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REGENERATION METHODS

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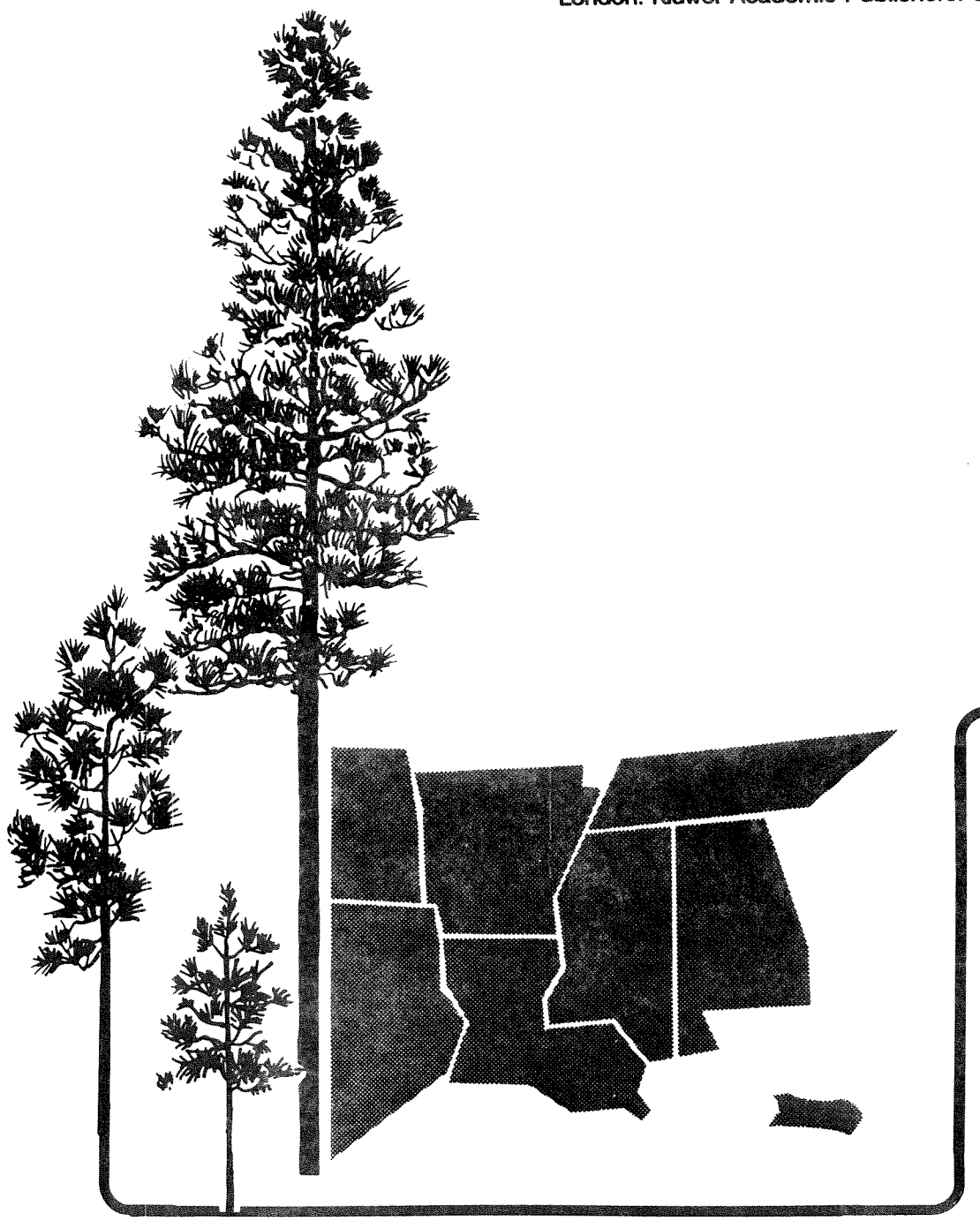

Southern Forest Experiment Station

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Chapter 3
Regeneration Methods

James P. Barnett and James B. Baker

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Abstract

Southern pines can be regenerated naturally, by clearcutting, seedtree, shelterwood, or selection reproduction cutting methods, or artificially, by direct seeding or by planting either container or bareroot seedlings. All regeneration methods have inherent advantages and disadvantages; thus, land managers must consider many factors before deciding on a specific method. A regeneration guide is provided to assist resource mangers in determining which method to use, how to employ it, and what results should be expected.

3.1 Introduction

Southern pines can be regenerated both naturally, by seeds provided from trees growing on or adjacent to the site, or artificially, by direct seeding or planting container or bareroot seedlings. This chapter discusses natural and artificial regeneration methods that can be used with the southern pines, presents production and economic comparisons for the various options, and provides practical regeneration guidelines.

3.2 Regeneration Options

Once the decision has been made to regenerate an area, several important details should be considered before the harvesting operation begins. First, the resource manager or landowner must decide whether to regenerate naturally or artificially. If the area is to be regenerated naturally, then a reproduction cutting method must be selected. If the area is to be regenerated artificially, then regeneration method (seeding or planting) and species must be selected.

Factors to consider before selecting the regeneration method include (1) landowner objective(s), (2) site and stand characteristics, (3) estimated cost of the regeneration method, and (4) expected cash flows associated with the silvicultural system to be employed.

3.2.1 Landowner Objectives

The landowner's objectives and commitment to regeneration often override all other considerations. If the landowner has the required capital and wants to maximize timber or fiber production, then artificial regeneration by planting seedlings would be best, provided that site quality is high enough to justify the investment. If the landowner can invest only limited capital, desires not to clearcut, or has land that will provide a poor return on a high-cost investment, then natural regeneration may be more appropriate than artificial regeneration. Other objectives, such as wildlife habitat, aesthetics, and recreation, should also be considered.

3.2.2 Site and Stand Characteristics

Both site and stand characteristics influence which regeneration method can be used. First, site quality must be determined; then barriers that would hinder regeneration must be identified. Site quality can be determined by site-index curves, soil survey reports, or field soil-site evaluation techniques; additional information regarding characterizing the site is given in chapters 9 through 11, this volume.

Barriers that hinder regeneration include lack of seed source, unwanted residual trees, poor drainage, steep slopes, droughtiness, and hardwood and herbaceous competition. Areas with an unsuitable or inadequate seed source cannot be regenerated naturally. Excessively wet or steep sites, or sites with highly erodible soils, may not be conducive to clearcutting and planting or to direct seeding. Areas with densely spaced hardwoods may not be suitable for some natural regeneration methods.

3.2.3 Cost of the Regeneration Method

The regeneration option providing the maximum return and meeting the cash flow and objectives of the landowner should be selected (see chapter 2, this volume). Costs of artificial regeneration methods are generally higher than those of natural methods because of more intensive site

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preparation, the need for seed or seedlings, and planting operations.

