the end of a cutting cycle as described by Reynolds (1959).

Forest and Stand Regulation

Regulation refers to the manner in which harvests are scheduled and implemented to provide the sustained, even flow of timber or other forest resources. In **even-aged or two-aged management**, regulation is principally achieved at the forest level by scheduling the rotation of mature stands. Either **area regulation** (designating the harvested area) or **volume regulation** (designating the harvested volume) can be used. The sustained, even flow of timber is not a goal at the stand level. By contrast, regulation is applied at both the forest and stand levels in **uneven-aged management**, because sustained yields are goals at both levels. Either area or volume regulation can be used in uneven-aged management. For example, area regulation of a 1,000-acre forest composed of uneven-aged stands might involve uneven-aged cutting on 100 acres during each year of a 10-year cutting cycle. At the stand level, however, volume and basal area, coupled with the d.b.h.-class distribution, are the accepted regulation techniques in stands under single-tree selection.

Volume/Guiding-Diameter-Limit (VGDL) Method

The VGDL regulation method of single-tree selection has been effectively used in loblolly-shortleaf pine stands in southern Arkansas for more than 50 years (Farrar 1984, Reynolds 1959, Reynolds and others 1984). A stand is regulated by cutting a sawtimber volume equal to the stand's sawtimber growth during the cutting cycle. Harvests are conducted when sawtimber volume reaches the upper limit acceptable for the development of pine reproduction. The expected volume growth for the next cutting cycle (annual volume growth times cutting-cycle length) is the **allowable cut**. Length of the cutting cycle can be varied to provide an operable timber harvest if the residual stand volume is large enough to sustain stand growth. Ideally, stand volume will grow to the upper limit by the end of the next cutting cycle. Thus, regulation by the VGDL method maintains stand volumes within acceptable lower and upper stocking levels. The VGDL method can also be adapted to increase stocking in understocked stands by cutting less than growth.

A **guiding diameter limit** is calculated so that harvesting trees in this diameter class and larger will provide the allowable cut. However, this diameter limit is only intended as a guide, and high-quality trees with acceptable growth may be retained above the limit, while an equal volume of lower quality trees may be cut below the limit. Thus, the method provides some flexibility in selecting individual trees for harvest, although the allowable cut calculated for the stand is strictly maintained unless the stand is understocked. Using this method requires some estimate of the stand's growth rate [see chapter 4] and the diameter distribution at the end of the cutting cycle. Implementing this method requires considerable skill because cutting in the sawtimber component is subjective. The pulpwood component is not consciously regulated in this method because stocking has traditionally been based solely on sawtimber volume (Reynolds 1959).

An example of implementing the VGDL is shown in table 2.2. This stand has a sawtimber volume of about 7,000 board feet (fbm)[1]/acre, which is at the upper stocking limit indicated in table 2.1. An annual growth rate of 400

[1] All board-foot values are given in Doyle scale unless otherwise stated.

Table 2.2.—*Example of the data and calculations needed to implement the Volume/Guiding-Diameter-Limit (VGDL) regulation method (number of trees would be determined by inventory)*

D.b.h.	Number	Preharvest volume: By d.b.h. class	Preharvest volume: Cumulative*	Cut volume: Target	Cut volume: Actual
Inches	*Per acre*	*Fbm/acre*			
4	18	0	0	0	0
5	16	0	0	0	0
6	13	0	0	0	0
7	12	0	0	0	0
8	9	0	0	0	0
9	8	0	0	0	0
10	7	197	7,013	0	0
11	7	278	6,816	0	0
12	6	336	6,538	0	112
13	5	385	6,202	0	0
14	4	411	5,817	0	103
15	4	400	5,406	0	100
16	3	505	5,006	0	0
17	3	624	4,501	0	208
18	2	505	3,877	0	0
19	2	604	3,372	0	0
20	2	712	2,768	0	0
21	1	414	2,056	414	414
22	1	478	1,642	478	0
23	1	546	1,164	546	546
24	1	618	618	618	618
Total	125	7,013	- -	2,056	2,101

* Starting with the largest d.b.h. and accumulating the volume in each smaller d.b.h. class.

fbm/acre and a 5-year cutting cycle are assumed. The volume growth during the cutting cycle would be 2,000 fbm/acre (5 years × 400 fbm/acre), which is the allowable cut. This is sufficient volume for an operable cut and leaves a volume that is above the lower limit for stocking (7,000 - 2,000 = 5,000 fbm/acre). Table 2.2 shows that trees 21 inches in d.b.h. and larger will provide the allowable cut. Thus, 21 inches is the guiding diameter limit. In marking the stand, however, some high-quality trees were retained above the diameter limit, while an equal volume of lower quality trees was cut below the limit.

The stand in this example is at the upper limit suggested for sawtimber volume, and harvesting is traditionally done at or near this limit using the VGDL method. However, harvesting could be done when stocking is below this limit depending on stand conditions, timber markets, and landowner objectives if there is an operable harvest and stocking is not reduced below the lower limit.

Basal Area—Maximum Diameter—q (BDq) Method

Regulation by the BDq method of single-tree selection avoids some shortcomings of the VGDL method by allowing the objective control of the entire diameter distribution (Farrar 1984, Marquis 1978). After each cutting cycle, the target structure of the residual stand is defined by the BDq guidelines in the following priority: (1) the target basal area is retained, (2) trees larger than the **maximum diameter** (the largest d.b.h. retained in the stand) are cut unless needed to meet the target basal area, and (3) the residual d.b.h.-class distribution should approach the target q as closely as possible. Adjustments for deficit d.b.h. classes are made by retaining additional trees in surplus classes. The maximum diameter in the BDq method is similar to the guiding diameter limit of the VGDL method except that the maximum diameter refers to the residual stand, while the guiding diameter limit refers to the harvested trees.

Figure 2.2 shows how basal area, maximum diameter, and q are varied to control stand structure. Varying basal area while holding the other factors constant affects the number of trees in each d.b.h class and the stand total but does not affect the shape of the distribution (fig. 2.2). Thus, mean d.b.h. and percentage of the stand in the sawtimber component are not affected by changing the basal area. By contrast, maximum d.b.h. and q strongly affect the shape of the distribution. For example, increasing maximum d.b.h. while holding the other factors constant

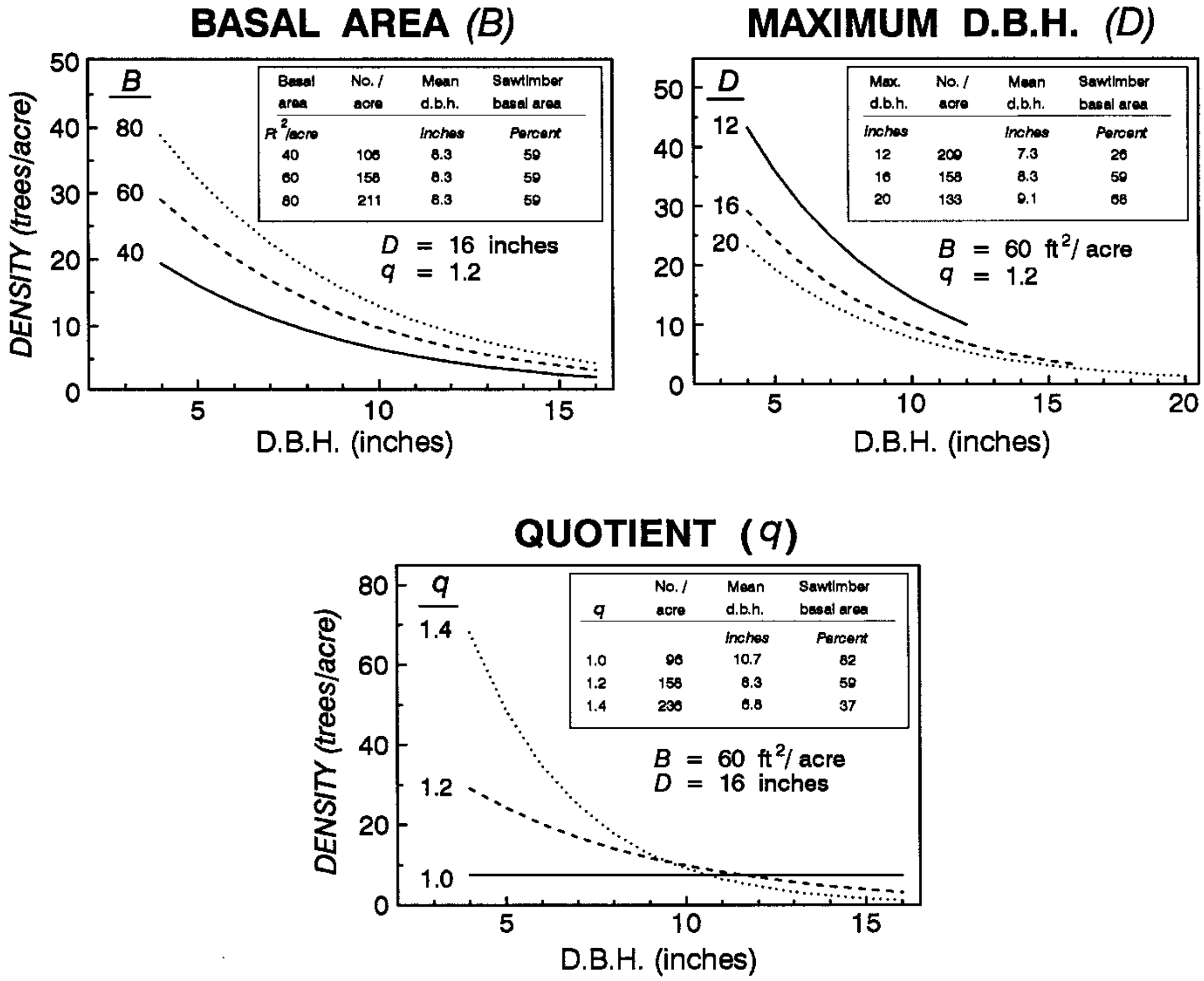

Figure 2.2. —*Effects of basal area, maximum d.b.h., and q on stand structure. In each illustration, the designated item varies, while the others remain constant. Mean d.b.h., is the quadratic mean; sawtimber basal area is for trees 10 inches and larger in d.b.h. and is expressed as a percentage of total merchantable basal area.*

results in: (1) flattening the d.b.h.-class distribution, (2) decreasing the number of trees, and (3) increasing the mean d.b.h. and percentage of the stand in sawtimber (fig. 2.2). Increasing the value of *q* while holding the other factors constant has the opposite effect as maximum d.b.h. and results in: (1) steepening the d.b.h.-class distribution, (2) increasing the number of trees, and (3) decreasing the mean d.b.h. and percentage of the stand in sawtimber (fig. 2.2).

Specific BD*q* targets are selected to meet landowner goals, timber markets, species requirements, and site conditions. The BD*q* method also imposes lower and upper limits for acceptable stocking, but limits are gauged by basal area rather than volume as with the VGDL method. Implementing the BD*q* method requires knowing the diameter distribution at the end of the cutting cycle and the expected basal area growth rates [see chapter 4]. The BD*q* method can also be combined with a tree-classification procedure to ensure the retention of high-quality, vigorous trees as future growing stock. Because the BD*q* method is featured in chapter 3, no example of its application is provided here.

The BD*q* method can be simplified by ignoring the *q* factor and basing regulation only on basal area and maximum diameter. This modification is called the **BD method**, and is similar to the VGDL method except that basal area is used for regulation rather than sawtimber volume. Data from a preharvest stand inventory are used to calculate the diameter limit that will leave the target basal area. This sets the maximum diameter to be retained in the stand. Using basal area for regulation has several advantages: (1) it includes both the pulpwood and sawtimber components, (2) no local volume table is needed,

(3) basal area may be more easily visualized when marking the stand than volume, and (4) stocking limits for basal area may apply to a wider range of site qualities than those for sawtimber volume. Although not widely tested, the BD method should produce an uneven-aged stand if a reasonable basal area is selected (for example, 45 to 60 ft^2/acre) and competing vegetation is periodically controlled. This method may be useful in situations such as: (1) the initial cutting in stands that have not been under uneven-aged silviculture and lack a balanced structure, and (2) where marking crews or landowners lack the technical skill or experience to apply more complicated methods of regulation in cutting only trees larger than the maximum diameter. The recommended alternative, however, is to consider the maximum diameter as a guide and cut individual trees based on their merits as with the VGDL method. A disadvantage of this simplified method is that yields may fluctuate because stand structure is not controlled.

An example of the BD method is shown in table 2.3. The preharvest basal area is 80 ft^2/acre and the target basal area in the residual stand is 60 ft^2/acre. Thus, the cut will be about 20 ft^2/acre. The maximum diameter is determined by starting with the largest d.b.h. class and accumulating the basal area in each smaller d.b.h. class. This approach shows that 20 ft^2/acre is reached about one-third of the way through the 16-inch class. Thus, cutting about one-third of the 16-inch trees and all of the larger trees would equal the allowable cut. In this example, however, some high-quality trees were retained above the maximum diameter, while an equal basal area of lower quality trees was cut below the limit.

Table 2.3.— *Example of the data and calculations needed to implement the Basal Area-Maximum Diameter (BD) regulation method (number of trees would be determined by inventory)*

		Preharvest basal area		Cut basal area	
D.b.h.	Number	By d.b.h. class	Cumulative*	Target	Actual
Inches	*Per acre*	*Ft^2/acre*			
4	14	1.2	80.0	0.0	0.0
5	18	2.4	78.8	0.0	0.0
6	19	3.7	76.4	0.0	0.0
7	17	4.5	72.7	0.0	0.0
8	14	4.9	68.2	0.0	0.0
9	11	4.9	63.3	0.0	0.0
10	9	4.9	58.4	0.0	0.0
11	8	5.3	53.5	0.0	0.7
12	7	5.5	48.2	0.0	0.0
13	6	5.5	42.7	0.0	1.8
14	6	6.4	37.2	0.0	0.0
15	5	6.1	30.8	0.0	0.0
16	5	7.0	24.7	2.8	1.4
17	4	6.3	17.7	6.3	4.7
18	3	5.3	11.4	5.3	5.3
19	2	3.9	6.1	3.9	3.9
20	1	2.2	2.2	2.2	2.2
Total	149	80.0	--	20.5	20.0

* Starting with the largest d.b.h. and accumulating the basal area in each smaller d.b.h. class.

Chapter 3

IMPLEMENTING UNEVEN-AGED SILVICULTURE

Uneven-aged silviculture can be used to develop and maintain uneven-aged stands of loblolly and shortleaf pines, and it can be implemented in pine stands of various stockings and structures. Options for implementing or sustaining uneven-aged silviculture are determined by the existing basal areas within the stand (fig. 3.1). Uneven-aged silviculture is commonly used in: (1) well-stocked stands with uneven-aged structure, (2) well-stocked stands with even-aged structure, and (3) understocked stands that have at least two size or product classes (Baker 1986, 1991; Reynolds and others 1984). How to implement uneven-aged silviculture for each of these three stand conditions will be discussed. First though, it must be decided whether to use the single-tree or group-selection reproduction cutting method because some silvicultural techniques depend on which cutting method is used.

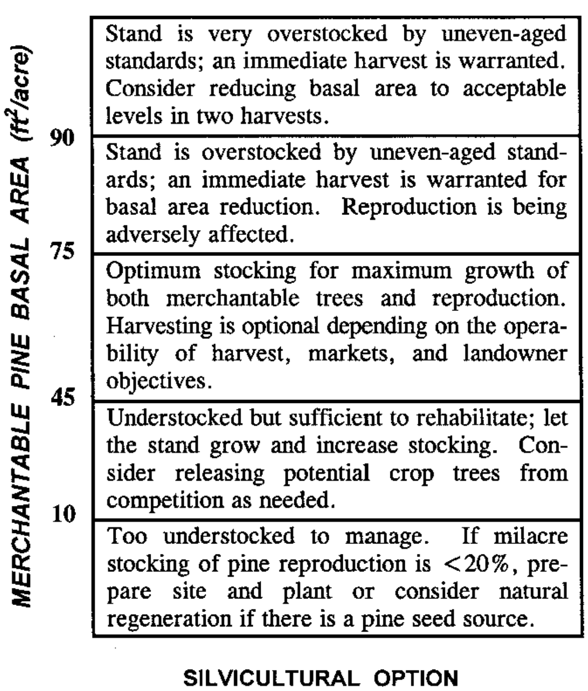

Figure 3.1.—*Silvicultural options to create or sustain uneven-aged stands based on basal area of the merchantable component.*

Each of the uneven-aged reproduction cutting methods has its strengths and weaknesses, as described in chapter 2. Single-tree selection is probably the preferred method for most stand and site conditions. It has been developed and used more extensively, both through research and industrial application in the loblolly-shortleaf pine types, than has the other method. However, group selection may be particularly useful for such stand and site conditions as: (1) uniform, well-stocked, even-aged stands that are being converted to uneven-aged structure, (2) pine-hardwood stands where a hardwood overstory is to be retained in portions of the stand [see chapter 5], and (3) highly productive, moist sites where competing hardwoods and herbaceous vegetation are vigorous. Under these conditions, group-selection cutting and appropriate site preparation would help ensure the establishment and development of pine reproduction.

Well-Stocked Stands with Uneven-Aged Structure

If a stand is well stocked (45 to 75 ft^2/acre of basal area in merchantable-size trees of good quality [see table 2.1] and has uneven-aged structure (at least three distinct size or product classes), uneven-aged silviculture using the single-tree selection method can perpetuate the stand while producing merchantable products from periodic harvests. The treatments recommended include: (1) inventorying the stand, (2) regulating stand structure, (3) establishing a cutting cycle, (4) marking trees for harvest, (5) establishing and evaluating reproduction, and (6) controlling competing vegetation (Baker 1991, Farrar 1981, Reynolds and others 1984).

Inventorying the Stand

An objective of uneven-aged silviculture is to modify the distribution of trees in a stand to conform to a specified structure. Good stand structure is maintained by harvesting the excess trees in diameter or product classes that do not have good growth or form. Thus, before the stand is harvested, it is important to know the density, size, volume, quality, and distribution of the trees.

The first step is to generate a stand-and-stock table for the merchantable component of the stand. Standard inventory methods, if properly implemented, will generally yield this information. A 10-percent cruise, using either fixed-radius (e.g., 1/5-acre) plots or strips, should provide a good estimate of the number of merchantable-size trees by d.b.h. class. Trees may be tallied by 1- or 2-inch d.b.h. classes or even by product classes: seedlings, saplings (1 through 3 inches in d.b.h.), pulpwood (4 through 9 inches in d.b.h.), small sawtimber (10 through 15 inches in d.b.h.), medium sawtimber (16 through 21 inches in d.b.h.), and large sawtimber (22 inches in d.b.h. and larger). The use of 2-inch d.b.h. classes or product classes often increases the productivity of the inventory and marking crews. A prism cruise could also be used, although a prism under-samples small trees. Sample stand inventory and summary forms (A-1 and A-2) are provided in the appendix.

Simulated inventory data from a hypothetical, 40-acre, well-stocked and well-structured stand (Compartment A, Stand 1) are presented in figures 3.2 and 3.3. Once the inventory is completed and summarized, a stand-and-stock table is prepared (table 3.1) using the total number of trees per acre for each d.b.h. class provided in the inventory summary (fig. 3.3). The stock table can be developed by assigning volumes to trees in the respective d.b.h. classes. A local volume table or a volume equation is sufficiently accurate to obtain the tree volumes. Volumes are needed at this time to ensure that an operable cut exists. More precise volumes for timber-sale purposes will be obtained when the stand is marked.

Table 3.1.—*Stand-and-stock table for hypothetical stand (Compartment A, Stand 1) derived from inventory data in figure 3.2 (tree volumes determined from a local volume table)*

D.b.h.	Trees per acre	Basal area	Volume	
Inches	*Number*	*Ft²/acre*	*Ft³/acre*	*Fbm/acre*
4	30	2.6	15	0
5	20	2.7	35	0
6	18	3.5	61	0
7	16	4.3	87	0
8	14	4.9	110	0
9	12	5.3	129	0
10	10	5.4	141	281
11	8	5.3	143	318
12	7	5.5	154	392
13	6	5.5	160	463
14	5	5.4	159	514
15	4	4.9	149	533
16	4	5.6	173	673
17	3	4.7	148	624
18	3	5.3	168	758
19	2	3.9	126	604
20	1	2.2	71	356
21	0	0.0	0	0
22	0	0.0	0	0
23	0	0.0	0	0
24	1	3.1	102	618
Total	164	80.1	2131	6134

Note that the columns for recording the number of trees by d.b.h. classes on both the inventory and inventory summary forms (figs. 3.2 and 3.3) are divided into three tree retention/harvest classes—growers, thinners, and cutters. Figure 3.4 illustrates some tree quality, form, and vigor characteristics associated with each class.

Growers are trees of good quality, form, and vigor that are growing at an acceptable rate and that do not exceed the prescribed maximum tree diameter. Growers should be left in a stand as crop trees for future harvest. **Cutters** are trees (1) of poor quality, form, or vigor or that are growing at an unacceptable rate; or (2) not expected to survive through the next cutting cycle; or (3) competing with a higher quality tree; or (4) exceeding the maximum diameter prescribed in the management objectives and are not needed to maintain the prescribed basal area. As many cutters as possible should be harvested during the next cyclic cut without reducing the prescribed residual basal area. **Thinners** are trees that do not meet the grower or cutter criteria. These trees could either be cut in the next cycle or left in the stand for future harvest. Most of the trees marked are in this class.

The tree classifications described above are flexible because of various degrees of quality, form, vigor, and competitiveness. For example, a poor-quality tree (damaged top) that is competing with a good-quality tree may be classified as a cutter; the same tree growing in the open and not competing with a grower may be classified as a thinner. Likewise, a tree with severe crook or sweep may be classified as a cutter whether it is competing with a better tree or not, whereas a tree with a slight crook or sweep would only be classified as a cutter if it were competing with a better tree.

It is also important to understand that growers and thinners can change in classification over time. Growers can become thinners or cutters, and thinners can become growers or cutters. Classifying the trees during the inventory process yields important information about the quality of the stand and provides a basis for marking (and harvesting) the stand to ensure improved growth and quality in the future.

Ideally, stands should be inventoried toward the end of each cutting cycle. However, for well-stocked and well-structured stands inventoried before the previous harvest, growth-and-yield models may be used to project stand development at the end of a future cutting cycle [see chapter 4] (Farrar and others 1984b; Murphy and Farrar 1982, 1988). This approach should be used, however, for only one or two cutting cycles, after which the stand should be reinventoried and trees marked for harvest according to current data.

Part of the inventory process is to map the forest types and stocking levels of the stand (fig. 3.5). Alternatively, if the stand is examined before the inventory, observations about the distribution of forest types and stocking can be recorded then. The stand map will be useful when marking trees for harvest because size classes and stocking levels will probably not be distributed uniformly across the tract. Stand maps enable timber markers to distribute more of the

STAND INVENTORY WITH TREE CLASSIFICATION

Location _Compartment A, Stand 1_ Acres _40_ Date _5/11/94_

Prism Factor/Plot Area _1/5-acre_ Crew _JBB, MGS, MDC_

POINT/PLOT NUMBER _1_ OF _20_

D.b.h. (inches)	PINE			HARDWOODS
	GROWERS	THINNERS	CUTTERS	
4	:. 3	: 2	. 1	0
5	: 2	. 1	. 1	0
6	: 2	: 2	0	: 2
7	: 2	. 1	. 1	0
8	: 2	0	. 1	. 1
9	:. 3	. 1	0	0
10	0	. 1	: 2	0
11	: 2	: 2	. 1	:. 3
12	. 1	:. 3	0	0
13	: 2	0	. 1	. 1
14	. 1	: 2	. 1	0
15	:. 3	. 1	0	0
16	. 1	0	: 2	0
17	0	:. 3	: 2	0
18	: 2	. 1	0	0
19	. 1	0	0	0
20	0	. 1	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	. 1	0

Figure 3.2.—*Completed stand inventory form for a plot taken in a hypothetical stand.*

STAND INVENTORY WITH TREE CLASSIFICATION

Stand Inventory (Summary of pine stems per acre)

Stand location Compartment A, Stand 1 Date 5/11/94

D.b.h. (inches)	GROWERS	THINNERS	CUTTERS	TOTAL	% CUTTERS
Seedlings 1 ft - 0.5 in	--	--	--	53	--
Saplings 1 - 3 in	--	--	--	42	--
4	15	13	2	30	
5	10	8	2	20	
6	9	9	0	18	9
7	8	6	2	16	
8	7	5	2	14	
9	8	3	1	12	
10	7	2	1	10	
11	5	3	0	8	
12	2	2	3	7	22
13	1	3	2	6	
14	2	2	1	5	
15	2	0	2	4	
16	3	0	1	4	
17	1	1	1	3	
18	2	1	0	3	15
19	1	1	0	2	
20	0	1	0	1	
21	0	0	0	0	
22	0	0	0	0	
23	0	0	0	0	100
24	0	0	1	1	

Figure 3.3.—*Completed stand inventory summary form for a hypothetical stand (twenty 1/5-acre plots taken in a 40-acre stand).*

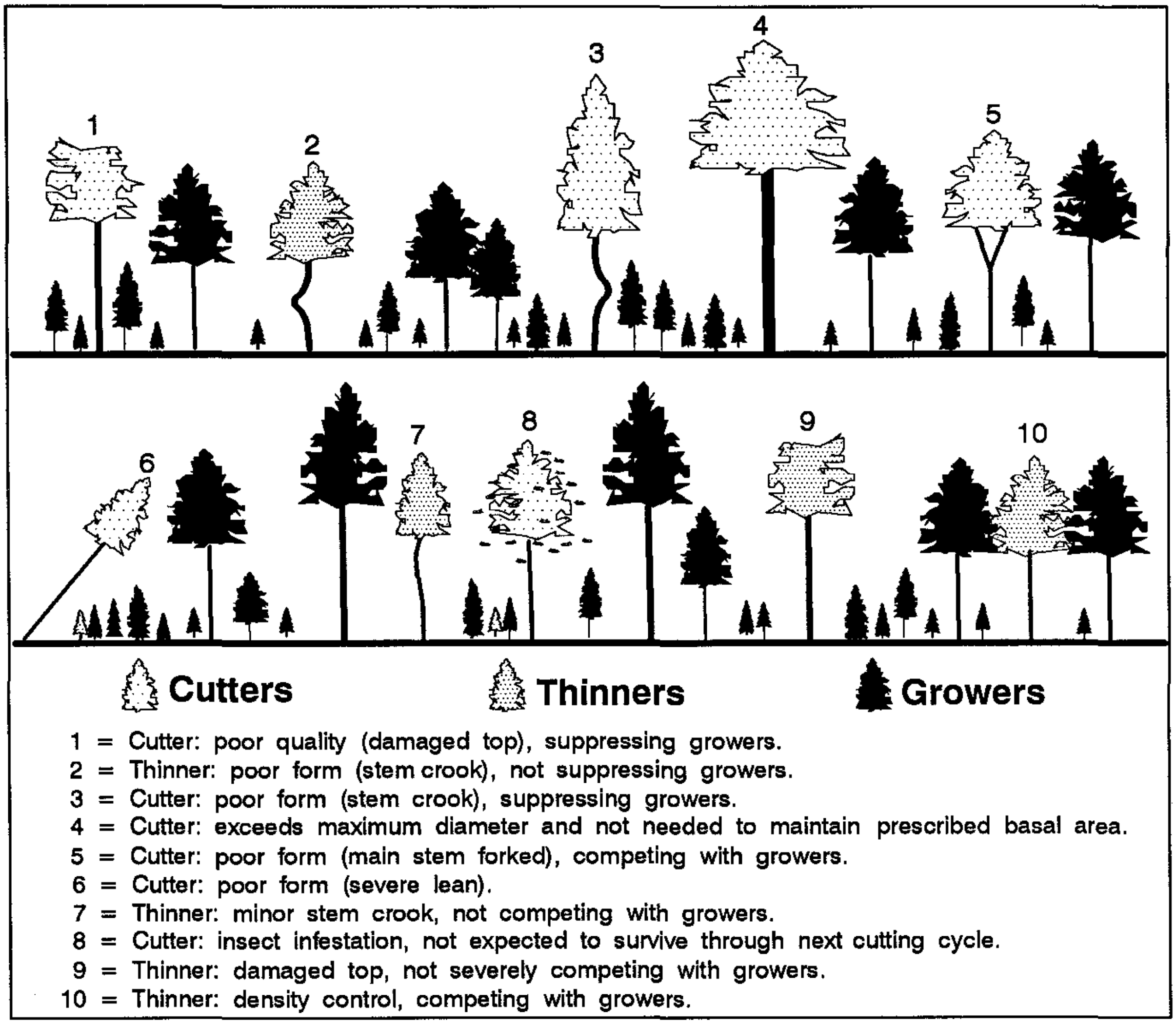

Figure 3.4.— *Characteristic pine tree classes based on retention or harvest criteria.*

allowable cut in areas heavily stocked with various size or product classes. For example, the hypothetical stand (fig. 3.5) has more basal area in its eastern half (type I) than in the western half (types II and III). Thus, using the map, the markers would know to mark heavily in the type I area and lightly in the type II and III areas of the stand.

Regulating Stand Structure

Once the stand has been inventoried and the data summarized in a stand-and-stock table (table 3.1), decisions must be made about regulating stand structure. Two techniques are discussed in chapter 2: (1) the VGDL method (described in detail by Farrar 1984, Reynolds 1959, and Reynolds and others 1984) and (2) the BD*q* method (Farrar 1981, 1984). Because the BD*q* method uses an objective approach and can employ a computer program for developing a target stand structure and marking guidelines, it is the recommended technique and will be used to develop the hypothetical examples throughout this chapter.

With the BD*q* method, stand structure is determined by the target residual (after-cut) basal area (*B*), the maximum d.b.h. to be retained (*D*), and the *q*-ratio. Recommended ranges of these three variables are: *B* (45 to 60 ft^2/acre), *D* (12 to 30+ inches), and *q* (1.1 to 1.4 for 1-inch d.b.h. classes; 1.2 to 2.0 for 2-inch d.b.h. classes). The range for residual basal area (*B*) encompasses the stocking levels that provide good sawtimber growth while allowing reproduction to develop in the understory. The range of maximum d.b.h. (*D*) is set to allow for good seed production (minimum *D* of 12 inches) and to provide flexibility in developing large or old trees as needed. The range of *q* is set to allow flexibility in stand structure.

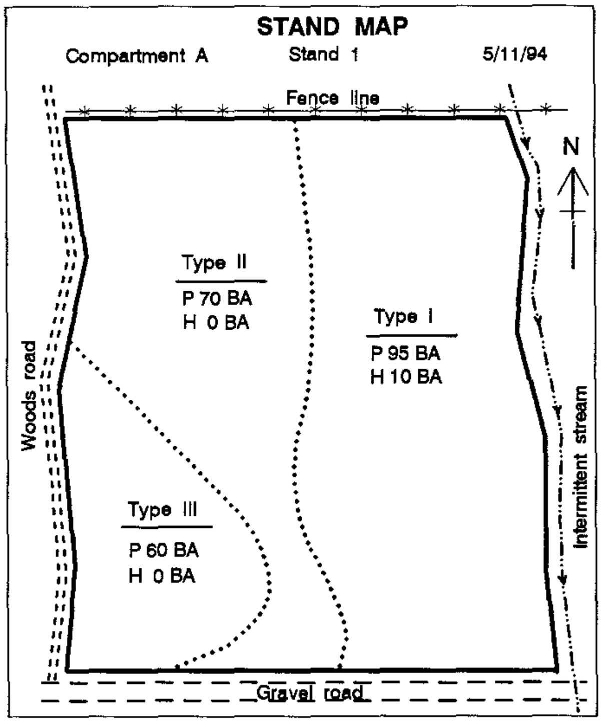

Figure 3.5.— *Map of hypothetical stand (Compartment A, Stand 1) illustrating basal area (BA) stocking for pine (P) and hardwood (H) in square feet per acre.*

A computer software program[2] calculates a "target" stand structure for specified combinations of *B*'s, *D*'s, and *q*'s. The program also calculates and displays numbers of trees and their basal areas in each d.b.h. class before harvest (based on the inventory data). It also displays the number of trees and basal area to be harvested from each d.b.h. class that will best approximate the target structure. An example of the computer output generated by running the program (using inventory data from table 3.1) is presented in table 3.2. Table 3.3 is this information expanded to produce a stand-and-stock table.

The computer output can be further summarized by delineating product classes; i.e.; pulpwood (4 through 9 inches in d.b.h.), small sawlogs (10 through 15 inches in d.b.h.), medium sawlogs (16 through 21 inches in d.b.h.), and large sawlogs (22 inches in d.b.h. and larger). By summing the numbers of trees to be cut for each product class, marking guides can be prepared to mark and cut the stand to a prescribed structure (table 3.4). This procedure should be followed after each cutting cycle to determine a marking prescription for the next cutting cycle.

[2] King, Bettina; Murphy, Paul A. 1993. TARGET: A program for calculating target stand structure and marking guides for uneven-aged loblolly-shortleaf pine stands on medium and good sites. Available by writing USDA Forest Service, P.O. Box 3516, Monticello, AR 71656, or calling (501) 367-3464.

Establishing the Cutting Cycle

For uneven-aged stands of loblolly and shortleaf pines on good sites (site index [S.I.] = >85 ft at 50 years), cutting cycles can range from 3 to 10 years. On poor sites (S.I. = <65 ft at 50 years), cutting cycles can range from 8 to 20 years.

Cutting-cycle length depends primarily on residual growing stock (immediately following a cyclic cut), site productivity or growth rate of the residual trees, and the minimum operable cut. The length of the cutting cycle is established (1) to maintain stocking within the prescribed limits (45 to 75 ft^2/acre of basal area) and (2) to provide an operable cut (approximately 1,200 fbm/acre at the end of the cutting cycle). For example, a well-stocked and well-structured uneven-aged stand on a good site will grow about 3 ft^2/acre/yr in basal area or about 400 fbm/acre/yr in sawlog volume. If the target residual basal area is 60 ft^2, then the cutting cycle should not exceed 5 years to keep the preharvest basal area from exceeding 75 ft^2 (i.e., 3 ft^2 x 5 years = 15 ft^2 + 60 ft^2 residual basal area = 75 ft^2). If a residual basal area of 45 ft^2 were left, then the cutting cycle could be extended to 10 years (i.e., 3 ft^2 x 10 years = 30 ft^2 + 45 ft^2 residual basal area = 75 ft^2). However, the cutting cycle could also be set as low as 3 years because at a growth rate of 400 fbm/acre/yr, 1,200 fbm (an operable cut) could be harvested in 3 years.