3.2.4 Cash Flow Associated with Silvicultural Systems

Expected cash flows (intermittent costs and incomes) must also be considered. Some natural regeneration methods (seedtree, shelterwood, and selection cutting) provide better cash-flow regimes than artificial methods. For example, with natural regeneration, selection cuts in uneven-aged management would allow frequent, periodic harvests and income every 3 to 7 years, whereas seedtree and shelterwood cuts in even-aged management would spread income from the harvested stand over 5 to 10 years as the residual overstory trees (overwood) are removed. With artificial regeneration, high costs would be incurred at the beginning of a rotation and no income obtained until an intermediate cut between ages 15 and 20.

3.3 Advantages and Disadvantages of Natural and Artificial Regeneration Methods

3.3.1 Natural Regeneration

Advantages

- Low establishment cost.
- Relatively little labor and heavy equipment required.
- Little soil disturbance.
- No problem with geographical origin of seed.
- Not dependent on availability of nursery-grown seedlings or processed seeds.
- Few insect and disease problems for established stand.

Disadvantages

- Little control over spacing and initial stocking.
- Cannot use genetically improved planting stock.
- Loss of income due to leaving seedtrees.
- Precommercial thinning often required in the resulting stand.
- Stand regeneration possibly delayed because of inadequate seed crops.
- Often produces irregular stands not well suited for mechanical harvesting or other stand treatments.
- May require a number of preharvesting operations to ensure regeneration.
- Does not permit species conversion.

3.3.2 Artificial Regeneration

Advantages

- Good control over spacing and initial stocking.
- Can use genetically improved planting stock.
- Not dependent on natural seed crops.
- Few entries into stand needed to prepare for regeneration.
- Permits species conversion.

Disadvantages

- High establishment costs.
- Intensive labor and equipment use.
- Severe insect and disease problems with some species.

3.4 Natural Regeneration

Managing for natural regeneration uses harvesting methods and cultural treatments to establish a new forest stand from seed produced on or near the area. If an adequate seed source is available, this method provides a versatile, practical, low-cost alternative to planting on some industrial and National Forest lands and is especially suitable for nonindustrial private land.

Several reproduction cutting methods are employed for the major southern pine species. Clearcutting, seedtree, and shelterwood methods establish even-aged stands, whereas selection cutting develops or maintains uneven-aged stands (see 3.4.2).

3.4.1 Basic Management Principles

Regardless of the reproduction cutting method used, certain basic principles must be considered to ensure successful natural regeneration: (1) a seed source must be available, (2) some site preparation and cultural treatments, including competition control, are usually required, (3) precommercial thinning in dense stands may be beneficial, and (4) regenerating seedlings must be protected [1]. Each of these important principles is discussed for loblolly pine (*Pinus taeda* L.), shortleaf pine (*P. echinata* Mill.), longleaf pine (*P. palustris* Mill.), slash pine (*P. elliottii* Engelm.), and the Choctawhatchee variety of sand pine (*P. clausa* var. *immuginata* D. B. Ward). Because the Ocala variety of sand pine (*P. clausa* var. *clausa* D. B. Ward) has serotinous cones, most natural reproduction cutting methods are not suitable for it [15, 32].

3.4.1.1 Seed-source characteristics

Good natural regeneration requires an adequate, high-quality seed source. Seeding characteristics of the southern pines vary with species, physiographic region, climatic factors, and tree and stand conditions. Some of these characteristics are summarized in Table 3.1.

A good seed crop is considered to be an adequate number of seeds to regenerate an area under average

Table 3.1. Seeding characteristics of southern pines for average sites. (Citation is in brackets next to species.)

Species	Frequency of good seed crops, years	Period of peak seedfall	Effective distance of seed dispersal, m (ft)
Loblolly [4]	2–4	Late Oct.–Nov.	69–91 (200–300)
Shortleaf [26]	3–6	Nov.	61–91 (200–300)
Longleaf [9]	3–5	Late Oct.–Nov.	18–21 (60–70)
Slash [34]	3	Oct.	46–76 (150–250)
Sand [31]	4–6	Oct.	61–76 (200–250)

conditions. For loblolly and shortleaf pines, > 197,680 sound seeds/ha (80,000 seeds/ac) is considered a good seed crop; 74,130 to 197,680 seeds/ha (30,000 to 80,000 seeds/ac) an average crop; and < 74,130 seeds/ha (30,000 seeds/ac) a marginal to poor crop [2]. About 123,550 seeds/ha (50,000 seeds/ac) is the minimum needed to adequately restock a prepared seedbed.

Procedures described by Trousdell [36], Wenger [39], Grano [22], and Croker and Boyer [17] provide estimates of total number of cones and/or seeds per tree or per unit area. Evidence of good, fair, or poor seed crops should be apparent by early summer; thus, the seedbed can be prepared before seedfall in early winter.

3.4.1.2 Site preparation and cultural treatments

Assuming an adequate seed crop, effective site preparation and hardwood control are the two most important elements for successful natural regeneration. They should be planned in advance and be carried out in a timely, effective manner, the type and intensity of treatment depending, of course, on the species, local site and stand conditions, abundance of the expected seed crop, and reproduction cutting method. Inadequate control of competing vegetation – particularly midstory and overstory hardwoods – is probably the primary reason for most regeneration failures. (For more information on site preparation, see chapters 12 and 13).

Because of their large seeds, longleaf and slash pines require a seedbed of exposed mineral soil to achieve satisfactory seedling establishment. Loblolly, shortleaf, and Choctawhatchee sand pine seeds do not require exposed mineral soil for germination and seedling establishment when the seed crop is heavy but do when the seed crop is light. In most cases, soil disturbance during logging is sufficient to expose mineral soil.

More intensive brush control is usually required on moist, highly productive sites than on drier, less productive soils. The competitive hardwoods can overtop the pine and occupy the site much faster on the good (productive) sites than the poor sites. Most of the time, however, natural regeneration of the southern pines has resulted in too much stocking, rather than too little. The exception is with longleaf, for which reproduction is rarely excessive. Thus, to achieve optimal stocking levels for species other than longleaf, the intensity of site-preparation and competition-control treatments before logging should be keyed to the abundance of the seed crop. If a survey indicates an abundant seed crop, then site preparation and brush control can be kept to a minimum; however, a sparse seed crop will warrant more intensive treatments. For the best results, overstory and midstory hardwoods should always be controlled.

With even-aged reproduction cutting methods (clearcutting, seedtree, and shelterwood), a well-planned prescribed burning program before the reproduction cut provides the least expensive site preparation and brush control. Prescribed burns not only reduce forest-floor litter and ground vegetation but also eliminate some of the smaller hardwoods. Midstory or overstory hardwoods should be harvested or treated with a suitable herbicide. On sites where pine seedlings are difficult to establish – because of droughty conditions or excessive litter and vegetative cover – some mechanical scarification by chopping, disking, or light scalping with a bulldozer may be required immediately before or after logging. Additional control of competing hardwoods may be needed once seedlings have become established (see also chapter 19). Young pines (≤ 3 years old) should be released from dense weeds, brush, or vines with herbicides. Once the trees reach 4 to 6 m (12 to 15 ft) tall and are safe from fire damage, prescribed burning may again be used to control hardwoods.