On poor sites, a well-managed, uneven-aged stand will grow about 1.5 ft^2 of basal area or about 150 fbm/acre/yr. Thus, cutting cycles could range from 8 to 20 years—8 years yielding a minimal operable cut of 1,200 fbm and 20 years providing a maximum basal area stocking of 75 ft^2.

Adopting the shortest cutting cycle that will ensure an operable cut offers the most opportunities for seedling establishment following logging disturbance. In areas where pine seeds are produced infrequently, this may be a valuable advantage. Cutting cycles can be flexible if they stay within the constraints of operable cuts and acceptable stocking.

Marking Trees for Harvest

Three steps are involved in marking uneven-aged stands for harvest under single-tree selection: (1) determine the allowable cut using either the VGDL method or the BD*q* method, (2) determine the kinds of trees to be marked to cut, and (3) mark the trees for harvest.

Allowable cut.—In uneven-aged stands, the allowable cut is the forester's estimate of the trees that can be removed to allow optimal development of the stand (Reynolds and others 1984). Under the BD*q* method, subtracting the target structure volume from the existing stand volume gives an allowable cut by diameter classes, product classes, or for the total stand.

For example, table 3.3 shows that the current volume of the stand is 6,134 fbm/acre and that a BD*q* target structure for a 5-year cutting cycle has a volume of 4,409

Table 3.2.— *Sample output (on a per-acre basis) for hypothetical, uneven-aged stand (Compartment A, Stand 1) generated by the* ***TARGET*** *computer program using stand inventory data from table 3.1 and the following stand structure parameters: Residual Basal Area (BA) = 60 ft²/acre; Maximum Diameter (D) = 21 inches;* q *value = 1.2*

D.b.h.	Target Number	Target BA	Before-cut Number	Before-cut BA	Cut Number	Cut BA	After-cut Number	After-cut BA
Inches		*Ft²*		*Ft²*		*Ft²*		*Ft²*
4	22.2	1.9	30.0	2.6	6.7	0.6	23.3	2.0
5	18.5	2.5	20.0	2.7	1.3	0.2	18.7	2.5
6	15.4	3.0	18.0	3.5	2.2	0.4	15.8	3.1
7	12.9	3.4	16.0	4.3	2.7	0.7	13.3	3.6
8	10.7	3.7	14.0	4.9	2.8	1.0	11.2	3.9
9	8.9	4.0	12.0	5.3	2.6	1.2	9.4	4.1
10	7.4	4.1	10.0	5.4	2.2	1.2	7.8	4.2
11	6.2	4.1	8.0	5.3	1.5	1.0	6.5	4.3
12	5.2	4.1	7.0	5.5	1.6	1.2	5.4	4.3
13	4.3	4.0	6.0	5.5	1.4	1.3	4.6	4.2
14	3.6	3.8	5.0	5.4	1.2	1.3	3.8	4.1
15	3.0	3.7	4.0	4.9	0.9	1.1	3.1	3.8
16	2.5	3.5	4.0	5.6	1.3	1.8	2.7	3.8
17	2.1	3.3	3.0	4.7	0.8	1.2	2.2	3.5
18	1.7	3.1	3.0	5.3	1.1	1.9	1.9	3.4
19	1.4	2.8	2.0	3.9	0.5	0.9	1.5	3.0
20	1.2	2.6	1.0	2.2	0.0	0.0	1.0	2.2
21	1.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	1.0	3.1	1.0	3.1	0.0	0.0
Total	128.2	60.0	164.0	80.1	31.8	20.1	132.2	60.0

fbm/acre. Thus, cutting the stand to the target structure would yield 1,981 fbm/acre. All trees larger than 20 inches in d.b.h. would be harvested, as well as those representing the differences between the target and the current stand in each size or product class (table 3.3 and fig. 3.6). If a particular size or product class in the current stand had fewer trees than the target stand, no trees would be marked in that class. After experience is gained, determining the allowable cut may become more of a silvicultural decision guided by tree classification with stand structure being a secondary consideration.

The marking prescription for the sample stand is shown in table 3.4. To achieve the prescribed stand structure, one-sixth of the pulpwood-size trees, one-fourth of the small sawlog-size trees, one-third of the medium sawlog-size trees, and all of the large sawlog-size trees should be harvested. Care should be taken to minimize damage to residual trees during logging. In some cases, such as on steep slopes or where large logging equipment is used, a few additional trees (2 to 3 ft²/acre of basal area) in the pulpwood and small sawlog classes could be left to offset mortality from logging damage.

Kinds of trees to be marked.—Two main silvicultural goals guide the choice of trees to be marked. The first goal is to create openings for pine reproduction by harvesting the trees larger than the prescribed maximum d.b.h. The second goal is to improve the overall quality of the residual stand by applying intermediate treatments (thinnings, improvement cuttings, release cuttings, etc.) to the trees smaller than the prescribed maximum d.b.h. (Reynolds and others 1984).

The quality of individual trees and their potential for future growth should be carefully evaluated when marking the stand. The basic principle is to retain the best trees in the stand until they exceed the prescribed maximum d.b.h. Trees of good form and vigor ("growers") and those that show evidence of past cone production should be retained; trees of poor form—those having sweep, crook, excessive branchiness, and other undesirable physical characteristics—and trees having poor vigor or those that are diseased or infested with insects ("cutters") should be harvested. If other factors are equal, trees retained should be uniformly spaced within similar diameter or product classes.

Figure 3.7 is an example of a completed tally form recording trees marked for a cyclic cut with instructions for marking the four product classes taken from table 3.4. A sample tally form (A-3) is provided in the appendix. The sample tally form can be modified to accommodate 1-inch d.b.h.

Table 3.3.—*Stand-and-stock table (on a per-acre basis) for hypothetical stand (Compartment A, Stand 1) derived from inventory data and TARGET computer program (tree volumes determined from a local volume table)*

D.b.h.	Target stand				Before-cut stand				Cut				After-cut stand			
	No. trees	BA	Volume		No. trees	BA	Volume		No. trees	BA	Volume		No. trees	BA	Volume	
Inches		*Ft*^{2}	*Ft*^{3}	*Fbm*		*Ft*^{2}	*Ft*^{3}	*Fbm*		*Ft*^{2}	*Ft*^{3}	*Fbm*		*Ft*^{2}	*Ft*^{3}	*Fbm*
4	22.2	1.9	11	0	30.0	2.6	15	0	6.7	0.6	3	0	23.3	2.0	12	0
5	18.5	2.5	33	0	20.0	2.7	35	0	1.3	0.2	2	0	18.7	2.5	33	0
6	15.4	3.0	53	0	18.0	3.5	61	0	2.2	0.4	8	0	15.8	3.1	53	0
7	12.9	3.4	70	0	16.0	4.3	87	0	2.7	0.7	15	0	13.3	3.6	72	0
8	10.7	3.7	85	0	14.0	4.9	110	0	2.8	1.0	22	0	11.2	3.9	88	0
9	8.9	4.0	96	0	12.0	5.3	129	0	2.6	1.2	28	0	9.4	4.1	101	0
10	7.4	4.1	105	209	10.0	5.4	141	281	2.2	1.2	31	62	7.8	4.2	110	219
11	6.2	4.1	110	246	8.0	5.3	143	318	1.5	1.0	27	61	6.5	4.3	116	257
12	5.2	4.1	114	290	7.0	5.5	154	392	1.6	1.2	35	88	5.4	4.3	119	304
13	4.3	4.0	115	332	6.0	5.5	160	463	1.4	1.3	39	112	4.6	4.2	121	351
14	3.6	3.8	114	369	5.0	5.4	159	514	1.2	1.3	38	124	3.8	4.1	121	390
15	3.0	3.7	111	398	4.0	4.9	149	533	0.9	1.1	32	115	3.1	3.8	117	418
16	2.5	3.5	107	419	4.0	5.6	173	673	1.3	1.8	56	217	2.7	3.8	117	456
17	2.1	3.3	103	433	3.0	4.7	148	624	0.8	1.2	39	164	2.2	3.5	109	460
18	1.7	3.1	97	437	3.0	5.3	168	758	1.1	1.9	61	275	1.9	3.4	107	483
19	1.4	2.8	91	435	2.0	3.9	126	604	0.5	0.9	30	145	1.5	3.0	96	459
20	1.2	2.6	85	427	1.0	2.2	71	356	0.0	0.0	0	0	1.0	2.2	71	356
21	1.0	2.4	78	414	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
22	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
23	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
24	0.0	0.0	0	0	1.0	3.1	102	618	1.0	3.1	102	618	0.0	0.0	0	0
Total	128.2	60.0	1,578	4,409	164.0	80.1	2,131	6,134	31.8	20.1	568	1,981	132.2	60.0	1,563	4,153

Table 3.4. —*Prescribed marking tally (on a per-acre basis) for hypothetical stand (Compartment A, Stand 1) with the following stand structure parameters: Residual Basal Area (BA) = 60 ft^2/acre; Maximum Diameter (D) = 21 inches;* q *value = 1.2*

	Target		Before-cut			Cut			After-cut	
D.b.h.	No. trees	BA	No. trees		BA	No. trees		BA	No. trees	BA
Inches		Ft^2			Ft^2			Ft^2		Ft^2
4	22.2	1.9	30.0		2.6	6.7		0.6	23.3	2.0
5	18.5	2.5	20.0		2.7	1.3	**<u>Pulpwood</u>**	0.2	18.7	2.5
6	15.4	3.0	18.0	**Total 110**	3.5	2.2	**Cut 18 of 110 trees/acre, or**	0.4	15.8	3.1
7	12.9	3.4	16.0		4.3	2.7	**1 tree in 6**	0.7	13.3	3.6
8	10.7	3.7	14.0		4.9	2.8		1.0	11.2	3.9
9	8.9	4.0	12.0		5.3	2.6		1.2	9.4	4.1
10	7.4	4.1	10.0		5.4	2.2		1.2	7.8	4.2
11	6.2	4.1	8.0		5.3	1.5	**<u>Sm. Sawtimber</u>**	1.0	6.5	4.3
12	5.2	4.1	7.0	**Total 40**	5.5	1.6	**Cut 9 of 40 trees/acre, or**	1.2	5.4	4.3
13	4.3	4.0	6.0		5.5	1.4	**1 tree in 4**	1.3	4.6	4.2
14	3.6	3.8	5.0		5.4	1.2		1.3	3.8	4.1
15	3.0	3.7	4.0		4.9	0.9		1.1	3.1	3.8
16	2.5	3.5	4.0		5.6	1.3		1.8	2.7	3.8
17	2.1	3.3	3.0		4.7	0.8	**<u>Med. Sawtimber</u>**	1.2	2.2	3.5
18	1.7	3.1	3.0	**Total 13**	5.3	1.1	**Cut 4 of 13 trees/acre, or**	1.9	1.9	3.4
19	1.4	2.8	2.0		3.9	0.5	**1 tree in 3**	0.9	1.5	3.0
20	1.2	2.6	1.0		2.2	0.0		0.0	1.0	2.2
21	1.0	2.4	0.0		0.0	0.0		0.0	0.0	0.0
22	0.0	0.0	0.0		0.0	0.0	**<u>Lg. Sawtimber</u>**	0.0	0.0	0.0
23	0.0	0.0	0.0	**Total 1**	0.0	0.0	**Cut all trees**	0.0	0.0	0.0
24	0.0	0.0	1.0		3.1	1.0		3.1	0.0	0.0
Total	128.2	60.0	164.0		80.1	31.8		20.1	132.2	60.0

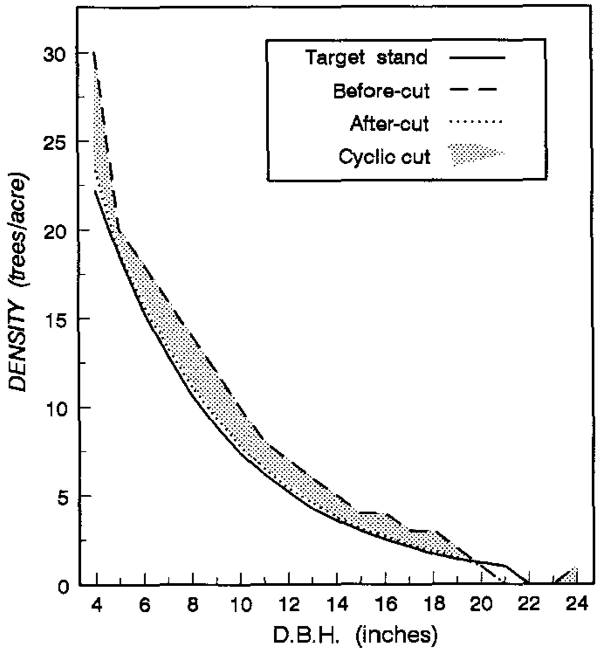

Figure 3.6.—*Target, before-cut, and after-cut stand and cyclic cut.*

classes or the use of a local volume table that disregards merchantable height or log height.

Until experience is gained, the following procedure will guide the marking of trees for harvest in uneven-aged stands. First, subdivide the allowable cut and the stand into four more-or-less equal units. Then, in the first quarter, mark one-quarter of the total allowable cut, keeping a tally of the trees marked. After the first quarter has been marked, check the tally against the prescribed marking intensity. If the marking has been too light, increase marking intensity in the appropriate size classes in the next quarter; if the marking has been too heavy, decrease the marking intensity in the heavily marked classes in the next quarter. The stand map showing areas of heavy stocking can be used to help decide where to mark lightly or heavily in particular size classes.

Establishing and Evaluating Reproduction

If uneven-aged loblolly-shortleaf pine stands with adequate seed crops are maintained within acceptable stocking levels (table 2.1), and if cyclic cuts are made and competition is controlled periodically, then pine seedlings should become established and develop. The reproduction may appear uniformly over the stand, particularly following an above-average or bumper seed crop or, more typically, in patches or small groups within the stand. Depending on seedbed conditions, pine seed crops, and severity of understory competition, pine reproduction can "trickle in" over several years after a harvest. Patience is required in obtaining and developing reproduction. Pine seedlings and saplings, growing in partial shade of a pine overstory, will not develop as rapidly as those growing in full sunlight. Thus, the development of the reproduction will be slow until it is released by removing some overtopping pines in the overstory.

The need for evaluating the establishment and development of reproduction depends on stand and site conditions and the experience of the forester. In locations where reproduction is easily obtained and develops rapidly, the need for frequent evaluations is not great. But, where reproduction is difficult to obtain and development is slow (because of infrequent seed crops or severe competition), more attention is needed.

The density and vigor of reproduction should be evaluated each time the stand is inventoried. If the pine reproduction is inadequate (<200 well-distributed stems per acre), or if the reproduction is not growing at least 6 inches in height per year (Chapman 1945, Wahlenberg 1960), additional site disturbance and/or vegetation treatments may be needed.

Research on Upper Coastal Plain sites has shown that natural loblolly and shortleaf pine reproduction tends to be greatest in uneven-aged stands when: (1) overstory/midstory hardwoods and/or understory vegetation are controlled (Cain 1991b, 1992, 1993b), (2) the seedbed is disturbed by logging during the cyclic cuts (Cain 1987, 1988, 1994), and (3) there are better-than-average pine seed crops (>100,000 potentially viable seeds per acre) (Cain 1991c, 1993b).

Pine reproduction in the understory can be evaluated by tallying well-established pine seedlings and/or saplings on a minimum of 100 uniformly spaced, milacre plots in the stand. If group selection is being used, the plots should be located in the group openings rather than uniformly throughout the stand. The pine reproduction should also be evaluated in terms of its "free-to-grow" status and the coverage of competing (nonpine) vegetation. A sample evaluation form (A-4) is provided in the appendix. For evaluation purposes, reproduction can be classified as either adequate (>200 well-distributed stems per acre or >20 percent milacre stocking) or inadequate (<200 stems per acre or <20 percent milacre stocking).

Controlling Competing Vegetation

Vegetation management or competition control in uneven-aged stands serves two purposes: (1) as a site-preparation tool it promotes the early establishment and growth of pine reproduction (Cain 1988, 1992) and (2) as a pine-release tool it aids in the survival and intermediate development of pine seedlings and saplings (Cain 1991a, 1991b, 1993a).

With single-tree selection, periodic control of competing vegetation (usually in conjunction with a harvest cut) across the entire stand is recommended and serves both these purposes. With group selection however, competition control may be needed only in the group openings or regeneration areas. Two distinct treatments are often used with

UNEVEN-AGED PINE MARKING TALLY

Stand location Compartment A, Stand 1 Acres 40 Crew JBB,MGS,MDC Date 5/18/94

PULPWOOD (MERCHANTABLE HEIGHT IN FEET)											
D.b.h.	10	15	20	25	30	35	40	45	50	55	60
4	⊠⊠⊠::	⊠⊠⊠:.	⊠⊠⊠⊠:	⊠⊠⊠⊠.	⊠⊠⊠⊠:	⊠⊠⊠⊔	⊠⊠⊠⊔	:.			
5		⊠.	⊠:	⊠.	⊔	:	:.	:	.		
6		⊠:.	⊠⊠.	⊠:	⊠:	⊠:.	□	:⁝	:	.	.
7			⊠:.	⊠⊠:	⊠⊠:	⊠:	⊠.	⊠:	⊠:⁝	.	
8			:.	⊠⊠:.	⊠:⁝	⊠⊠⊠.	⊠⊠	⊠	⊠		
9			.	⊠.	⊠:	⊠.	⊠□	⊠	⊠⊠	⊠.	⊠

SAWTIMBER (16-FOOT LOG HEIGHT)							
D.b.h.	1	1½	2	2½	3	3½	4
10	⊠⊠⊠:⁝	⊠⊠⊠:	⊠⊠:				
11	⊠:.	⊠⊠:⁝	⊠⊠:				
12	:⁝	⊠⊠⊠:⁝	⊠⊠:.	:			
13	:	⊠⊠:⁝	⊠⊠:.	⊔			
14		⊠⊠:	⊠:⁝	⊠:.			
15		⊠:	⊠⊔	□			
16		.	⊠:	⊠⊠:⁝	⊠::		
17			⊠:	⊠⊠::	⊠::		
18			⊠:	⊠⊠.	⊠.		
19				⊠:	□		
20			.	:.	:		
21				:.		:.	
22			.	:.	:⁝	:.	:.
23			.	.	:	:.	:
24				.	:	::	::

PULPWOOD:
Target No. 720
Marking Ratio
720:4400 or 1:6
(cut:total)

Instruction:
9% (410) of the 4400 trees are cutters, thus about ½ of trees marked should be cutters.

SMALL SAWLOGS:
Target No. 360
Marking Ratio
360:1600 or 1:4
(cut:total)

Instruction:
22% (352) of the 1600 trees are cutters, thus all trees marked should be cutters.

MEDIUM SAWLOGS:
Target No. 160
Marking Ratio
160:520 or 1:3
(cut:total)

Instruction:
15% (78) of the 520 trees are cutters, thus about ½ of trees marked should be cutters.

LARGE SAWLOGS:
Target No. 40
Marking Ratio
40:40 or 1:1
(cut:total)

Instructions:
Cut all trees.

Figure 3.7. —*Completed tally form for marking the hypothetical stand.*

group selection—site preparation in the group openings shortly after the harvest and pine release 3 to 5 years later.

Because loblolly and shortleaf pines are shade intolerant, adequate light (approximately 50 percent of full sunlight) must reach pine reproduction for survival and growth (Baker and Guldin 1991, Baker and Langdon 1990). Excessive shading can be caused by a dense canopy of overstory, midstory, and/or understory vegetation. If seed production is adequate and if pine overstory basal area is maintained within acceptable levels (table 2.1, fig. 3.1) and if there is no shading from understory vegetation, then sufficient pine reproduction will survive and develop to perpetuate the stand.

To ensure that adequate sunlight reaches developing pine reproduction, periodic control of competing hardwoods and/or herbaceous vegetation is often required, especially on moist, productive sites. If the pine reproduction is receiving adequate light, most of the seedlings and saplings should exhibit good apical dominance, be vigorous in appearance, and be growing at least 6 inches in height per year. If pine reproduction is absent or does not have these characteristics, competition control is probably needed. Specific guides for competition control are based on estimates of competing ground cover and stocking of pine reproduction (fig. 3.8).

Free-to-grow pine reproduction* (Milacre stocking)	Competing vegetation† (percent ground cover)		
	Light (<40%)	Medium (40%-70%)	Heavy (>70%)
Light (<20%)	NO CONTROL	CONTROL	IMMEDIATE CONTROL
Medium (20%-50%)	NO CONTROL	POSTPONE CONTROL	CONTROL
Heavy (>50%)	NO CONTROL	NO CONTROL	NO CONTROL

*Milacre stocking = Number of milacres with at least one pine seedling (1 ft tall to 0.5 inch in d.b.h.) or sapling (0.6 inch to 3.5 inches in d.b.h.) divided by the total number of milacres.

†Percent ground cover is determined by ocular estimation.

Figure 3.8.—*Guide to competition control for pine reproduction in uneven-aged stands.*

Competing vegetation can be controlled by chemical or mechanical means. Prescribed winter fire may also be used in certain situations. For example, in shortleaf pine stands, reproduction will often sprout after being top-killed by fire; and in stands on poor sites where cutting cycles are long (10 to 15 years), reproduction may survive prescribed winter fire used toward the end of the cutting cycle. For most stand and site conditions however, dormant-season burning cannot be applied frequently enough or intensely enough to control competing vegetation.

Experience has shown that chemical control (using approved, selective herbicides every 10 to 20 years, depending on site productivity and the vigor and aggressiveness of the competing vegetation) is the most effective means of vegetation management in uneven-aged stands. Good sites (>85 site index [S.I.]) will require control more frequently than poor sites (<65 S.I.). Because of the open-canopy pattern of uneven-aged pine stands at recommended basal area levels (45 to 75 ft^2/acre), a ground cover of lush herbaceous vegetation (>70 percent) on good sites may prevent the establishment and growth of natural pine reproduction, even when pine seeds are abundant and hardwood competition is absent (Cain 1985, 1991b, 1992).

Table 3.5 lists some competing vegetation conditions typically encountered in uneven-aged stands and some management alternatives. For southern pines, specific recommendations for controlling competing vegetation are available in published references (Cantrell 1985, Miller and Mitchell 1988, Nelson and Cantrell 1991, Walstad and Kuch 1987).

Table 3.5.— *Typical competing vegetation conditions encountered in uneven-aged management and some control alternatives*

Competing vegetation	Management alternatives
Excessive (>10 ft^2/acre of basal area) overstory and/or midstory (>4 inches in d.b.h.) hardwoods.	Cut and sell if operable, or cut and leave, or inject with herbicide.
Dense hardwood understory (<4 inches in d.b.h.) with <200 free-to-grow pine seedlings and/or pine saplings per acre.	Release individual pines by mechanical or chemical removal of overtopping hardwoods, or apply a broadcast herbicide treatment.
Herbaceous vegetation and/or vines that prevent pine seedling or sapling development.	Apply a broadcast treatment with approved, selective herbicide.
Excessive hardwood basal area (>10 ft^2/acre) or vines in even-aged pine stands that are to be converted to uneven-aged structure.	Conduct at least three annual or biennial, prescribed, winter burns before the first basal-area reduction harvest, and cut residual hardwoods or inject with herbicide.

Well-Stocked Stands with Even-Aged Structure

On occasion, landowners or resource managers would like to convert even-aged stands to uneven-aged structure. This can be done by imposing either the single-tree selection or the group selection cutting method. With group selection, some openings would be created by harvesting all trees in part of the stand (generally 5 to 20 percent, depending on the cutting cycle). These openings would become the regeneration areas in which new age classes would be established over several cutting cycles [see chapter 5].

The difficulty and duration of the conversion process using single-tree selection depend on the initial stand condition and age. Uniform, well-stocked (basal area >90 ft^2/acre), old (>70 years of age) even-aged stands are generally more difficult and take longer to convert than irregular, younger (30- to 50-year-old) stands that have <80 ft^2/acre of basal area. To convert to uneven-aged structure using single-tree selection, the same six techniques explained in this chapter under "Well-Stocked Stands with Uneven-Aged Structure" should be followed with a few exceptions. Because the establishment of new age classes within the stand is essential to developing uneven-aged structure, the most critical element of the conversion process is the timely establishment and development of pine reproduction. To obtain new age classes, overstory pine basal area must be reduced and hardwood competition must be controlled.

Thus, establishing an appropriate residual basal area of high-quality, seed-producing pines is imperative, even at the expense of a desired maximum d.b.h. and q. Once several new age classes have become established over two or three cutting cycles, then greater attention can be paid to the stand structure.

Inventorying the Stand

The initial inventory of the even-aged stand is done primarily to determine the current stocking on which the initial basal-area reduction cut is based. Thus, the intensity or accuracy of the inventory is not as critical as with uneven-aged stands, as described earlier. As a minimum, about 20 prism points per 40 acres (using a 10-factor, basal-area prism) should be taken to determine average basal area of the stand. When this estimate is used, the stand can be marked to reduce the current basal area to 45 to 60 ft^2/acre, depending on cutting cycle length and basal-area growth rate of the stand. If the current basal area exceeds 95 ft^2/acre, two cuts may be required to prevent excessive mortality caused by a single, severe thinning. The first cut would reduce the basal area from 95+ to 75 ft^2/acre; 3 to 5 years later a second cut would reduce basal area to 45 to 60 ft^2/acre.

When marking the stand, remove all cutters, then thinners, and enough growers to achieve the prescribed basal area. The marking should favor an irregular spacing of trees. Most of the trees should be marked in the mid- to upper-d.b.h. sizes. It is not important to abide by a rigid maximum d.b.h. or q in the initial basal-area reduction cut; the important thing is to reduce overstory stocking and increase the amount of light reaching the forest floor sufficiently to promote the establishment and growth of pine seedlings. After two cyclic cuts, and after at least two new age classes have been established, a complete stand inventory should be conducted and BDq regulation imposed.

Developing Uneven-Aged Structure

The following hypothetical example describes the conversion of a typical even-aged pine stand to uneven-aged structure. The 50-year-old stand, growing on a medium site (S.I. = 70 ft at 50 years), is uniform and has an average basal area of 90 ft^2/acre (table 3.6 and fig. 3.9a). A stand having a residual basal area (B) of 55 ft^2/acre, a maximum tree diameter (D) of 21 inches, and a q factor of 1.2 is prescribed (tables 3.7 and 3.8). The cutting cycle is 10 years.

The first cut results in a residual basal area of 55 ft^2/acre after 35 ft^2 and 2,114 fbm/acre are removed (table 3.8 and fig. 3.9a). At an annual growth rate of 2 ft^2/acre in basal area and 200 fbm/acre in sawlog volume, in 10 years the stand has 75 ft^2/acre of basal area and 4,100 fbm/acre of sawlog volume (fig. 3.9b). In addition, a new age class of 10-year-old pine reproduction has been established.

Table 3.6.— *Stand-and-stock table (on a per-acre basis) for a typical, 50-year-old, even-aged stand (Compartment B, Stand 2) [tree volumes determined from a local volume table]*

D.b.h.	Number of trees	Basal area	Volume	
Inches		*Ft²*	*Ft³*	*Fbm*
4	6	0.5	3	0
5	8	1.1	14	0
6	11	2.2	38	0
7	14	3.7	76	0
8	18	6.3	142	0
9	19	8.4	204	0
10	22	12.0	309	618
11	26	17.2	463	1033
12	18	14.1	396	1009
13	11	10.1	293	848
14	9	9.6	286	925
15	4	4.9	149	533
16	0	0.0	0	0
17	0	0.0	0	0
18	0	0.0	0	0
19	0	0.0	0	0
20	0	0.0	0	0
21	0	0.0	0	0
Total	166	90.1	2,966	4,966

The stand is harvested again after 10 years to the prescribed BDq, reducing basal area to 55 ft^2/acre. In 10 more years (20 years after the initial harvest cut), the stand has grown back to 75 ft^2/acre of basal area, and a third age class has been established (fig. 3.9c). By this time, three age classes exist in the stand—70 (residual overstory), 20, and 10.

The stand is cut again following the original BDq prescription; then after another 10 years (30 years after the initial harvest cut) four age classes are present and the bell-shaped, normal diameter distribution curve of the initial even-aged stand is giving way to a reversed-J diameter distribution curve representative of an uneven-aged stand

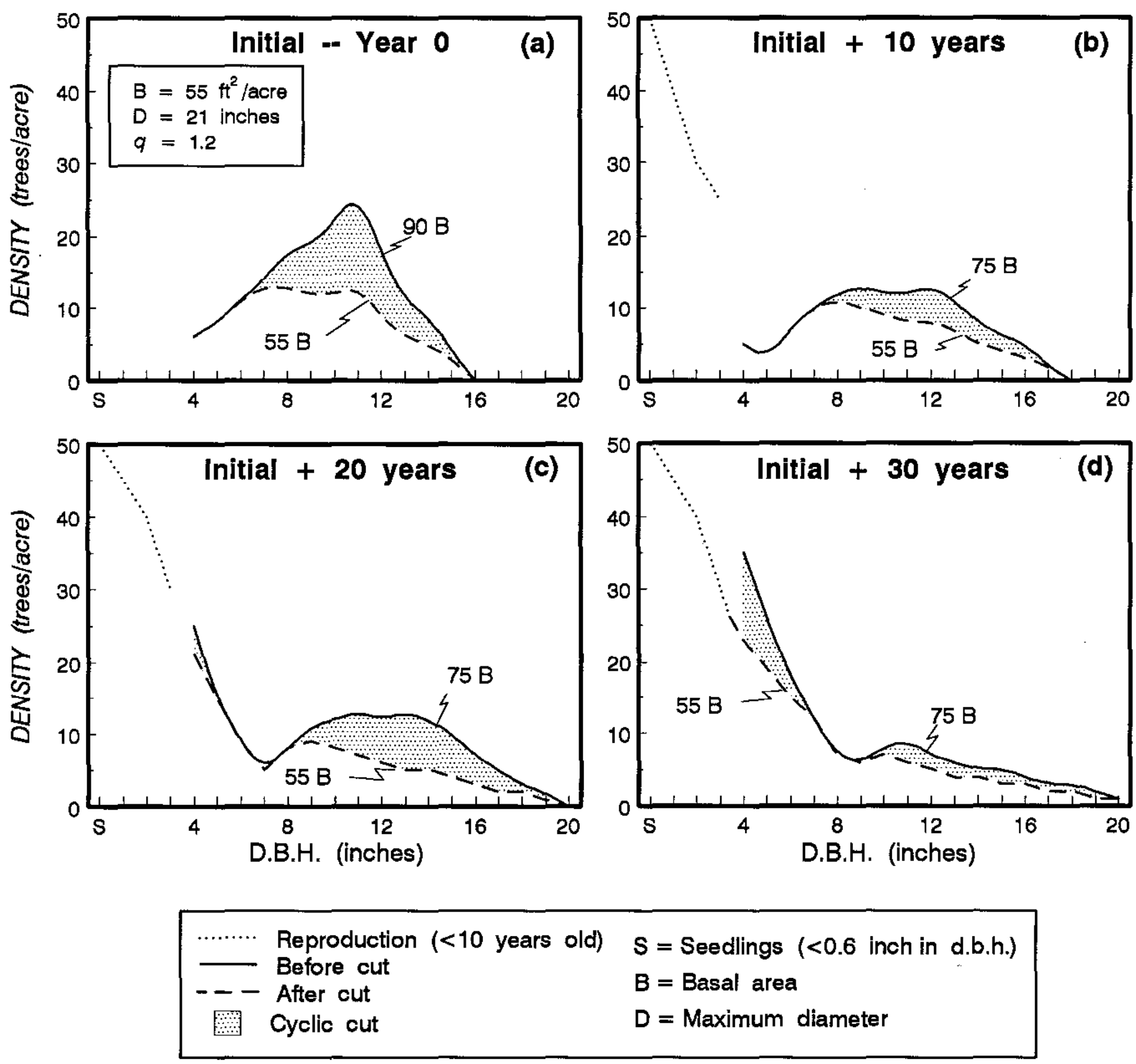

Figure 3.9.—*Hypothetical conversion of an even-aged stand to uneven-aged structure during 30 years of management.*

(fig. 3.9d). At this point, the guidelines described for a well-stocked stand having uneven-aged structure can be followed to move toward a balanced, uneven-aged structure.

Understocked Stands

Uneven-aged silviculture is well suited for rehabilitating an understocked stand, particularly if the stand has sufficient stocking in at least two size or product classes (i.e., pulpwood and sawlogs, or saplings and pulpwood) (Baker 1989b, Dennington and Baker 1989, Reynolds and others 1984).

To determine if a stand has sufficient stocking to be rehabilitated by uneven-aged silviculture, a 10-percent inventory of the merchantable-size (>3.6 inches in d.b.h.) trees is required. The sample stand inventory form (A-1) provided in the appendix can be used. In addition, pine

Table 3.7.—*Sample output (on a per-acre basis) for hypothetical, even-aged stand (Compartment B, Stand 2) generated by* **TARGET** *computer program using stand inventory data from table 3.6 and the following stand structure parameters: Residual Basal Area = 55 ft²/acre; Maximum Diameter = 21 inches; q value = 1.2*

D.b.h.	Target		Before-cut		Cut		After-cut	
	Number	BA	Number	BA	Number	BA	Number	BA
Inches		*Ft²*		*Ft²*		*Ft²*		*Ft²*
4	20.4	1.8	6.0	0.5	0.0	0.0	6.0	0.5
5	17.0	2.3	8.0	1.1	0.0	0.0	8.0	1.1
6	14.2	2.8	11.0	2.2	0.0	0.0	11.0	2.2
7	11.8	3.2	14.0	3.7	1.4	0.4	12.6	3.3
8	9.8	3.4	18.0	6.3	5.3	1.8	12.7	4.5
9	8.2	3.6	19.0	8.4	7.0	3.1	12.0	5.3
10	6.8	3.7	22.0	12.0	9.8	5.4	12.2	6.6
11	5.7	3.8	26.0	17.2	13.1	8.6	12.9	8.6
12	4.7	3.7	18.0	14.1	8.6	6.7	9.4	7.4
13	4.0	3.6	11.0	10.1	4.6	4.2	6.4	5.9
14	3.3	3.5	9.0	9.6	3.7	3.9	5.3	5.7
15	2.7	3.4	4.0	4.9	0.8	1.0	3.2	3.9
16	2.3	3.2	0.0	0.0	0.0	0.0	0.0	0.0
17	1.9	3.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.6	2.8	0.0	0.0	0.0	0.0	0.0	0.0
19	1.3	2.6	0.0	0.0	0.0	0.0	0.0	0.0
20	1.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0
21	0.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Total	117.7	55.0	166.0	90.1	54.3	35.1	111.7	55.0

reproduction should be evaluated by counting the well-established pine seedlings and/or saplings on a minimum of 100, uniformly spaced, milacre plots in the stand. A sample evaluation form (A-4) is provided in the appendix. Pine reproduction should also be evaluated in terms of its freedom-to-grow and the coverage of competing vegetation. Notes on the free-to-grow status of the pines will help in detecting the need for release.