With uneven-aged selection cutting, site preparation is achieved almost exclusively by the logging operation and by chemicals to control the larger hardwoods [11]. If fully stocked uneven-aged stands are cut on relatively short cycles (5 to 10 years), logging usually scarifies the site and retards the development of hardwood brush sufficiently to permit adequate reproduction.

3.4.1.3 Precommercial thinning

If the new stand contains more than 12,360 stems/ha (5,000 stems/ac) at 3 to 5 years of age, it should be precommercially thinned. Stands having between 3,700 and 12,360 stems/ha (1,500 to 5,000 stems/ac) between ages 3 and 5 should be thinned only if it is estimated that live-crown ratios of dominant and codominant trees will be < 35% at the time of the first commercial thinning [28]. Precommercial thinning is critical for slash pine because this species tends to stagnate in young, dense stands.

Mechanical thinning with a tractor-drawn rotary mower is one of the most practical methods for reducing stocking if the site is relatively free of high stumps and slash. Sometimes, heavier equipment such as a rolling chopper must be used, but thinning costs will increase. Stands should be thinned to leave 1,480 to 1,730 dominant stems/ha (600 to 700 stems/ac) by mowing or chopping lanes 2.4 to 3.7 m wide (8 to 12 ft wide), leaving uncut strips 0.3 to 0.6 m wide (1 to 2 ft wide).

3.4.1.4 Protection

Regenerated stands must be protected from wildfires, insects, and diseases. Loblolly, shortleaf, slash, and sand pines are particularly susceptible to wildfire the first 6 to 10 years following establishment. With seedtree and shelterwood methods, some insurance against complete loss by fire can be provided by retaining 5 to 7 seedtrees/ha (2 to 3 seedtrees/ac) until the first pulpwood thinning.

Early in the rotation insect and disease problems are not generally as common or devastating in naturally regenerated stands as in planted stands, but some pests are likely (see chapter 20). Seedling debarking weevils (*Hylobius* and *Pachylobius* spp.) can infest young naturally regenerated trees near felled green timber. The pine

tipmoths (*Rhyacionia* spp.) may damage young open-grown stands such as those in clearcuts but are not usually a severe problem where some type of overstory or brush is intermingled with the seedlings. Fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) is typically not as severe in natural stands as in plantations, but there may be some damage to susceptible species in high rust-hazard areas [4].

3.4.2 Reproduction Cutting Methods

3.4.2.1 Even-aged methods

Three reproduction cutting methods are available for natural regeneration of even-aged stands: clearcutting, seedtree, and shelterwood.

Clearcutting. – For loblolly, shortleaf, and sand pine, clearcutting can be used to regenerate small blocks, patches, or narrow strips if there is an available seed source from adjacent stands (Fig. 3.1A). The long axis of the clearcut areas should be perpendicular to the direction of prevailing winds during seedfall. The clearcut should not exceed 91 to 122 m (300 to 400 ft) in width or 3.3 to 4.0 ha (8 to 10 ac) in total area to ensure adequate seeding over the entire area. Site preparation, if any, should increase in intensity with distance from the seed source to encourage uniform stocking in the new stand. This method is generally not suitable for longleaf pine because seed dispersal is limited to short distances.

Most southern pine species and areas larger than described in the previous paragraph can be regenerated by clearcutting with either seed or seedlings in place (Figs. 3.1B, C). With seed in place, the stand may be clearcut

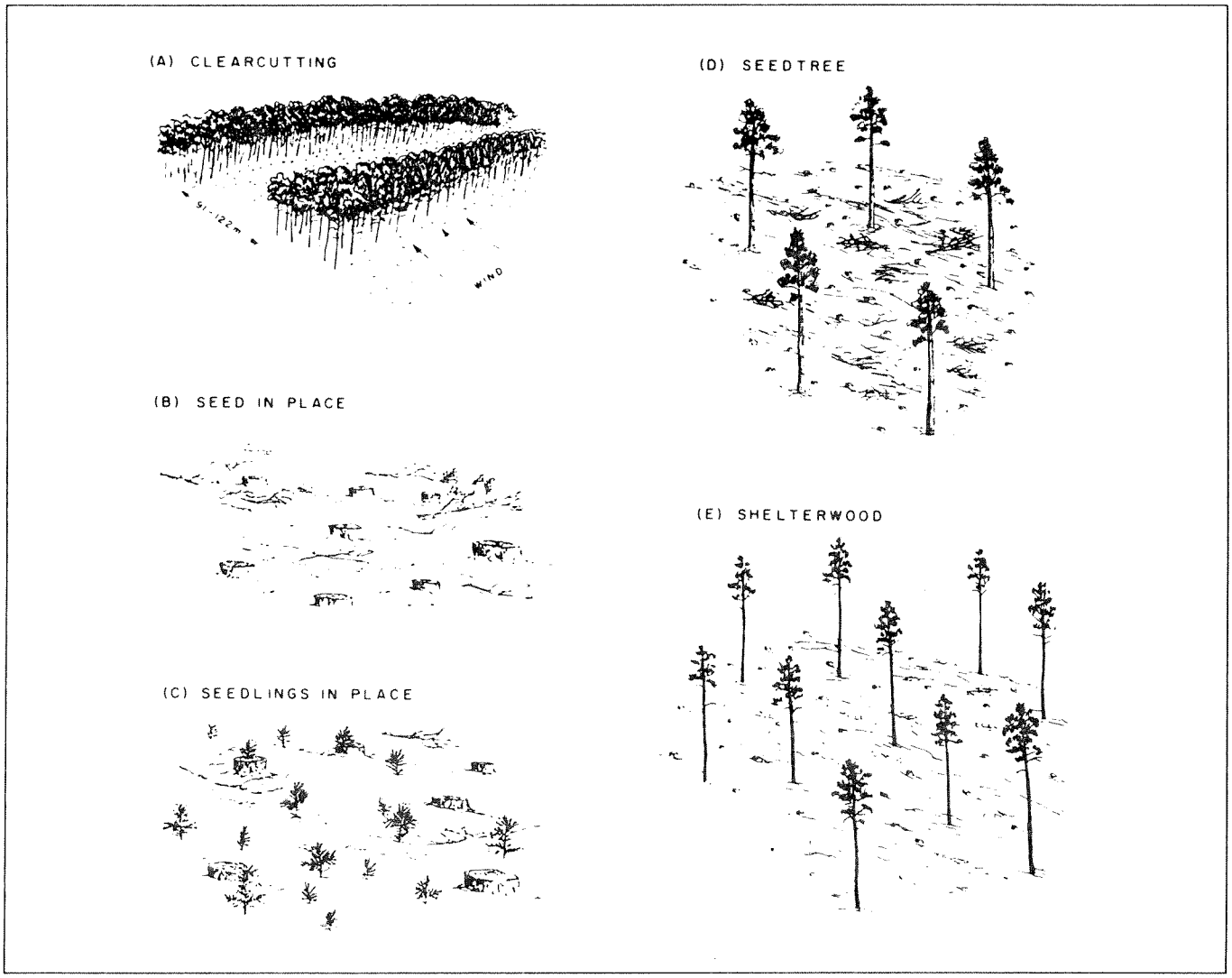

Figure 3.1. Natural regeneration by several methods. (A) Clearcutting in strips: Seeds are provided by adjacent stands. (B) Seed in place: Stand is clearcut after cone maturity and peak seedfall but before germination. (C) Seedlings in place: Stand is clearcut in late summer following a good seed year. (D) Seedtree: All but 10 to 15 trees/ha (4 to 20 trees/ac), depending on species and size, are cut. (E) Shelterwood: All but 75 to 120 trees/ha (30 to 50 trees/ac), comprising 5 to 7 m^2/ha (20 to 30 ft^2/ac), are cut. (Adapted from Williston et al. [41]).