From this information, one can determine if there is adequate stocking to rehabilitate the stand, and the time required to reach full stocking can be estimated (Baker 1989b). Stocking can be quantified by using the sample worksheet form (A-5) provided in the appendix, which was derived from solving the following equation for each d.b.h. class:

$$\text{Stocking (percent)} = 0.16667(N) + 0.00404(\Sigma D) + 0.00434(\Sigma D^2)$$

where: N = number of trees ≥1 ft in height per acre,

ΣD = sum of d.b.h. of trees ≥1 inch in d.b.h., and

ΣD^2 = sum of squared d.b.h. of trees ≥1 inch in d.b.h.

This stocking equation was derived by fitting USDA—Forest Service's, Forest Inventory and Analysis (FIA) stocking guides to Chisman and Schumacher's (1940) tree-area ratio equation. Thus, the stocking equation is a measure of stocking based on the number of stems per acre and basal area of stems >4.5 ft tall.

Uneven-aged stands having at least 15 to 25 percent stocking or 5 to 10 ft²/acre of merchantable basal area (distributed equally among the size or product classes) can grow to an acceptable stocking of 60 percent or 45 ft²/acre of basal area in 15 years or less if hardwoods are controlled (Baker 1989b). Because the rehabilitation rate depends on the development of the residual trees and reproduction in the stand, control of competing vegetation is crucial. Hardwoods that overtop pines, or that could within the next 10 years, should be cut or controlled with a herbicide.

The free-to-grow pines (saplings through pole-size) that have at least a 20-percent live crown and display apical dominance will develop quickly, and stocking should rapidly reach an acceptable level. Once stocking exceeds 60 ft²/acre of basal area, BD*q* regulation of structure and periodic harvesting can begin, as described in this chapter under "Well-Stocked Stands with Uneven-Aged Structure."

Historical Application of Uneven-Aged Silviculture in Loblolly-Shortleaf Pine Types

Uneven-aged silviculture has been the focus of research and practice in both the West Gulf Coastal Plain of southern Arkansas and the Interior Highlands of northwest Arkansas. In the Coastal Plain, the method has been applied, both in research and in practice, in the mixed-species forest type

Table 3.8.—*Stand-and-stock table (on a per-acre basis) for hypothetical, even-aged stand (Compartment B, Stand 2) derived from inventory data and the* **TARGET** *computer program (tree volumes determined from a local volume table)*

D.b.h.	Target Stand				Before-cut Stand				Cut				After-cut Stand			
	No. trees	BA	Volume		No. trees	BA	Volume		No. trees	BA	Volume		No. trees	BA	Volume	
Inches		Ft^2	Ft^3	*Fbm*		Ft^2	Ft^3	*Fbm*		Ft^2	Ft^3	*Fbm*		Ft^2	Ft^3	*Fbm*
4	20.4	1.8	10	0	6.0	0.5	3	0	0.0	0.0	0	0	6.0	0.5	3	0
5	17.0	2.3	30	0	8.0	1.1	14	0	0.0	0.0	0	0	8.0	1.1	14	0
6	14.2	2.8	48	0	11.0	2.2	38	0	0.0	0.0	0	0	11.0	2.2	38	0
7	11.8	3.2	64	0	14.0	3.7	76	0	1.4	0.4	8	0	12.6	3.3	68	0
8	9.8	3.4	78	0	18.0	6.3	142	0	5.3	1.8	42	0	12.7	4.5	100	0
9	8.2	3.6	88	0	19.0	8.4	204	0	7.0	3.1	75	0	12.0	5.3	129	0
10	6.8	3.7	96	192	22.0	12.0	309	618	9.8	5.4	138	275	12.2	6.6	171	343
11	5.7	3.8	101	226	26.0	17.2	463	1033	13.1	8.6	234	521	12.9	8.6	229	512
12	4.7	3.7	104	266	18.0	14.1	396	1009	8.6	6.7	188	480	9.4	7.4	208	529
13	4.0	3.6	105	304	11.0	10.1	293	848	4.6	4.2	121	351	6.4	5.9	172	497
14	3.3	3.5	104	338	9.0	9.6	286	925	3.7	3.9	117	379	5.3	5.7	169	546
15	2.7	3.4	102	365	4.0	4.9	149	533	0.8	1.0	30	108	3.2	3.9	119	425
16	2.3	3.2	99	386	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
17	1.9	3.0	94	396	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
18	1.6	2.8	89	402	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
19	1.3	2.6	83	398	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
20	1.1	2.4	78	391	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
21	0.9	2.2	72	318	0.0	0.0	0	0	0.0	0.0	0	0	0.0	0.0	0	0
Total	117.7	55.0	1,445	3,982	166.0	90.1	2,373	4,966	54.3	35.1	953	2114	111.7	55	1,420	2852

dominated by loblolly pine but containing minor and varying proportions of shortleaf pine. In the Interior Highlands, the method has been applied primarily in practice, but with increasing research support, in shortleaf pine forests.

For both forest types, the method has been used primarily to grow pine; hardwoods have been viewed simply as competitors of pine and thus aggressively controlled. We know then, that uneven-aged silviculture can successfully produce pine. The question is whether mixed pine-hardwood stands can be managed with uneven-aged silviculture. The challenge is to include hardwood species that are shade intolerant when developing uneven-aged stand structures and canopies that are ecologically sustainable [see chapter 5].

Coastal Plain Loblolly-Shortleaf Pine

The longest record of research and experience with uneven-aged silviculture in Arkansas is in the Coastal Plain loblolly-shortleaf pine type from the work begun by R.R. Reynolds at the Crossett Experimental Forest (Reynolds 1980). Because loblolly pines are shade intolerant, Reynolds and his colleagues quickly realized that the key to sustained, uneven-aged silviculture was reproduction. Reynolds and his successors prescribed a combination of single-tree selection and group selection. Reynolds' work established that, with uneven-aged silviculture, this forest type is best regenerated and developed using short (5- to 10-year) cutting cycles.

Because loblolly pine is such a prolific seed producer in natural stands, establishing reproduction under selection cutting has usually been less of a concern than its development. Reynolds was unconcerned with opening size if all the trees to be removed were poorer in quality than others in the same size class. In the West Gulf Coastal Plain, loblolly pine produces an adequate seed crop 7 to 8 years out of 10; under this hail of pine seeds, most openings are quickly stocked with pine reproduction as a result of the normal ground scarification caused by logging.

Because cutting cycles were short, Reynolds and his associates did not worry when a given cutting cycle failed to yield reproduction because it would be only a short time before another cutting was scheduled. If the typical results at Crossett are to be adapted to species less prolific than loblolly pine, such questions for securing reproduction as cutting during favorable seed years and additional site preparation, must be addressed.

Besides producing large seed crops, both the reproduction and the residual stand develop rapidly in the West Gulf region. A level of residual basal area that inhibits pine reproduction can quickly develop after a harvest. To ensure continued development of all size classes, Reynolds used short cutting cycles and carefully monitored residual stocking after the harvest. By allowing the stand basal area to vary between 60 and 75 ft^2/acre, of which 65 to 75 percent was in sawtimber, Reynolds could maintain ingrowth of pine seedlings and saplings into the merchantable size-classes.

Aggressive hardwood control, primarily with the use of herbicides, was the key to the success of the selection method on the Crossett Experimental Forest. The challenge facing researchers in the Coastal Plain today is to refine the method for use in mixed pine-hardwood stands.

The major industry practitioner of uneven-aged management in the Coastal Plain is Deltic Farm and Timber Company, Inc., which manages about 200,000 acres of loblolly-shortleaf pine. Deltic uses a 7-year cutting cycle and regulates stand structure by volume control (VGDL) in the sawlog component of the stand. Their foresters are not too concerned about uniform size distributions in all diameter classes; however, their goal is to maintain at least three product sizes (pulpwood, small sawlogs, and large sawlogs) plus reproduction in their stands. Deltic aggressively controls competing hardwoods periodically, thus their stands are primarily pine in the upper and mid-canopies.

Interior Highlands Shortleaf Pine

Deltic, also practices uneven-aged silviculture in the Interior Highlands of Arkansas, supplying a sawmill in the town of Ola with pines from about 200,000 acres of shortleaf pine in the northern Ouachita Mountains. The management strategy that Deltic uses there is similar to that used in its Coastal Plain loblolly pine stands, with one notable exception. Because of the slower growth rate of shortleaf pine in the Interior Highlands, harvesting is done about every 10 years rather than about every 7 years as in Coastal Plain loblolly pine. Hardwoods of all sizes that compete with the pines are aggressively controlled. As in the Coastal Plain, well-structured and fully stocked pine stands managed under uneven-aged silviculture for 40 years can be seen on Deltic land in the Interior Highlands. These stands demonstrate classic, uneven-aged appearance with crowns of pines contributing to a multi-layered canopy.

In the early 1990's, the Ouachita and Ozark National Forests began using uneven-aged silviculture in shortleaf pine stands on the Interior Highlands, with plans to convert 15,000 acres annually from even-aged to uneven-aged structure. This strategy is part of the ecosystem management philosophy adopted by the USDA Forest Service in 1992.

Researchers are only beginning to understand uneven-aged silviculture for shortleaf pine. The oldest experimental plots have been managed for little more than a decade (Murphy and others 1991). More recent research involves a wide array of studies, both with small plots (Shelton and Baker 1992b) and at the stand level (Baker 1992, 1994; Guldin and others 1993).

Chapter 4

GROWTH, YIELD, AND STAND DEVELOPMENT

Knowledge has been accumulating about the growth of uneven-aged, loblolly-shortleaf pine stands. This information comes from case studies, designed experiments, and growth and yield models, which are usually derived from comprehensive experimental studies (table 4.1). Although growth and yield models are the most helpful in decision-making, each source can provide valuable information for managing uneven-aged stands.

Case Studies and Experiments

The oldest information on uneven-aged silviculture for loblolly-shortleaf pine stands comes from the Crossett Experimental Forest in the Coastal Plain of southern Arkansas. A 29-year history is available for a cutting-cycle study (Reynolds 1969), and a 41-year history is available for the Crossett Farm Forestry Forties (Reynolds and others 1984). Site index for loblolly pine on the Crossett Experimental Forest is 90 ft at age 50. A 33-year history is also available for a tract in southwest Arkansas with a lower loblolly pine site index (80 ft at age 50) (Farrar and others 1984a). A case study in east-central Mississippi (Farrar and others 1989) occurred on a site index intermediate to the Arkansas studies (85 ft at age 50).

Despite differences among these studies in stocking, merchantability, etc., some useful inferences can be made. Records indicate that long-term, annual growth per acre in southern Arkansas can be expected to average around 3 ft^2 of basal area, 84 to 116 ft^3 of merchantable volume, and about 400 fbm of sawtimber (table 4.1). The Mississippi study showed lower production.

Information from the Piedmont in central Georgia (Brender 1973) is from stands of a lower site index (73 to 77 ft at age 50). The growth is correspondingly lower than for the Coastal Plain sites (table 4.1).

Not much information is available for stands where shortleaf pine is the dominant or sole species. A 10-year history is available for a 67-acre tract in southeastern Texas (Gibbs 1958) (table 4.1). However, the tract had been cutover and was understocked; consequently, the first 10 years did not indicate expected growth under long-term management. Another case study for shortleaf pine comes from three experimental watersheds in the Ouachita Mountains of Arkansas (Murphy and others 1991). The watersheds were managed by the basal area—maximum diameter—quotient (BD*q*) method with a residual basal area of 60 ft^2/acre, a maximum d.b.h. of 20 inches, and a *q* of 1.2 (1-inch d.b.h. classes). Despite only 6 years of management, basal area and merchantable volume growth (table 4.1) conform to that predicted by a growth and yield model (Murphy and others 1991), although sawtimber growth was lower than predicted.

Table 4.1.—*Growth comparisons from uneven-aged stands of loblolly and shortleaf pines in the South*

Location	Physiography	Species	Study area size	Study duration	Cutting cycle length	Site index (base age 50)	Product	Annual growth per acre: Basal area	Merch. volume	Sawtimber volume	Source*
			Acres	*Years*	*Years*	*Ft*	*Sawtimber*	*Ft²*	*Ft³*	*Fbm*	
Arkansas	Coastal Plain	Lob-shlf	960	29	3,6,9	90	Large	NA†	84	432 Int. ¼"	(1)
Arkansas	Coastal Plain	Lob-shlf	34‡	41	1,5	90	Medium	3.2	116	397 Doyle	(2)
Arkansas	Coastal Plain	Lob-shlf	40§	41	1,5	90	Large	2.9	95	412 Doyle	(2)
Arkansas	Coastal Plain	Lob-shlf	26	15	6	80	Large	2.9	88	423 Doyle	(3)
Mississippi	Coastal Plain	Lob-shlf	40	27	1	85	Large	2.2	62	299 Doyle	(4)
Mississippi	Coastal Plain	Lob-shlf	40	27	5	85	Large	2.5	62	229 Doyle	(4)
Texas	Coastal Plain	Shortleaf	67	10	10	NA	NA	NA	NA	169 Int. ¼"	(5)
Georgia	Piedmont	Lob-shlf	288	21	8	77	Large	NA	77	319 Int. ¼"	(6)
Georgia	Piedmont	Lob-shlf	260	19	8	73	Small	NA	75	290 Int. ¼"	(6)
Arkansas	Interior Highlands	Shortleaf	35	6	6	53	Medium	2.0	57	157 Doyle	(7)

* Source: (1) Reynolds 1969; (2) Reynolds and others 1984; (3) Farrar and others 1984a; (4) Farrar and others 1989; (5) Gibbs 1958; (6) Brender 1973; (7) Murphy and others 1991.

† NA = Not available.

‡ Poor Farm Forestry Forty, Crossett Experimental Forest.

§ Good Farm Forestry Forty, Crossett Experimental Forest.

Loblolly Pine Growth Study

Case studies generally indicate the potential for volume production and are benchmarks with which to compare other stands. However, they do not answer such questions as: "what is the effect of site quality on growth?" Replicated experiments provide more data.

In a study begun in 1983 (Murphy and Shelton 1994), eighty-one 0.5-acre plots were installed in southern Arkansas and northern Louisiana in stands of three site index classes—<80 ft, 81 to 90 ft, and >90 ft. The plots were cut to combinations of 40, 60, and 80 ft^2/acre of merchantable basal area; maximum diameters of 12, 16, and 20 inches; and a *q* of 1.2 for 1-inch d.b.h. classes. Competing hardwoods were injected with herbicide, and all shortleaf pines were cut, leaving only loblolly pines in the merchantable stand. After 5 years the plots were remeasured.

The 20-inch maximum residual d.b.h. probably represents an upper limit in today's economy, while the 12-inch maximum residual d.b.h. is the minimum size for reliable seed production. The residual basal areas of 40 and 80 ft^2/acre are beyond the normal operating densities for uneven-aged loblolly pine stands. They were chosen to test whether management at these density extremes is sustainable. A basal area of 40 ft^2/acre may not be adequate stocking, and 80 ft^2/acre may be too dense to allow pine reproduction to become established and develop. Evidence suggests that uneven-aged loblolly pine stands should not exceed 75 ft^2/acre of basal area at the end of a cutting cycle. So, only growth for currently recommended basal areas for a 5-year cutting cycle will be considered.

Because the results are preliminary, trends are more significant than absolute growth. Figure 4.1 shows the trends in net basal-area growth for the normal range of density that would be used in a 5-year cutting cycle. The average basal-area growth was 3 ft^2/acre/yr. Annual basal-area growth tended to increase with an increase in residual basal area and decrease with an increase in maximum diameter or site index. The reason for less basal-area growth on good sites might be that there is less ingrowth into merchantable d.b.h. classes because vigorous competition impedes the establishment and development of loblolly pine reproduction. Moreover, the stands on poor sites might have had more submerchantable trees than those on the better sites before the study was installed (Murphy and Shelton 1994). The reason for less basal-area growth in stands having trees of larger maximum diameter might be that those trees are older and less vigorous than stands of smaller trees.

Overall, the average merchantable volume growth was 111 ft^3/acre/yr. Figure 4.2 depicts the growth trends for merchantable cubic-foot volume. As with basal-area growth, volume growth tended to increase with increasing residual basal area and decrease with an increase in maximum diameter. However, no effect of site index was detected in the analysis.

Annual sawtimber growth averaged 420 fbm/acre over all treatments. The effects of residual basal area, maximum diameter, and site index on sawtimber growth were all positive (fig. 4.3). An increase of 10 ft in site index resulted in about a 9-percent increase in board-foot growth.

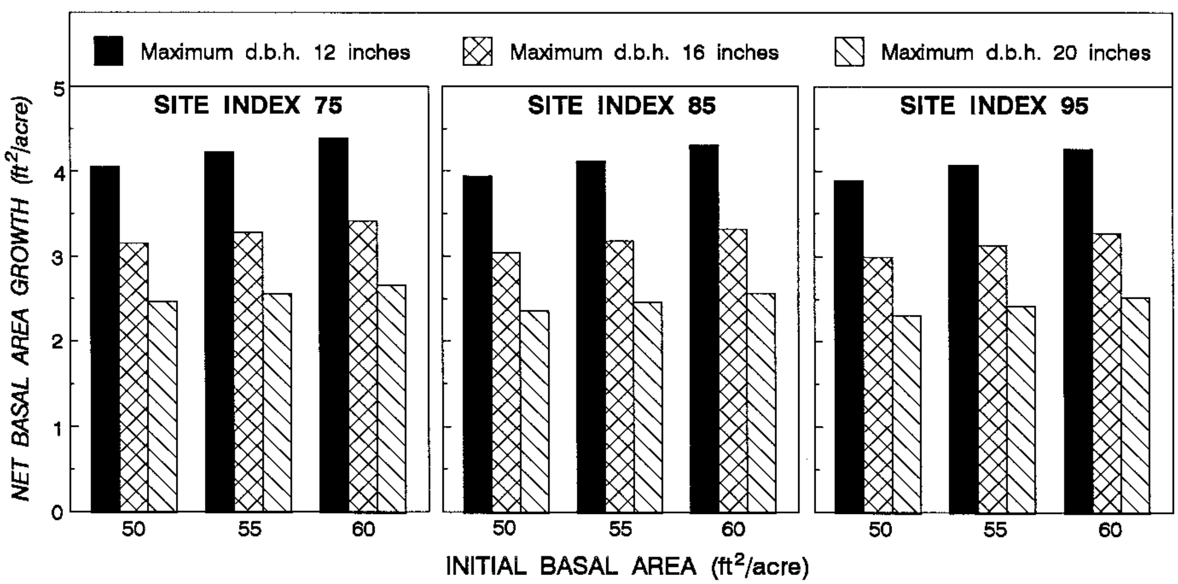

Figure 4.1.—*Annual net basal area growth per acre for loblolly pine stands in the West Gulf Coastal Plain after the first 5 years of single-tree selection silviculture.*

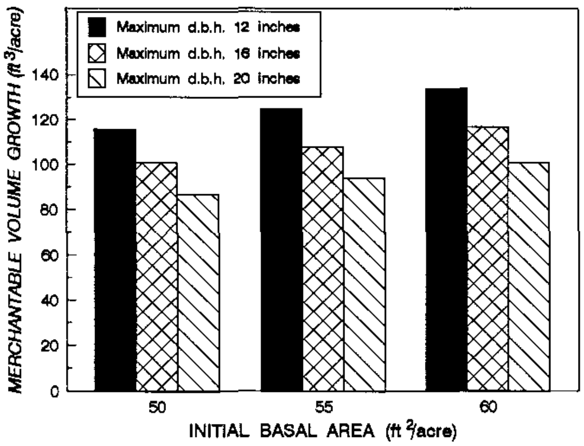

Figure 4.2.—*Annual merchantable cubic-foot volume growth per acre for loblolly pine stands in the West Gulf Coastal Plain after the first 5 years of single-tree selection silviculture.*

Growth and Yield Models

Stand-level growth and yield models are available for uneven-aged loblolly-shortleaf pine and for uneven-aged shortleaf pine. The model for loblolly-shortleaf pine (Farrar and others 1984b; Murphy and Farrar 1982, 1983) was developed from long-term studies conducted on the Crossett Experimental Forest. The user specifies initial merchantable and sawtimber basal areas and cutting cycle. The model calculates projected sawtimber and merchantable basal areas; current and projected merchantable and sawtimber cubic-foot volumes; and current and projected Doyle, Scribner, and International ¼-inch board-foot volumes. Because the data came from a small area with a uniform site, the model is restricted to the site indexes of 85 to 95 ft for loblolly pine.

The second model (Murphy and Farrar 1985) was developed for uneven-aged shortleaf pine stands in the Interior Highlands of Arkansas and eastern Oklahoma. The user must specify initial merchantable and sawtimber basal areas, cutting cycle, and site index to use this model. The model provides projected sawtimber and merchantable basal areas; current and projected merchantable and sawtimber cubic-foot volumes; and current and projected Doyle, Scribner, and International ¼-inch board-foot volumes.

Rather than describing how to use these models, you should obtain the pertinent publications and spreadsheet templates that will do the calculations [see "Computer Software Available" at the end of this chapter].

Uneven-Aged Versus Even-Aged Production

Controversy has raged interminably about the timber production of uneven-aged versus even-aged stands. The issue is further clouded by disagreement over the length of the growth period that should be used for comparison. The intensity of the debate is ameliorated if it is realized that selection of one system over another depends upon owner objectives, and volume production may be just one of these. Nonetheless, there have been several comparative studies for the loblolly-shortleaf pine type.

Baker and Murphy (1982) compared the 36-year production of four reproduction cutting methods—clearcutting, heavy seed-tree, single-tree selection, and diameter-limit cutting—in loblolly shortleaf pine stands in southern Arkansas. Strictly speaking, the diameter-limit is not a reproduction cutting method but was included to represent the usual cutting practice in 1942 when the study was installed. After 36 years, the single-tree selection, the heavy seed-tree, and the diameter-limit stands had produced significantly more annual board-foot volume per acre (selection, 377 fbm; heavy seed-tree, 362 fbm; diameter-limit, 330 fbm) than the clearcut (260 fbm). It is important to note, however, that no thinning was done in the clearcut stands during the 36-year period. The seed-tree stands were also not thinned except that the seed trees were removed 15 years after the initial harvest. Their volume growth is included in the totals for the seed-tree method. The single-tree selection and clearcut stands produced significantly lower annual merchantable cubic-foot volume per acre (84 and 93 ft^3, respectively) than the seed-tree (117 ft^3, seed trees included) and the diameter-limit (107 ft^3) stands.

Using a combination of case studies and growth and yield model simulations, Baker (1987) compared two even-aged (plantation and natural stand) and two uneven-aged systems (single-tree selection with high and low stocking). The even-aged systems produced more cubic-foot volume, while the intensively managed, even-aged plantation and the high-stocking, uneven-aged system produced the most saw-log volume.

Baker and others (1991) and Guldin and Baker (1988) compared the empirical yields from conventional silviculture versus intensive silviculture as applied to plantations, natural even-aged stands, and uneven-aged stands of loblolly-shortleaf pine. They concluded that merchantable cubic-foot yields are highest for intensively managed plantations; sawtimber cubic-foot yields are highest for intensively managed uneven-aged and even-aged natural stands, and board-foot yields are higher for uneven-aged stands. The differences in yields are probably attributable to stocking; i.e., growth increases with stocking. Plantations, which have the highest merchantable cubic-foot growth, generally have the optimum stocking of merchantable trees. Uneven-aged stands, which have the highest sawtimber growth, generally have the highest proportion of stocking in sawtimber trees. The underscale of the Doyle rule in small trees favors uneven-aged stands because their sawtimber-sized trees are generally larger.

Interest is also great in comparing log quality of trees in even-aged versus uneven-aged stands. Guldin and Fitzpatrick (1991) analyzed the log grades, knots, and

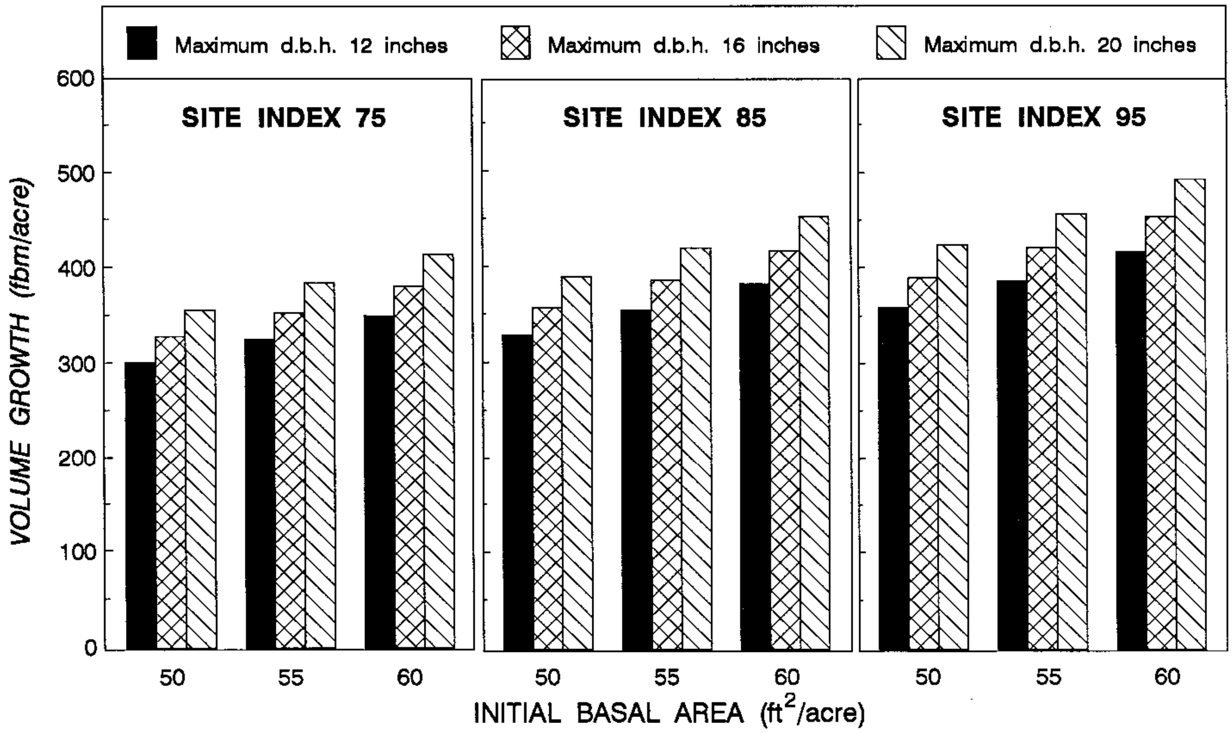

Figure 4.3.—*Annual board-foot (Doyle rule) growth per acre for loblolly pine stands in the West Gulf Coastal Plain after the first 5 years of single-tree selection silviculture.*

volumes of the first two logs of loblolly pine trees in plantations and natural even-aged and uneven-aged stands. Trees in uneven-aged stands had higher grade butt logs than trees in plantations. Log quality was similar in trees from uneven-aged and even-aged natural stands, but the even-aged stands had butt logs of higher quality although with more taper. They concluded that more intensive management will be needed to produce plantation-grown loblolly trees that are comparable in quality to those produced in natural stands.

Economics

The decision to practice uneven-aged versus even-aged management can be based partly on economics. The economics of uneven-aged stand silviculture will be examined and then compared with even-aged silviculture.

Uneven-Aged Stand Management Decisions

Two major variables that the forest manager can control in uneven-aged stands are cutting cycle and stocking. The minimum cutting cycle depends upon the residual stocking, the growth rate of the stand, and the minimum operable cut. The maximum cutting cycle is contingent upon how dense the stand can become without impeding the development of desirable reproduction. Stocking and cutting cycle are interdependent. If the cutting cycle is increased, residual stocking must be decreased so that the stocking will not become too great for reproduction to become established and develop. Within these confines, however, stocking and cutting cycle can be determined by financial criteria.

Extending the results of Duerr and Bond (1952), Chang (1981) formulated the simultaneous determination of the best growing-stock level and cutting cycle using maximum net present value as the criterion. Applying marginal analysis, Chang found (1) that the extra revenue gained by extending a cutting cycle for a year should equal the cost of holding both the land and timber for the additional year, and (2) that the marginal revenue gained by having an additional unit of growing stock should equal the cost of holding that additional unit for the length of the cutting cycle. An increase in the interest rate decreases both cutting cycle length and growing-stock level. However, stumpage price did not affect either cutting cycle or growing-stock level. Chang's analysis dealt with growing stock in terms of stand volume. The analysis could be done with stand-table projection or individual-tree growth models.

Hotvedt and others (1989) examined optimum management regimes for uneven-aged loblolly-shortleaf pine stands in terms of net present value and sawtimber production. Residual basal area, cutting cycle, and the ratio of sawtimber basal area to merchantable basal area were the variables investigated. These variables were constrained within reasonable biological limits. They found that optimum management regimes based upon maximum net present value had short cutting cycles (4 to 5 years) and low ratios of sawtimber basal area to merchantable basal area (0.55). Management regimes based upon maximum sawtimber production tended to have high residual basal areas (60 to 65 ft^2/acre), high ratios of sawtimber basal area to merchantable basal area (0.70 to 0.80), and short cutting cycles (4 to 6 years). Opting for high sawtimber production results in management regimes with lower net present values than regimes selected on maximum net present value.

Hotvedt and Ward (1990) investigated the problem of optimal management; i.e., maximizing net present value over an infinite period, of uneven-aged loblolly-shortleaf pine stands with different initial stand structures. They concluded that: (1) there is no single best stand structure for all uneven-aged stands, (2) the initial stand condition will determine the best strategy for converting the stand to an optimal structure, and (3) understocked stands would be easier to convert to a stable stand structure than overstocked stands.

The concept of financial maturity can also be applied to individual trees and their growth rates in uneven-aged stands, as described by Duerr and others (1956). It is based upon the premise that a tree can be kept if its marginal value growth rate is greater than the alternative rate of return. The concept can be extended to include the effect of removing neighboring trees (Duerr and others 1956) and trees that will replace the cut tree (Murphy and Guldin 1987). It can be applied to both the performance of individual trees and selection of a maximum diameter in BD*q* regulation. Figure 4.4 shows the board-foot growth rate of loblolly pine trees growing at different annual diameter-growth rates in an uneven-aged stand managed under a 5-year cutting cycle. Within the constraints of the residual volume or stand structure imposed by regulation, financial maturity can help in selecting trees to cut. For example, if the alternative rate is 6 percent, then all trees growing slower than this could be candidates for harvest. Another use of financial maturity would be in selecting the maximum diameter with BD*q* regulation. If the alternative rate is 8 percent and an annual diameter growth rate of 0.4 inch can be expected on large trees, then a maximum diameter of 16 to 17 inches might be selected. Financial maturity is one of many concepts that can be used to manage uneven-aged loblolly pine stands.

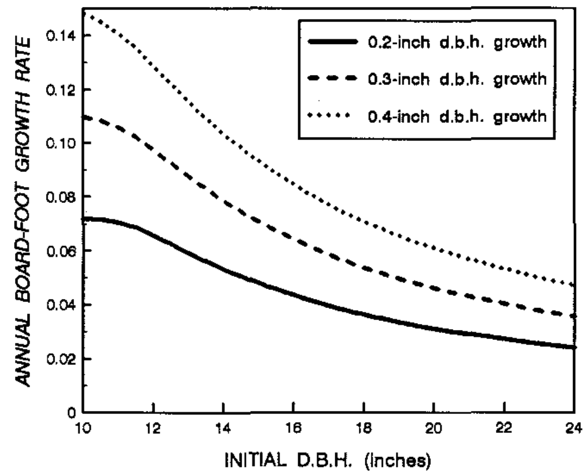

Figure 4.4.—*Annual board-foot (Doyle rule) growth rate of loblolly pines in uneven-aged stands on good sites (S.I. =90), with a 5-year cutting cycle.*

Timber Harvesting

Little information is available on timber harvesting in uneven-aged loblolly and shortleaf pine stands. Kluender and others (1992) analyzed harvesting production on the Farm Forestry Forties, located on the Crossett Experimental Forest in southern Arkansas. Two stands had been under uneven-aged management for 53 years. Felling was done by chainsaw; felled trees were limbed and topped before being skidded by grapple skidders. Harvesting productivity (measured as cubic feet per hour) for both felling and skidding was influenced most by the diameter of the stems cut. In addition, a slight change in the size distribution of removed stems greatly affected productivity.

In another study, Kluender and others (1994) analyzed different harvesting intensities—clearcut, shelterwood, and single-tree selection—in shortleaf pine stands in the Ouachita Mountains. The harvest operation consisted of chainsaw felling and skidding by cable and grapple skidders. Because the single-tree selection cut was the first one in essentially even-aged stands, the results do not necessarily indicate harvest productivity in stands managed by single-tree selection for a long period. Nonetheless, some valuable guidelines can be obtained from the study. The authors found that felling time was affected by the d.b.h. of harvested stems, the average distance between harvested trees, and harvest intensity (the proportion of the stand that was cut). Skidding time was affected by pull distance, skidder type, number of stems per pull, harvest intensity, and average volume per skidder cycle.

These studies indicate that harvest productivity will be higher in uneven-aged stands if large trees can be cut, the distance between marked trees can be decreased, and skidding distance can be shortened. All these factors can be controlled.