Table 3.2. Schedule of activities for clearcutting and naturally regenerating a hypothetical loblolly or shortleaf pine stand having the following characteristics: fully stocked, 50 years old, even aged, some midstory and overstory hardwoods, no previous hardwood control.

Activity	Schedule
(1) Control hardwoods (first burn)	6 years before clearcutting
(2) Control hardwoods (second burn)	3 years before clearcutting
(3) Prepare site	Spring in year of clearcutting
(4) Treat nonmerchantable hardwoods with herbicide[1]	Spring in year of clearcutting
(5) Harvest all merchantable pines and hardwoods	Before September,[2] or September-March,[3] or fall[4] 1 year after a good seed year
(6) Evaluate stocking	Winter 2 years after clearcutting
(7) Evaluate need for pine release and/or precommercial thinning	3 to 5 years after clearcutting

[1] May use foliar or basal spray, cut-surface treatment, or soil-applied herbicide. Treatment will depend on size and number of hardwood stems.
[2] If area is to seed from trees in adjacent stands.
[3] If seed in place technique is used.
[4] If seedlings in place technique is used.

from September through March, after cone maturity or seedfall but before seed germination. Probably the most common, and perhaps the best, application is after cones have matured, but before they open. Once the mature cones distributed in the logging slash (debris) open, seeds fall on a scarified site. If the site is logged after seedfall, many seeds are buried in the slash. With seedlings in place, the stand is clearcut in late summer following a good seed year. Both methods require ample seed crops and involve a high risk because they provide a one-time chance for successful natural regeneration.

The advantages and disadvantages of clearcutting are as follows:

Advantages
- Management areas easily defined and treated.
- Harvesting and cultural operations concentrated in time and space.
- No high-value trees left on the site.
- A relatively low level of technical skill and supervision required.
- Wildlife dependent on early successional vegetation benefits.

Disadvantages
- A large amount of logging debris generated.
- Fairly intensive site preparation may be required.
- The regenerated stand may be more susceptible to insect and disease hazards.
- No merchantable material can be harvested from the new stand for a relatively long time (15 to 20 years).
- The site may be aesthetically less pleasing for a short period following harvest.
- Wildlife dependent on mature trees may be displaced.

A proposed schedule of activities for obtaining natural regeneration of a hypothetical loblolly or shortleaf pine stand with the clearcutting method is presented in Table 3.2. If conditions for a specific stand differ from those of the hypothetical stand, then the schedule of activities may have to be altered accordingly. Some activities, for example, (1), (2), and (4) in Table 3.2, may not be needed if the specific stand was under a good hardwood-control program.

Seedtree. – The seedtree method, which can be used for loblolly, shortleaf, slash, and Choctawhatchee sand pine, requires cutting all but 10 to 50 well-spaced, wind-firm, high-quality seed-bearing trees/ha (4 to 20 trees/ac), leaving 1.4 to 2.8 m^2/ha (6 to 12 ft^2/ac) basal area (Fig. 3.1D). The number of seedtrees left depends on species, tree size, and site conditions (Table 3.3). The seedtree method is not recommended for longleaf pine because seed production and dispersal are not adequate with as few as 50 trees/ha (20 trees/ac).

Before the reproduction cut, the area should be prescribe-burned to prepare a seedbed and control small hardwoods. The reproduction cut should be timed so that seeds will be dispersed on a site freshly scarified by logging. To ensure obtaining adequate seeds, seedtrees can be released three to five growing seasons before the reproduction cut by cutting a radius of 5 to 10 m around each seedtree or by thinning the stand to 14 to 16 m^2/ha (60 to 70 ft^2/ac) merchantable basal area; such release will enhance seed production during the first year after the

Table 3.3. Minimum recommended number of seedtrees per hectare (per acre) and basal area, BA [m^2/ha (ft^2/ac)], by species and diameter for four southern pine species growing on average sites (adapted from Williston et al. [41]).

dbh,[1]	Loblolly		Shortleaf		Slash		Sand	
cm (in.)	No.	BA	No.	BA	No.	BA	No.	BA
25.4 (10)	30 (12)	1.5 (6.5)	50 (20)	2.5 (10.9)	30 (12)	1.5 (6.5)	42 (17)	2.2 (9.4)
30.5 (12)	20 (8)	1.4 (6.3)	35 (14)	2.5 (11.0)	22 (9)	1.6 (7.1)	30 (12)	2.2 (9.4)
35.6 (14)	15 (6)	1.5 (6.4)	25 (10)	2.4 (10.7)	15 (6)	1.5 (6.4)	22 (9)	2.2 (9.6)
40.6 (16)	10 (4)	1.3 (5.6)	20 (8)	2.6 (11.2)	10 (4)	1.3 (5.6)	17 (7)	2.2 (9.8)

[1] Stem diameter 1.37 m (4.5 ft) above ground.

Table 3.4. Schedule of activities for using seedtrees to naturally regenerate the same hypothetical loblolly or shortleaf pine stand as described in Table 3.2.

Activity	Schedule
(1) Control hardwoods (first burn)	6 years before reproduction (seedtree) cut
(2) Control hardwoods (second burn)	3 years before reproduction cut
(3) Make preparatory cut[1]	3 years before reproduction cut
(4) Prepare site (burn)	Spring in year of reproduction cut
(5) Select and mark seedtrees	After the site-preparation burn, in year of reproduction cut
(6) Treat nonmerchantable hardwoods with herbicide[2]	Spring in year of reproduction cut
(7) Cut all merchantable pine and hardwoods except previously marked seedtrees	Late summer or fall
(8) Evaluate stocking	Winter 2 years after reproduction cut
(9) Remove seedtrees	As soon as seedlings are well established (usually 2 to 5 years after reproduction cut)
(10) Evaluate need for pine release and/or precommercial thinning	3 to 5 years after reproduction cut

[1] A preparatory cut would be required only if the stand is overstocked and potential seedtrees are small-crowned and poor cone or seed producers.
[2] May use foliar or basal spray, cut-surface treatment, or soil-applied herbicide. Treatment will depend on size and number of hardwood stems.

reproduction cut. This technique is particularly important if the crowns of seedtrees are small. The seedtrees should be removed as soon as possible (usually 3 to 5 years) after at least 2,470 well-distributed seedlings/ha (1,000 seedlings/ac) have become well established.

The advantages and disadvantages of the seedtree method are similar to those of clearcutting, with the following additions:

Advantages
- There is no need to rely on adjacent stands for seeds; thus, larger areas can be established and treated efficiently.
- Delayed removal of seedtrees following stand regeneration safeguards against loss from fire or climatic agents.
- Some precommercial thinning can be done, if needed, by skidding logs from the reproduction cut through dense patches of young seedlings.
- Some control of species composition is possible.

Disadvantages
- Seedtrees may limit site preparation and slash disposal.
- The seed source is exposed to lightning, wind, and other hazards.
- Removing the seedtrees from the site may not be economically practical.

A proposed schedule of activities for obtaining natural regeneration of a hypothetical loblolly or shortleaf pine stand with the seedtree method is presented in Table 3.4. If conditions for a specific stand differ from those of the hypothetical stand, then the schedule of activities may have to be altered accordingly. Some activities, for example, (1), (2), (3), and (6) in Table 3.4, may not be needed if the specific stand was under a good hardwood-control program.

Shelterwood. – The shelterwood method is similar to the seedtree method except that 75 to 125 trees/ha (30 to 50 trees/ac), comprising 5 to 7 m^2/ha (20 to 30 ft^2/ac) of basal area (Table 3.5), should be left to regenerate the area (Fig. 3.1E). As for the seedtree method, the number of trees left depends on tree size, species, and site and stand conditions. However, leaving more trees usually helps suppress the development of competing hardwood brush. The shelterwood method is well suited to regenerating most of the southern pines, and is the recommended method for longleaf.

A two-cut shelterwood – the first cut to leave the seedtrees, the second to remove the overwood – is usually recommended unless the stand is overstocked (Fig. 3.2). In unthinned or dense stands, a preparatory cut may also be required. Competing hardwoods should be controlled before the first cut, by prescribed fire for the small hardwoods and by herbicides for the larger ones. Once enough pine seedlings become well established after the first cut (usually within 3 to 6 years), the overwood is removed. If seedlings are too dense – over 12,350 stems/ha (5,000 stems/ac) – stands can be precommercially thinned by skidding logs through the dense seedling patches.

The advantages and disadvantages of the shelterwood method are summarized as follows:

Advantages
- Slash disposal is less necessary than with the clearcutting or seedtree methods.

Table 3.5. Number of trees per unit area required to leave a shelterwood basal area of between 5 and 7 m^2/ha (20 to 30 ft^2/ac).

dbh, cm (in.)	Lower limit, per hectare (acre)	Upper limit, per hectare (acre)
25.4 (10)	91 (37)	136 (55)
30.5 (12)	62 (25)	94 (38)
35.6 (14)	47 (19)	69 (28)
40.6 (16)	35 (14)	52 (17)
45.7 (18)	27 (11)	42 (17)

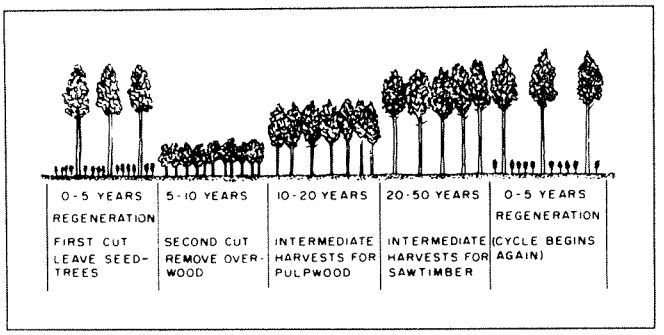

Figure 3.2. Stages of a typical two-cut shelterwood system. (Adapted from Baker [1]).

- Overwood often suppresses development of competing hardwood brush.
- Overwood continues to produce high-quality growth until removed.
- Control of species composition is possible.
- The site is better protected and more pleasing aesthetically than with the clearcutting and seedtree methods.

Disadvantages
- Large numbers of residual trees are subject to logging damage and impede harvesting and site preparation.
- Overwood may hinder growth of young pines.
- The number of seedlings produced may be excessive, requiring precommercial thinning.
- A high level of technical skill and adherence to scheduled treatments and harvests may be required.

The schedule of activities for the shelterwood method is basically the same as for the seedtree method (see Table 3.4).

3.4.2.2 Uneven-aged methods

If the management objective is to maintain an uneven-aged stand (in which seedlings, saplings, pulpwood, and small and large sawtimber are all represented) and to harvest at relatively frequent intervals, the selection method is the best alternative for some southern pine species. Uneven-aged management is particularly suitable for loblolly and shortleaf pines and can be used to some extent for longleaf. This system is not suited to slash pine because slash tends to stagnate in dense, young stands and has not been tested with sand pine.

The selection method involves periodic cutting (3- to 10-year intervals) of selected trees from all merchantable diameter classes. In fully stocked stands – stands having 14 to 17 m^2/ha (60 to 75 ft^2/ac) of merchantable basal area with two-thirds to three-fourths of the basal area as sawlogs – harvest volumes should generally approximate growth for the cutting period or cutting cycle. In stands that are not fully stocked, only a portion of growth is cut. Trees selected for harvest can be single, isolated trees of groups of trees. However, if at all possible, the slow-growing and/or poor-quality trees should be cut and the best trees left so that stand quality and growth are improved.

To maintain an adequate uneven-aged stand structure, establishment of new seedlings is usually necessary only about 1 year out of 10. Pine seedlings will usually develop under single-tree selection if density after overstory removal is reduced to 10 to 14 m^2/ha (45 to 60 ft^2/ac) of basal area and site conditions are favorable. Structure in the merchantable component of the stand can be maintained by either the BDQ (basal area, maximum diameter, and constant ratio of number of trees in successive diameter classes) method or the guiding-diameter-limit method of volume regulation.

The advantages and disadvantages of the selection method are summarized as follows:

Advantages
- Provides periodic and flexible income without interruption for stand regeneration.
- Upgrades the stand if fast-growing, high-quality trees are left to reproduce.
- The stand is not as vulnerable to destruction by fire and biotic or climatic agents as with even-aged methods.
- Production is concentrated on valuable sawtimber trees.
- May be more aesthetically pleasing and provide more varied habitat for wildlife.

Disadvantages
- Makes specific, efficient management practices, such as prescribed burning and chemical treatments, difficult to apply.
- Harvesting operations may be difficult and expensive.
- Requires more management skill and supervision than other reproduction methods.
- Inventorying and growth projections are difficult.

3.5 Artificial Regeneration: Direct Seeding

Direct seeding is a versatile reforestation technique that may be used on most sites and in some situations where a suitable natural seed source is not available and where access, terrain, or soil conditions make planting difficult, expensive, or impossible [40]. The method has been used to reforest areas ranging from a few to 14,160 ha (35,000 ac).

Direct seeding is an effective, rapid, and inexpensive regeneration alternative for southern pines. But like other regeneration methods, it is not fail-safe. However, most recorded failures have been due to improper application techniques such as seeding on unsuitable sites or out of season, inadequate site preparation, use of poor-quality seed, and sowing too few or untreated seeds. Many such failures can be easily avoided by following some simple guidelines.