Even-Aged Versus Uneven-Aged Economic Comparisons

Although some economic comparisons have been made between even-aged and uneven-aged stands, the results are mixed. Moreover, no economic comparisons have been made between an even-aged forest with stands of various ages and an uneven-aged forest of the same acreage. The following review is mostly confined to loblolly-shortleaf pine stands. Some general conclusions follow the review.

In a limited economic comparison, Chang (1981) concluded that uneven-aged management might be favored at high interest rates (using net present value) because of the more frequent but smaller revenues from an uneven-aged stand versus the larger but less frequent revenues from an even-aged stand. Baker (1987) compared two even-aged (plantation and natural) and two uneven-aged (low and high stocking) management systems for loblolly pine using three criteria—net present value, benefit/cost, and cost efficiency (total production/total discounted costs). The natural, even-aged system ranked highest in net present value, benefit/cost, and cost efficiency for merchantable volume production. The uneven-aged, high-stocking alternative ranked highest in cost efficiency for sawtimber production and second highest for benefit/cost. No sensitivity analysis was done to see what effect variations in interest rates, costs, etc., had on the rankings.

Baker and others (1991) and Guldin and Guldin (1990) evaluated several studies with a 36-year history of management in loblolly-shortleaf pine stands on the West Gulf Coastal Plain in terms of net present value, benefit/cost, and cost efficiency. The studies included plantations, natural even-aged stands, and natural uneven-aged stands. When the initial growing stock was not considered a cost, the uneven-aged stands ranked highest in terms of net present value. However, if initial growing stock was considered as a cost, the uneven-aged stands ranked lower than most even-aged alternatives. The even-aged natural stands ranked higher than both plantations and uneven-aged stands in terms of benefit/cost and cost efficiency. With a decrease in the differential paid for sawtimber versus small roundwood, net present value of uneven-aged stands decreased while that for even-aged systems increased. When growing stock was a cost and the interest rate was 4 percent, uneven-aged stands with high initial growing stock had higher net present value than those stands with lower initial volumes. But at higher interest rates (7 and 10 percent), uneven-aged stands with low initial growing stock had higher net present values than those with higher initial volumes.

Redmond and Greenhalgh (1990) compared the investment alternatives of rehabilitating understocked loblolly-shortleaf pine stands using uneven-aged management versus liquidating the stands and establishing a loblolly pine plantation. Initial stocking levels were 10, 30, and 50 percent of full stocking. The investment alternatives were evaluated using net present values and interest rates of 4, 7.125, and 10 percent. They found that uneven-aged management was best for 30- and 50-percent stocked stands when the interest rate was 7.125 percent or higher. At these stocking levels, plantation management was best at 4 percent interest (liquidation of the existing stand provided additional returns that made plantation management more attractive). For stands with 10-percent stocking, plantation management was best at all interest rates; the recovery period was too long for uneven-aged management to be competitive.

Straka and Baker (1991) examined three different alternatives for managing storm-damaged loblolly shortleaf pine stands: (1) uneven-aged silviculture, with 25 to 30 percent initial stocking, (2) even-aged silviculture in natural stands with chemical release of suppressed pine seedlings, and (3) pine plantation silviculture. Net present values were calculated at 4-, 7-, and 10-percent interest rates and with and without land costs. At 4-percent interest, the plantation had the highest net present value whether or not land cost was included. Conversely, at 7- and 10-percent interest, uneven-aged silviculture and natural, even-aged silviculture had higher net present values than the plantation. However, when land cost was included at 7- and 10-percent interest rates, all three options had negative net present values.

These studies are not conclusive. However, if the landowner has decided upon uneven-aged silviculture and economic return is a primary objective, the following guidelines should be helpful:

(1) Other factors being equal, the rate of financial return from uneven-aged stands is markedly decreased if the value of the initial growing stock is considered a cost.

(2) Short cutting cycles and low sawtimber growing-stock levels might increase net present value under some conditions (such as high interest rates).

(3) A range of 15 to 17 inches is probably a good choice for maximum diameter in BD*q* regulation.

(4) Moderately understocked stands probably represent the best financial opportunity for uneven-aged silviculture.

(5) Recommended growing stock for a residual stand on a 5-year cutting cycle might be a basal area of 60 ft^2/acre, a maximum d.b.h. of 16 inches, and a *q*-value of 1.2 (1-inch d.b.h. classes) for BD*q* regulation on an 85- to 90-ft site index.

Computer Software Available

The stand-level growth and yield model for uneven-aged loblolly-shortleaf pine (Farrar and others 1984b; Murphy and Farrar 1982, 1983) and the one for uneven-aged shortleaf pine (Murphy and Farrar 1985) are available (with instructions) as spreadsheet templates for Borland® Quattro® Pro 4.0. To receive a copy, send either a 3.5- or 5.25-inch diskette and a stamped, self-addressed diskette mailer to the following address: USDA Forest Service, P.O. Box 3516, Monticello, AR 71656-3516.

Chapter 5

OPTIONS FOR RETAINING HARDWOODS

Pines and hardwoods are common associates throughout the Southern United States. However, the establishment and management of pine-hardwood stands has only recently been proposed (Phillips and Abercrombie 1987, Sims and others 1981, Zahner 1982). Much of the interest in these stands results from current environmental issues and changes in wood utilization processes and markets (Lentz and others 1989). Some reasons for creating or maintaining pine-hardwood stands are: (1) new markets exist for hardwoods, (2) multiple-resource goals desired by many land-owners are satisfied, (3) diversity of tree species is increased, (4) habitat for some wildlife species is improved, (5) stands are more esthetically pleasing to some landowners, and (6) poorly stocked pine stands may be managed as mixed pine-hardwoods.

Although some landowners may desire pine-hardwood stands, attempting to manage this composition has its problems: (1) shade-intolerant pine reproduction may be difficult to establish and develop, (2) hardwoods reduce pine growth rates, (3) revenue is less because hardwood products on upland sites are of low value, (4) fewer options exist for applying broadcast treatments, such as herbicides or fire, and (5) the different growth rates of pines and hardwoods complicate management. Experience indicates that a pine-hardwood composition will be especially difficult to maintain in uneven-aged stands because of problems in obtaining the recurring pine reproduction needed to sustain uneven-aged structure. Some strategies are discussed here that may achieve a compatible balance between pines and hardwoods in uneven-aged stands. Timber production is again assumed to be a major silvicultural objective.

Single-Tree Selection Option

Uniform Spatial Distribution

Chapters 1, 2, and 3 emphasize that a principal goal of uneven-aged silviculture is to create an environment where recurring pine regeneration can survive and develop at acceptable rates to sustain future harvests. However, overtopping hardwoods suppress the reproduction of the shade-intolerant pines more than an equivalent basal area of overtopping pines (Becton 1936, Shelton and Murphy 1993, Wahlenberg 1960). Hardwoods generally produce about twice the shade or canopy coverage of an equivalent pine basal area (Reynolds 1950; Shelton and Baker 1992a, 1992b; Shelton and Murphy 1993; Tappe and others 1993) because hardwoods have broader leaves, more robust crowns, and are shorter than pines. Of course, characteristics of hardwood species vary greatly, and shade-intolerant species may produce much less shading and coverage than shade-tolerant ones.

Some adjustment in pine stocking levels must be made if a hardwood component is to be retained (Shelton and Baker 1992b). As a rule of thumb, pine basal area should be reduced by 2 ft^2/acre for each 1 ft^2/acre of retained hardwoods. This is illustrated in table 5.1 for a stand in which 60 ft^2/acre of pure pine would be reasonable stocking. Clearly, there is a limit to the amount of uniformly distributed hardwoods that can be retained in uneven-aged stands without severely affecting pine timber production and the regeneration process. Perhaps 5 to 10 ft^2/acre of hardwood basal area could be retained with pine stocking of 45 to 55 ft^2/acre. If pine basal area drops below 45 ft^2/acre, timber production will likely be reduced.

Table 5.1.—*Combinations of merchantable pine and hardwood basal areas that will produce the same overstory competition as that of 60 ft^2/acre of pine basal area*

Pine	Hardwood*	Total
	Ft^2/acre	
60	0	60
50	5	55
40	10	50
30	15	45

*Based on the general rule-of-thumb that hardwoods produce twice the shade or canopy coverage as an equivalent pine basal area.

Structural goals for the hardwood component can be set in a manner similar to that described for the pine component, although no suitable guidelines exist other than for basal area. It seems reasonable that retaining 5 ft^2/acre of merchantable-sized hardwoods might include four pulpwood-sized trees (1.5 ft^2/acre); two, small, sawtimber-sized trees (2 ft^2/acre); and one, large, sawtimber-sized tree (1.5 ft^2/acre). Guldin (1991) discusses a rationale for combining targets in western, mixed-conifer stands that could be adapted for pine-hardwood stands in the Southern United States. Ideally, desired structure for hardwoods would be achieved and maintained by harvesting, but the volumes may be too low to support an operable harvest in many local markets. Some nonindustrial private landowners might achieve structural targets for hardwoods by cutting firewood.

Area-Wise Spatial Distribution

An alternative to retaining a hardwood component on each acre of an uneven-aged pine stand is to leave hardwoods in certain parts of the stand while maintaining pure or nearly pure pine in the rest of the stand. This area-wise distribution could concentrate hardwoods on some terrain feature, such as drainages or north-facing slopes. These areas have the highest hardwood site quality and are where uneven-aged pine silviculture is most costly and difficult because of competing vegetation. Another option would be to leave hardwoods in clumps or clusters as they occur within the existing stand.

Regulation in these stands requires a preharvest inventory as described in chapter 3 and a decision about the acreage to be allocated to pines and hardwoods. Management of the pine areas would follow traditional pine guidelines or those for retaining a minor hardwood component as previously discussed. Some landowner objectives will be best met by not cutting within the hardwood areas. Other landowners might want to cut firewood or conduct commercial timber harvests based on appropriate silvicultural guidelines for hardwoods.

Concentrating hardwoods in certain areas is the simplest and most biologically sound way to retain a hardwood component within uneven-aged pine stands under single-tree selection. This approach also benefits wildlife by providing cover and migration corridors and concentrating mast-producing trees. The area allocated to pines and hardwoods can be varied to produce the balance of resources desired by individual landowners. Operational concerns probably limit the acceptable combinations of pines and hardwoods more than biological limitations. The advantages of an area-wise distribution of pines and hardwoods in uneven-aged stands are: (1) the possibility of retaining a significant hardwood component, (2) optimization of species-site relationships, (3) protection of ecologically sensitive areas, (4) protection of hardwoods during vegetation management in the pine component, (5) simplification of stand regulation and marking, and (6) provision for diverse wildlife habitats (Shelton and Murphy 1993).

Group Selection Options

Group selection creates or maintains an uneven-aged stand by establishing a new age class of regeneration in scattered small openings after each cutting cycle. When applied over several cutting cycles, it will produce a fragmented stand of small, even-aged groups. The regeneration effort is focused within the openings. Group selection results in much larger openings than usually occur under single-tree selection. These large openings may be needed for the development of pine reproduction when a significant hardwood component is retained or herbicide use is restricted. In addition, group selection appears to be a suitable method for regenerating the intermediate-tolerant oaks (Murphy and others 1993). Concentrating regeneration within openings may also result in less logging damage to residual trees.

Openings are located where stand regeneration is needed, such as in groups of mature trees or in areas with low stocking and/or poor-quality trees. The environmental requirements of the desired reproduction are critical to setting suitable opening sizes and shapes. Opening size is also affected by the character of the surrounding trees (height, density, and species) and the terrain (slope and aspect). Although specific guidelines have yet to be developed for pine-hardwood stands, opening diameters that are two to three times the potential height of the bordering trees at maturity seem to be reasonable for regenerating pines and oaks (Murphy and others 1993). If a significant oak component is desired, preharvest treatments may be needed to obtain sufficient advance reproduction on some sites. Openings should typically range from 0.33 to 1.5 acres in loblolly-shortleaf pine-hardwood stands. The shape of the openings should be varied to meet the specific characteristics of the area, with the general restriction that the width should be no less than half the length.

Regulation techniques suitable for group selection are still hotly debated, probably because they have not been adequately field tested over long periods. Techniques for single-tree selection (VGDL and BD*q*), as discussed in chapter 2 can be used, but the cut must be allocated between the openings and the rest of the stand (Law and Lorimer 1989). Area regulation can also be used to determine the number of openings to create during each cutting cycle; this technique seems to have merit early in the conversion of even-aged stands to uneven-aged structure (Murphy and others 1993). Until further information is available, reasonable guidelines for group selection in pine-hardwood stands are: (1) create openings with diameters two to three times the potential height of the bordering trees at maturity, (2) create openings in 5 to 20 percent of the stand depending on the cutting-cycle length, and (3) use cutting cycles of 5 to 10 years on good sites ($>$85 ft at 50 years), 10 to 20 years on poor sites ($<$65 ft at 50 years), and something in between on medium sites. The residual stand between the openings should be thinned during each cutting cycle as necessary. For reasonable timber production, basal areas should be 70 to 80 ft^2/acre for pines and 10 to 30 ft^2/acre for hardwoods.

SUMMARY

The uneven-aged silvicultural system is based on the ecological concepts of natural disturbance and succession. The small-scale disturbances associated with the selection method represent natural disturbances that occur when a single tree or a small group of trees in a stand dies. Successional development represents the stand-reinitiation stage; i.e., the establishment of reproduction in small openings.

Loblolly and shortleaf pines can be regenerated and managed successfully by using the uneven-aged silvicultural system. For selection silviculture to be successful with these shade-intolerant species, the forest manager must know how to: (1) regulate stand structure, (2) maintain appropriate stocking, and (3) control competing vegetation. The goal of these processes is shade management, which is critical for the establishment and development of shade-intolerant species beneath overstory trees.

The steps for implementing uneven-aged silviculture in loblolly-shortleaf pine stands include: (1) selecting a reproduction cutting method, (2) inventorying the stand, (3) regulating stand structure, (4) establishing a cutting cycle, (5) marking trees for harvest, (6) establishing and evaluating reproduction, and (7) controlling competing vegetation. If these steps are followed, uneven-aged stands of loblolly and shortleaf pine can be developed and maintained over extended periods.

Long-term case studies and rigorous field experiments have established the growth and yield potential for uneven-aged stands of loblolly and shortleaf pines growing on poor to good sites throughout the Southern United States. On good sites, well-regulated and well-structured stands should average about 3 ft^2 of basal area growth and about 400 fbm (Doyle) of sawlog growth per acre annually; growth rates for poor sites are about half those for good sites. Total merchantable cubic-foot volume production is generally higher in even-aged stands, while sawtimber production is generally higher in uneven-aged stands. Selection silviculture is often more financially feasible with high interest rates, when stocking is maintained at relatively low levels (45 to 60 ft^2 of basal area per acre), and when short cutting cycles (3 to 5 years on good sites) are used.

Even though uneven-aged silviculture has been mainly researched and applied in pure pine stands, some options may be available for retaining hardwoods in pine stands. Some midstory and overstory hardwoods may be retained in uneven-aged pine stands if shade is managed rigorously or if hardwoods are spaced strategically. Group selection probably lends itself better to the retention of hardwoods in uneven-aged pine stands than does single-tree selection.

There are advantages and disadvantages to the practice of uneven-aged silviculture (Baker 1989a, Barnett and Baker 1991, Williston 1978). Some of the advantages include:

(1) Periodic and flexible harvests take place without interruption for stand regeneration.
(2) Stands are upgraded if fast-growing, high-quality trees are left to regenerate the stand.
(3) Volume production is concentrated on valuable sawtimber trees.
(4) Cut-over or understocked stands can be quickly restored to full stocking.
(5) Stands may be more esthetically pleasing to some people and provide more varied habitat for wildlife.
(6) Stands are not as vulnerable to complete destruction by wildfire, ice storms, disease, and insects as are even-aged stands.

Some of the disadvantages of uneven-aged silviculture include:

(1) Some area-efficient management practices, such as prescribed burning and chemical treatments, are difficult to apply.
(2) Harvesting may be more difficult and expensive.
(3) More management skill and supervision are required than for other methods.
(4) Competition for light and space occurs in the understory, midstory, and overstory, thereby slowing the early development of the young crop trees.

The uneven-aged silvicultural system is one of several suited for regenerating and managing loblolly and shortleaf pine stands in the South. Some are more suitable to specific site and stand conditions and may meet landowner objectives better than others. This publication can help resource managers determine if the selection method is a viable alternative for meeting their land-management objectives and provide the technical information necessary for implementing and practicing uneven-aged silviculture. It should also be useful to educators as a teaching aid for uneven-aged silviculture.

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APPENDIX

Glossary Of Forestry Terms[3]

All-aged silviculture -- See uneven-aged silviculture (cf. selection method and all-aged stand).

All-aged stand -- See uneven-aged stand (cf. even-aged stand).

Allowable cut -- The volume of wood that can be cut from a stand during a given period without exceeding the stand's net growth during that period.

Artificial regeneration -- Establishing a new forest by planting or direct seeding.

Basal area -- A measurement designation: (*a*) of a tree—the cross-sectional area (in square feet) of the trunk at breast height (4.5 ft above the ground); basal area = 0.005454 times d.b.h. squared or (*b*) of an acre—the sum of basal areas of the individual trees on the area.

Benefit-cost ratio -- The ratio of the sum of discounted revenues over time divided by the sum of discounted costs over time.