3.5.1 Selecting Seeding Sites

Every seeding situation is different and must be judged on its individual merits before a prescription can be prepared. Nearby planted or natural stands on similar soils should be examined to determine whether direct-seeded

(A)

(B)

(C)

Figure 3.3. Artificial regeneration by (A) aerial seeding with a helicopter, (B) row seeding with a furrow seeder, and (C) spot seeding with a hand tool to clear the spot.

stands will be successful. Sites where planting has already failed should be considered unsuitable. Generally, sites that can be planted can be seeded, but the following should always be avoided:

(1) Sites subject to heavy grazing unless grazing can be controlled the first 2 to 3 years.

(2) Low-lying, poorly drained sites where seeds are likely to be covered with standing water for a week or more during February, March, or April.

(3) Deep, upland sands that dry out rapidly after a rain. (Not only is soil moisture usually too low to sustain germination, but a sandy surface often forms crusts and prevents penetration of the radicle even if the seeds do germinate.)

(4) Highly erodible soil and steep slopes where seeds are likely to be displaced by water movement.

Seedlings established by direct seeding require better growing conditions and more intensive site preparation than planted ones. Sites with a heavy grass sod must be disked or harrowed before seeding to reduce competition during the first growing season when young pines are susceptible to low soil moisture [18]. There is one ground rule for direct seeding – seeds must be in contact with mineral soil.

3.5.2 Seed Handling and Protection

An important prerequisite for direct seeding success is the use of good seeds that have been properly stored, stratified, and treated with bird and rodent repellents [18] (see chapter 4). Heavy concentrations of seed predators can consume up to 11.2 kg/ha (10 lb/ac) of untreated loblolly seeds during the germination period.

Few forest managers are equipped to collect cones, then extract, store, stratify, and treat the seeds with repellents. The simplest procedure, especially for the small landowner, is to purchase seeds ready for sowing from a reputable seed dealer. Seeds should be purchased and a sowing contractor (if needed) engaged well in advance of the seeding operation. Seed delivery should be delayed until time for sowing, however. Stratified and repellent-treated seeds can be held only about 2 weeks under *cool* conditions; air-conditioned facilities are advisable. If seeds are to be held longer than 2 weeks, they should be cold-stored between –4 and 4.4°C (25 and 40°F) [8]. Storage below –4°C will

damage the water-saturated megagametophytes; storage too long above 4.4°C will promote germination or spoilage.

Repellent-treated seeds are coated with thiram, an effective bird repellent, and endrin, an effective rodent repellent that is highly toxic to humans. After handling treated seeds, even with rubber gloves, the hands and face should be washed thoroughly before eating, drinking, or smoking. Do not take the slightest chance of getting endrin on the skin or in the mouth, nose, or eyes. Treated seeds are perfectly safe to handle when proper precautions are followed; otherwise, they can be very dangerous.

3.5.3 Seeding Methods

3.5.3.1 Broadcast seeding

Broadcast seeding is a technique of scattering seeds over the entire reforestation area. Usually, the most economical way to seed small areas is by hand. One person using a cyclone grass seeder on easily walked terrain can cover up to 5 ha (12 ac) per day. Walking in straight, carefully flagged lines will result in a fairly uniform distribution of seeds. The seeder must be carefully calibrated for the desired sowing rate. On small farm woodlots, seeds may be scattered by hand in a relatively uniform pattern.

Larger acreage is best seeded by aircraft, but such aircraft must also be calibrated for the desired sowing rate (Fig. 3.3A). On a calm day when everything goes well, a helicopter can cover up to 1,200 ha (3,000 ac); however, the usual daily average is about 600 to 800 ha (1,500 to 2,000 ac) [12].

The major advantages of broadcast seeding are its speed and low cost. Major disadvantages are the lack of spacing and stand-density control and high consumption of seeds by predators.

3.5.3.2 Row seeding

Row seeding consists of sowing seeds in bands across an area. It may be preferred over broadcast sowing when the landowner desires better control over spacing and density or needs trees in rows for mechanical harvesting. On a well-prepared site, seeds can be dropped by hand as one person walks a furrow, row, or line. Seeds should be spaced 0.3 to 0.6 m (1 to 2 ft) apart within the row. A common recommendation for spacing between rows is 3 m (10 ft) to reduce the number of trips across an area.

Furrow seeders, drawn behind tractors, are effective on light- to medium-textured soils with good internal drainage (Fig. 3.3B). Up to 6 ha (15 ac) per day can be seeded with a furrow seeder. Some seeders use hillers to leave a ridge of soil about 15 cm (6 in.) wide down the center of the furrow; seeds are dropped on the ridge and pressed firmly into the soil by a packing wheel [16]. The elevated seedbed reduces seed losses due to soil movement and temporary flooding. On coarse and droughty sands, hillers are not effective. Instead, seeds should be planted in a shallow trench in the bottom of the flat furrow and lightly covered with soil by a drag plate. Furrow seeders are not practical on sites subject to prolonged flooding due to poor surface drainage.

Some row seeders have rotating disks that throw up a seedbed 7.5 to 15 cm (3 to 6 in.) high. These seeders work well on low-lying, poorly drained sites because surface water drains off into the furrow on either side of the elevated seedbed, preventing seed losses by submergence and washing, although some seeds may be lost by silting on a rough bed surface [18].

3.5.3.3 Spot seeding

Spot seeding is just what the name implies: dropping a predetermined number of seeds on a small spot (Fig. 3.3C). It offers the same spacing control as planted nursery seedlings, but is the slowest and most labor-intensive of the three sowing methods. However, spot seeding is the most highly recommended method for small landowners who can do the work in their spare time with a minimum of tools and equipment and who must keep out-of-pocket expenses to a minimum.

When the site has been properly prepared and mineral soil is exposed, three to five seeds should be dropped in a cluster. If surface litter or grass sod still occupies the site, a spot should be cleared with the foot, a hoe, a firerake, or other means to bare mineral soil. Seeds should be dropped and pressed lightly into the soil surface with the foot. On drier sites or sloping terrain, it may be wise to cover seeds with a layer of soil not to exceed 1 cm (0.38 in.) deep.

Sowing three to five seeds per spot is recommended to ensure stocking. However, two or more seeds will germinate on many spots and result in a cluster of seedlings. Such multiple-stocked spots should be thinned to a single seedling after 2 or 3 years because clustered seedlings have significantly reduced height and diameter growth by age 15 [13].

3.5.4 Time and Rate of Sowing

In most areas, including the Middle and Upper Coastal Plain from Louisiana to South Carolina, sowing should be done from mid-February through early March with stratified seeds [18, 25]. Seeds sown at these times will usually germinate in a few weeks and develop good root systems before the weather becomes hot and dry in early summer. Fall sowing for early spring germination generally is not recommended because the seeds may lose their repellent coating by weathering and are subject to numerous hazards when on the ground for a lengthy period [27]. Tender young seedlings from fall-sown seeds are clipped by rabbits or other predators during midwinter when few other plants are green. In addition, some young seedlings may be lost to frost heaving on disked or harrowed soils.

However, fall sowing is recommended for the extreme southern portion of the range, including sites within 80 km (50 mi) of the Gulf Coast and interior central Florida. Here, dry weather in early spring frequently causes heavy losses in stands established in February [18]. This region has mild winters with temperatures frequently above 21°C (70°F), the point at which most longleaf and slash pine seeds will germinate. Moreover, clipping damage during winter has not been a serious problem.

Table 3.6. Suggested sowing rates, by sowing method, for southern pines (adapted from Derr and Mann [18]).

Pine species	No. of seeds/kg ((lb)[1]	Weight of dry seeds, kg/ha (lb/ac)		
		Broadcast	Row[2]	Spot[3]
Longleaf	2,040 (4,500)	1.36 (3.00)	0.73 (1.60)	0.60 (1.33)
Slash	5,900 (13,000)	0.45 (1.00)	0.25 (0.55)	0.21 (0.46)
Loblolly	8,400 (18,500)	0.45 (1.00)	0.18 (0.39)	0.15 (0.32)
Shortleaf	20,400 (45,000)	0.18 (0.40)	0.07 (0.16)	0.06 (0.13)
White[4]	9,980 (22,000)	0.45 (1.00)	0.15 (0.33)	0.15 (0.27)
Virginia[4]	20,400 (45,000)	0.18 (0.40)	0.07 (0.16)	0.06 (0.13)

[1] Dry, untreated seed, with a viability of 95 to 100%.
[2] Two meters (6 ft) between rows.
[3] One thousand spots/acre.
[4] White pine (*Pinus strobus* L.) and Virginia pine (*P. virginiana* Mill.).

Seeding rates per unit area frequently used for loblolly and slash pine seeds weighed before being stratified and repellent-coated are 0.45 kg (1 lb) for broadcast seeding, 0.34 kg (0.75 lb) for row seeding on a disked bed, and 0.23 kg (0.50 lb) for either spot or furrow seeding. However, rates are frequently reduced by about one-third in the Southeast, where first-year survival is generally higher because of frequent summer showers and where landowners are willing to accept lower stand densities (Table 3.6). As experience is gained, the trend is toward lower rates and prescription sowing, i.e., adjusting the sowing rate to conditions on each particular site [14]. The sowing rate may be lower on well-prepared, moist soils, for example, than on coarse, dry sands. But increased sowing rates must not be used as a substitute for site preparation, repellent coating, or high seed quality. Instructions on these points must be followed or the operation may be a failure regardless of seeding rate.

3.5.5 Evaluating Seeding Success

The seeded area should be closely evaluated during the first year to measure overall seedling establishment and to assess the losses of seeds and new seedlings. The information gained will be valuable for future seeding operations and should indicate whether additional treatments are needed (see also chapter 18).

For the purpose of evaluation, several inspection stations should be set out, clearly marked for relocation, and sown with an ample supply of seed [18]. A station in a row-seeded area can be a 6-m (20-ft) row segment; in a broadcast area, it can be a 4.6- to 9.3-m^2 (50- to 100-ft^2) plot. The number of such stations will vary with ground cover type, but 50 are sufficient for an area of 400 ha (1,000 ac). Stations are inspected at weekly or biweekly intervals from seeding time until germination is complete, usually by early summer. Empty seed hulls, condition of repellent coating on ungerminated seed, and type of damage to seeds and seedlings are noted. New seedlings are conspicuously marked in order to follow their progress during this critical period.

In any case, seedlings should be inventoried twice during the first year to evaluate overall success of the seeding operation, once in the spring after germination is complete and once in the fall after annual vegetation dies back. The difference between the two inventories indicates losses during the critical first summer. Losses thereafter are usually low.

One caution when evaluating new stands: young seedlings are difficult to find. Many operations have been written off as failures when adequate seedlings were present but unobserved. Before admitting defeat, get down on your knees to look closely.

3.5.6 Recommended Uses of Seeding

Although direct seeding is not now widely used to regenerate southern pines, it does meet several reforestation objectives. Seeding is an excellent technique for landowners to inexpensively regenerate small areas; it can also be used to quickly reforest large acreages ruined by wildfires. Clearly, direct seeding will continue to be used to meet these special needs. However, general interest in direct seeding has declined because of the lack of control of tree spacing and failures under unfavorable climatic conditions. Furthermore, direct seeding does not efficiently utilize genetically improved seeds because the process uses many seeds to establish one seedling.

3.6 Artificial Regeneration: Planting Bareroot and Container Stock

Performance in the field is the ultimate measure of the quality of seedlings used for reforestation, of the care provided to seedlings after completion of the nursery phase, and of the care and supervision of the planting operation. Although planting bareroot stock is the mainstay of artificial regeneration, the use of container-grown seedlings continues to increase in the South.

3.6.1 Comparison of Bareroot and Container Stock

The relative merits of container and bareroot stock have been summarized by a number of workers [5, 19, 21, 24] and are discussed briefly in chapter 7. Advantages usually listed for container seedlings include a longer planting season, a shorter bed time for producing plantable stock, higher survival rates at outplanting, more efficient use of costly genetically improved seeds, superior initial height growth, greater uniformity in seedling production, and potentially greater adaptability to fully automated tree-planting machines.

Nevertheless, container seedlings are not yet widely used for regeneration, probably because they cost substantially

more at the outset than bareroot stock. However, Guldin's [23] careful comparison of the economics of producing southern pine seedlings with both systems shows the final costs to be comparable. The move toward growing container seedlings in the open (no greenhouse structure) further reduces seedling cost.

The merits, production technology, and field performance of container stock are discussed in detail in chapter 7; comparative information for bareroot stock is presented in chapters 6 and 8. However, some comparisons are presented here.

3.6.1.1 Seed utilization

Guldin [23] evaluated the effect of closer control over germination and initial seedling growth conditions in a container nursery. With conventional seed handling and seedling practices, 55% of the seeds sown produced plantable seedlings in a bareroot nursery, whereas at least 75% of the seeds sown produced plantable seedlings in a container nursery [23]. The percentage increase means that an extra 2 ha (5 ac) could be planted at 1.8- × 3-m (6- × 10-ft) spacing; this represents a 36% increase in area per unit weight of seed.

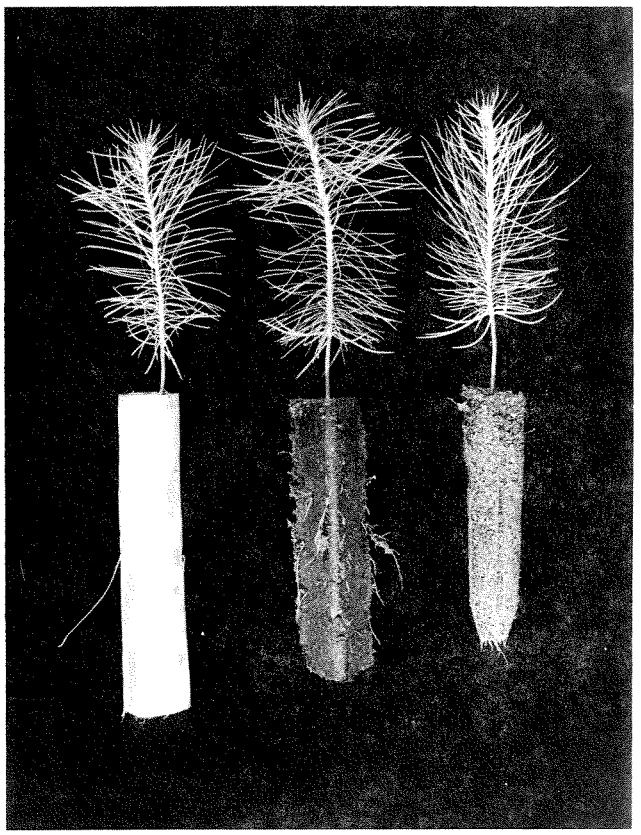

Figure 3.4. Loblolly pine seedlings grown in three types of containers (left to right): a biodegradable plastic tube, a peat moss-vermiculite molded block, and a plug from Styroblock-2.