Broadcast treatment -- A treatment (i.e., herbicide, prescribed burn) applied over an entire area.

Climax forest -- The final stage of plant succession in which species composition remains relatively stable. Pine stands are an intermediate stage preceding the climax forest.

Commercial harvest -- A cut of a sufficient number or volume of merchantable-sized trees to make the harvesting operation economically feasible (cf. merchantable timber).

Competing vegetation -- Plant species that utilize limited site resources (i.e., sunlight, nutrients, water, and growing space) to the detriment of more desirable crop trees.

Competition control -- Silvicultural treatments to favor one or more plant species over others.

Cost efficiency -- The results of comparing alternatives in situations where dollar values of costs are known, but the outputs are in nondollar or physical units. For example: The volume production per acre over a time period divided by the sum of the discounted costs for the same time period.

Crop tree -- A tree to be grown to maturity and for final harvest. It is usually selected on the basis of its quality, species, and vigor and its proximity to other trees (cf. tree classes: growers).

Cutting cycle -- The planned time interval between major harvesting operations in an uneven-aged stand. For example, a cutting cycle of 10 years in a stand means a harvest every 10 years.

Density -- Number of trees per unit area.

Diameter-limit cutting -- A method of harvesting wherein all merchantable trees above a specified d.b.h. are harvested. In some cases, minimum diameter may be the stump diameter. Unless all trees above the designated minimum d.b.h. are cut, this cutting method could be a form of high-grading.

Even-aged silviculture -- A silvicultural system that involves periodic harvesting of all trees on part of the forest at one time or in several cuttings over a short time to produce stands of trees all the same or nearly the same age.

Even-aged stand -- A stand of trees that are about the same age (usually within 20 percent of rotation age). An even-aged stand may be natural or artificially regenerated (cf. reproduction cutting method).

Fbm -- Abbreviation for board-foot measure.

Financial maturity -- The point in time at which the growth or increase in value of a financial asset (such as a tree) falls below the alternative rate of interest.

Forest cover type -- A descriptive term used to group stands of similar character, composition, and development.

Forest management -- Informally, a long-term program of proper care to ensure that the forest stays healthy and vigorous and provides the products and values the landowner desires. Technical definition: applying forestry principles, technology, and business practices (such as accounting, benefit-cost analysis, etc.) to the forest.

Free-to-grow -- Not overtopped by competing vegetation. The term generally applies to seedlings and saplings.

[3]Adapted from Ford-Robertson (1971), Monaghan and Parker (1980), SAF (1993), and Wenger (1984).

Ground cover -- That proportion of a sample area occupied or overtopped by various vegetative components. A measure of ground cover is often obtained by ocular estimate.

Group selection -- A method of regenerating uneven-aged stands in which trees are removed and new age classes are established in small groups. The maximum width of openings can vary depending on shade tolerance of the species but is approximately twice the height of mature trees in the stand.

Growing stock -- All live trees in a forest or stand, including sawtimber, pulpwood, saplings, and seedlings, that have the potential of becoming merchantable.

Herbaceous vegetation -- Nonwoody species of plants (i.e., forbs, grasses, semiwoody plants, and vines) that normally die back to the ground in winter.

High grading -- The practice of harvesting only the biggest and best trees from a stand and leaving only the poorest to dominate the site.

Improvement cut -- A type of intermediate harvest with the primary objective of improving the remaining stand by harvesting trees of poor quality or form.

Ingrowth -- Trees that grow out of one diameter or height class into another during a specified period of time. Ingrowth is usually measured as basal area or volume per unit area.

Log rule -- A table of values that gives estimated board foot contents for logs of various diameters and lengths. The three log rules most used in the United States are the International ¼-inch, Scribner, and Doyle Rules. Doyle is the most common log rule in the South and is the legal rule in many Southern States.

Mature tree -- A tree that has reached the desired size or age for its intended use. Maturity can be based on financial, biological, or pathological factors (cf. financial maturity).

Merchantable size -- Trees that are ≥3.6 inches in d.b.h. or logs that are >4 inches in diameter at the small end.

Merchantable timber -- Standing trees that are of sufficient size and volume per acre to provide a commercial harvest.

Milacre -- An area of 0.001 acre (3.725 ft in radius), which is convenient for sampling the density and stocking of seedling and sapling size classes.

Milacre stocking -- Proportion of milacres occupied by a plant species of interest, expressed as a percentage of the total number of milacres sampled.

Multiple use -- Land management for more than one purpose, such as wood production and/or water, wildlife, recreation, forage, aesthetics, or clean air.

Natural stand -- A stand resulting from natural seedfall or sprouting.

Net present value -- A comparison of cost and revenues that have been discounted back to the present time, thus rendering revenue directly comparable in time to costs. All discounted costs are summed and subtracted from discounted revenues.

Overtopped -- Trees with crowns entirely below the general level of the crown cover or below competing vegetation and that receive no direct sunlight either from above or from the sides.

Precommercial thinning -- The elimination of trees in a submerchantable-size stand (trees too small to be sold for forest products) to increase the growth rate of residual trees (cf. thinning).

Prescribed burn -- The controlled use of fire to achieve forest management objectives. Prescribed fire can be used to prepare seedbeds for natural pine regeneration, reduce hazardous fuel levels, control unwanted vegetation, improve visibility, and improve wildlife habitat.

Prescription stand -- See stand prescription.

Product classes -- A loose term generally signifying the size limits of trees from which manufactured materials can be derived (cf. pulpwood, sawlog).

Pulpwood -- Wood to be converted into pulp for the manufacture of paper, fiberboard, or other wood-fiber products. Pulpwood-size trees are usually 4 to 9 inches in d.b.h.

***q* (quotient) factor** -- The ratio of the number of trees in any given diameter class to the number in the next smaller diameter class. For example, the q would be 1.2 if there were 12 trees in the 15-inch d.b.h. class and 10 trees in the 16-inch d.b.h. class.

Regeneration cut -- A cutting to remove the old trees and leave environmental conditions favorable for establishment of reproduction.

Regulation -- Scheduling the harvest within a stand to ensure a sustained, even-flow of forest products. When using area regulation, the harvest is based on a defined area. When using volume regulation, the harvest is based on timber volume.

Release -- (*a*) A treatment designed to free young trees from undesirable, usually overtopping, competing vegetation or (*b*) cuttings made to regulate the species composition and improve the quality of very young stands.

Reproduction -- (*a*) Young trees that will grow to become the future forest; or (*b*) the process of forest replacement or renewal, which may be artificial (by direct seeding or planting) or natural (from sprouting or natural seeding).

Reproduction cutting method -- Techniques used to harvest crop trees either in a single cut (clearcut) or in a series of partial cuts (i.e., group selection, seed-tree, shelterwood, single-tree selection) while facilitating the regeneration of forest stands.

Reversed J-shaped distribution -- A d.b.h.-class distribution wherein the number of trees declines as d.b.h. increases (cf. *q* factor).

Sapling -- A small tree, usually 0.6 to 3.5 inches in d.b.h.

Sawlog -- A log large enough to be sawed into lumber.

Sawtimber -- Trees in size classes that are usually specified by a range in d.b.h.: small sawtimber is usually 10 to 15 inches, medium sawtimber is usually 16 to 21 inches, and large sawtimber is usually ≥22 inches in d.b.h.

Seedcrop -- Quantity of seeds produced and dispersed by a plant. Loblolly and shortleaf pine seeds are dispersed from October through February, with peak seedfall in November, throughout the Southeastern United States.

Seedling -- A tree, usually less than 0.6 inch in d.b.h., that has grown from a seed.

Selection method -- Harvesting individual trees or small groups of trees at periodic intervals (usually 5 to 15 years) based on their physical condition, size, age, or degree of maturity. The goal is to produce an uneven-aged stand (cf. group selection, single-tree selection, uneven-aged forest management, uneven-aged silvicultural system).

Shade tolerance -- A tree's capacity to develop and grow in the shade of, and in competition with, other trees.

Single-tree selection -- An uneven-aged reproduction cutting method in which trees are selected from all d.b.h. classes for harvest or retention based on individual tree merits.

Site index (S.I.) -- A measure of forest site quality based on the average height (in feet) of the tallest (never suppressed) trees of a species at a specified age (usually 50 years for natural stands). Site index is usually an approximation in uneven-aged stands because the tallest trees were probably overtopped during the regeneration phase. In this publication, the subjective site quality classes for loblolly-shortleaf pines at 50 years are as follows: good sites (>85 S.I.), medium sites (65 to 85 S.I.), and poor sites (<65 S.I.).

Site preparation -- Preparing an area of land for planting, direct seeding, or natural reproduction by clearing, chemical vegetation control, manual vegetation control, burning, disking, bedding, windrowing, raking, or combinations of these treatments.

Stand prescription -- Usually a document written by a forester prescribing present and future treatments for a forest stand aimed at accomplishing certain forest management objectives.

Stand structure -- The distribution of age or size classes of trees within a forest stand.

Stand types -- Forest stands categorized by species composition. Examples:
- Pine type = >75 percent merchantable pine basal area;
- Pine-Hardwood type = 50 to 74 percent merchantable pine basal area;
- Hardwood-Pine type = 25 to 49 percent merchantable pine basal area;
- Hardwood type = <25 percent merchantable pine basal area.

Stocking -- An estimate of growing-space occupancy. Stocking levels are defined in terms of desirable density, basal area, or tree-area ratio for best growth and management. Examples: fully stocked—a stand with all the growing space effectively occupied but having ample room for the developing crop trees; overstocked—overcrowding in a stand leading to retarded growth of crop trees; understocked—a stand with the growing space not effectively occupied by crop trees.

Stumpage -- The value or volume of a standing tree, or group of trees, uncut "on-the-stump."

Submerchantable size -- Trees too small to be harvested for products (cf. merchantable size, reproduction, sapling, seedling).

Succession -- The replacement of one plant community by another until ecological stability (climax forest) is achieved. For example, an abandoned farm, if left to nature, would gradually go through different stages of vegetative cover and finally reach the climax forest stage after 100 or more years (cf. climax forest).

Sustained yield -- Management of forest land to produce a relatively constant amount of timber and/or revenue. It implies maintaining the best possible forest health and site productivity.

Thinning -- Generally, a partial harvest in an immature stand to reduce the number of trees per acre and encourage the remaining trees to grow faster and produce higher quality wood (cf. precommercial thinning).

Timber marking -- The process of designating trees to be cut or trees not to be cut, usually by spraying a spot of brightly colored paint at the base of the tree and another at eye level. It implies selecting the trees to be removed on the basis of sound forest management principles to meet a specific objective.

Tree-area ratio -- The ratio of the ground area allocated to trees on a sample plot to the total sample plot area. It can be used as an expression of stocking.

Tree classes -- Retention/harvest criteria for classifying trees in uneven-aged stands.
Examples:
Cutters—Trees of poor quality, form, and vigor that are growing at an unacceptable rate, are not expected to survive through the next cutting cycle, or exceed the maximum tree diameter prescribed in the management objectives.
Growers—Trees of good quality, form, and vigor that are growing at an acceptable rate and do not exceed the maximum tree diameter prescribed in management objectives.
Thinners—Trees that could either be harvested immediately or left in the stand for future harvest.

Uneven-aged forest management -- A forest management system that involves frequent partial cuttings to produce uneven-aged stands.

Uneven-aged silvicultural system -- The manipulation of a stand for a continuous forest cover, recurring regeneration of desirable species, and the orderly growth and development of trees through a range of age or diameter classes to provide a sustained yield of forest resources and values.

Uneven-aged stand -- A stand composed of three or more age classes. A balanced uneven-aged stand consists of three or more age classes that are spaced at uniform intervals from reproduction to mature trees. Irregular uneven-aged stands do not contain all the age classes necessary to ensure that trees will reach maturity at short intervals indefinitely.

Value growth rate -- The rate at which a financial asset is growing or increasing in value, usually measured in percent.

Volume table -- A table used to estimate the volume of wood in (a) standing trees, based on dimensions such as d.b.h. and merchantable height or (b) logs, based on diameter and length.

Appendix Forms

STAND INVENTORY WITH TREE CLASSIFICATION

Location ____________________ Acres ______________ Date ______________

Prism Factor/Plot Area _____ Crew ______________

POINT/PLOT NUMBER _____ OF _____

D.b.h. (inches)	PINE			HARDWOODS
	GROWERS	THINNERS	CUTTERS	
4				
6				
8				
10				
12				
14				
16				
18				
20				
22				

Form A-1.—*Sample stand inventory form.*

STAND INVENTORY WITH TREE CLASSIFICATION

Stand Inventory (Summary of pine stems per acre)

Stand location ______________________________ Date ____________

D.b.h. (inches)	GROWERS	THINNERS	CUTTERS	TOTAL	% CUTTERS
Seedlings	- -	- -	- -		- -
Saplings	- -	- -	- -		- -
4					
6					
8					
10					
12					
14					
16					
18					
20					
22					

Form A-2.—*Sample stand inventory summary form.*

UNEVEN-AGED PINE MARKING TALLY

Stand location ______________ Acres ________ Crew ________ Date ________

PULPWOOD (MERCHANTABLE HEIGHT IN FEET)

D.b.h.	10	15	20	25	30	35	40	45	50	55	60
4											
6											
8											

PULPWOOD:
Target No. ___
Marking Ratio
____
(cut:total)
Instruction:
____
____
____
____

SAWTIMBER (16-FOOT LOG HEIGHT)

D.b.h.	1	1½	2	2½	3	3½	4
10							
12							
14							
16							
18							
20							
22							
24							

SMALL SAWLOGS:
Target No. ___
Marking Ratio
____
(cut:total)
Instruction:
____
____
____
____

MED. SAWLOGS:
Target No.___
Marking Ratio
____
(cut:total)
Instruction:
____
____
____
____

LARGE SAWLOGS:
Target No. ___
Marking Ratio
____
(cut:total)
Instruction:
____
____
____

Form A-3.—*Sample tally form for marking uneven-aged pine stands.*

PINE REPRODUCTION AND UNDERSTORY EVALUATION IN UNEVEN-AGED STANDS

Stand location ______________________________ Acres ________________

Date ____________ Crew ____________ Remarks ____________________

(For each milacre, place a ✓ in appropriate boxes across the form.) Page ____ of ____

Mil-acre No.	DOMINANT SUBMERCH. PINE					UNDERSTORY VEGETATION				MERCH. TREE COVER			
	FTG SAP	FTG SDL	OT SAP	OT SDL	NONE	DOMINANT GROUP: HERB	VINE	WOODY	PERCENT COVER	NONE	PINE	HWD	P/H

ABBREVIATIONS AND TERMINOLOGY:

FTG = Free-to-grow from understory vegetation; **OT** = Overtopped by understory vegetation; **SAP** = Pine sapling (0.6 to 3.5 inches in d.b.h.); **SDL** = Pine seedling (1 ft tall to 0.5 inch in d.b.h.); **HERB** = Herbaceous (forbs, grasses, and semiwoody plants); **WOODY** = Nonpine woody vegetation; **HWD** = Hardwood; **P/H** = Pine/hardwood; **SUBMERCH. PINE** = Pine ≤3.5 inches in d.b.h.; **MERCH. TREE** = tree ≥3.6 inches in d.b.h. If SAP or SDL is OT, then the dominant group is that overtopping vegetation; otherwise, the dominant group is the type of vegetation with the greatest coverage. Ocularly estimate "Percent Cover" to nearest 10% (used with fig. 3.1). A milacre is 3.72 ft in radius.

Form A-4.—*Sample tally form for evaluating pine reproduction and understory competition.*

DETERMINATION OF STOCKING LEVELS

C1 D.b.h. class *Inches*	C2 Number *Per acre*	C3 Stocking *Constant*	C4 % stocking *Per acre*	C5 Basal area *Constant*	C6 Basal area *Per acre*
Seedlings		0.167		0.000	
1		0.175		0.000	
2		0.192		0.000	
3		0.218		0.000	
4		0.252		0.087	
5		0.295		0.136	
6		0.347		0.196	
7		0.408		0.267	
8		0.477		0.349	
9		0.555		0.442	
10		0.641		0.545	
11		0.736		0.660	
12		0.840		0.785	
13		0.953		0.922	
14		1.074		1.069	
15		1.204		1.227	
16		1.342		1.396	
17		1.490		1.576	
18		1.646		1.767	
19		1.810		1.969	
20		1.983		2.182	
TOTAL		STOCKING	______	BASAL AREA	______

NOTES:

Column 2 is the cruise summary from the stand.
Column 3 was derived from: Stocking (%) = $0.16667(N) + 0.00404\Sigma(D) + 0.00434\Sigma(D^2)$.
Column 4 is the product of C2 and C3, which is summed to give the stand total.
Column 5 was derived from $0.005454(D)^2$.
Column 6 is the product of C2 and C5, which is summed to give the stand total.

Form A-5.—*Sample worksheet form for determining stocking percent and basal area per acre from cruise data.*

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The results of a half-century of experience and research with uneven-aged silviculture within the loblolly-shortleaf pine type of the Southern United States are summarized, and silvicultural guidelines for developing and managing uneven-aged stands are provided in this publication.

Keywords: Basal-area—maximum diameter—*q* (*BDq*) regulation, group selection, growth and yield, natural stand management, *Pinus echinata* Mill., *Pinus taeda* L., single-tree selection, volume/guiding-diameter-limit regulation.