3.6.1.2 Planting season

Planting bareroot southern pine seedlings is largely restricted to the seedlings' dormant season, generally mid-December to mid-March. Outside the dormant season, seedling moisture requirements can quickly overwhelm the root system that remains after lifting. Because container-grown seedlings are planted with their root system intact (Fig. 3.4), they can be set in the ground during their active growing season and suffer little transplant shock. However, care is still required during the hottest summer months to assure sufficient moisture in the rooting zone.

Using container seedlings can at least double the 3-month bareroot planting season. A longer season has three major benefits. First, because of their extended planting season and low transplant shock, container seedlings can be successfully interplanted in the fall 6 to 9 months following the original bareroot planting [20]. They do not fall behind like bareroot seedlings set out late in the planting season and therefore enter stand development on an equal footing with the survivors of the original planting. It is becoming typical to plant container stock, grown over summer in the open, in the fall once soil moisture is adequate.

Second, areas too wet to plant during the conventional bareroot season, such as river bottom sites frequently flooded in early spring, can be prepared and planted with container stock after water levels fall. Such sites may still be flooded for short periods, but this should not adversely affect growth. Evaluation of an actual case history of planting wet bottomland sites indicated that an 11.9% interest was earned over a 20-year rotation when container seedlings were used instead of bareroot stock [23]. Even though container seedlings initially cost more, they survived much better because the bareroot seedlings were planted late in the season.

Third, many more container seedlings can be planted than bareroot seedlings, with fewer scheduling problems. Guldin [23] uses for an example a company currently planting 800 ha (2,000 ac) annually, but needing to expand to 4,000 ha (10,000 ac) annually. The reforestation manager looks ahead with trepidation to a 5-fold increase in contracting hand planting with its supervision responsibilities, all within the 3-month bareroot planting season. Switching to container seedlings would improve seed utilization and expand the planting season from 3 to 6 months, the additional time only doubling daily supervisory responsibilities for the same 5-fold increase in planting acreage. Scheduling would also be much easier. Several new full-time jobs dealing solely with planting supervision could be justified as far more efficient than reassigning a dozen people from their regular jobs for 3 months each winter to temporarily oversee planting. Another circumstance requiring a sudden increase in production would be a bad wildfire season.

3.6.1.3 Nursery expansion

Because seedling demand is outstripping production capacity throughout the South, many nursery managers

must consider whether to develop completely new facilities or expand the existing ones. Given the capital investments at existing nurseries, expansion is often strongly favored.

Guldin [23] compared the economics of developing container seedling growing facilities instead of bareroot nurseries. Guldin assumed that 15 million more seedlings were needed and that the bareroot facility already encompassed enough land for expansion. If only site preparation and additional equipment were considered (possible building remodeling ignored), bareroot seedlings could be raised on the expanded nursery beds for $32.88/1,000 seedlings. If a new timber-truss greenhouse nursery were constructed for a container facility, the container seedlings could be produced for $30.56/1,000 seedlings. The reduced cost of growing container seedlings, $2.32/1,000 seedlings, translates into a savings of $0.68/ha ($1.68/ac) at a 1.9- x 3-m (6- x 10-ft) spacing. Moreover, this does not include an additional $1.26/ha ($3.11/ac) that would result from stating up the container nursery 2 years earlier than the bareroot nursery. So total savings amounts to $1.94/ha ($4.79/ac) in today's dollars.

3.6.1.4 Regeneration costs

Lower transplant shock for container seedlings means that they can compete better than bareroot seedlings with surrounding vegetation for water, nutrients, and sunlight immediately after planting [35], reducing outplanting mortality. Benefits from better survival of the container stock are measured as an increased future harvest value per unit area.

Other reasons why container stock may reduce regeneration costs include increased flexibility in seedling supply, allowing site preparation to be done over an extended period without delaying reforestation a year or more, and increased efficiency of the field labor force by providing for a smaller, better trained crew over the extended period.

3.6.2 Production of Quality Stock

Regardless of stock type used, field performance is greatly influenced by stock quality at the time of outplanting. But what constitutes a high-quality southern pine seedling? Ultimately, it is one that survives and grows well in the field. A recent study showed that survival of southern pine plantations decreased from an average of 82% during 1960–64 to 73% during 1975–79 [38]. Factors such as greater competition and less supervision of planting may contribute to this decline, but the need to grow and plant high-quality seedlings is clear. Development of seedling quality is discussed in detail in chapters 6, 7, and 8, for container and bareroot stock, respectively.

3.6.3 Handling and Planting

Most efforts to produce excellent quality seedlings in the nursery may be useless if seedlings are not cared for during post-nursery operations (see chapter 16). However, one aspect of this process deserves special mention because it markedly improves performance of difficult-to-store species such as longleaf pine. Recent studies have shown that storage of southern pine seedlings can be improved by incorporating fungicides into the packing medium [7] (Fig. 3.5). This technology is being rapidly developed and should become routine.

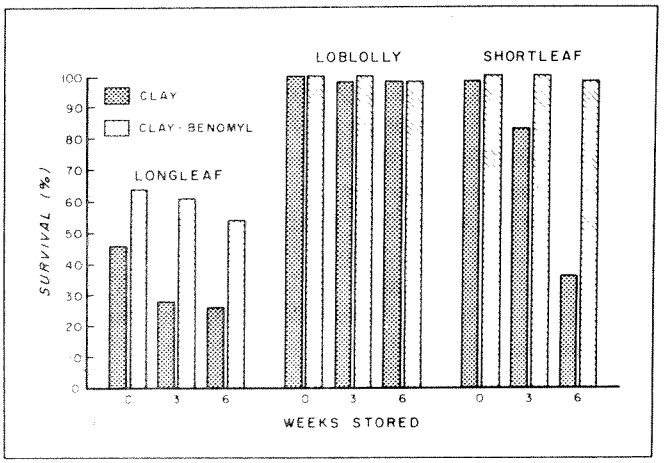

Figure 3.5. First-year survival of pine seedlings stored for 0, 3, or 6 weeks and treated with one of two fungicides. (Adapted from Barnett and Brissette [6]).

Planting techniques and the supervision of the planting operation markedly affect field performance of southern pines. Details of planting methodology are presented in chapter 17.

3.6.4 Recommended Uses of Planting Techniques

Planting is and will remain the mainstay of southern pine regeneration. It is the most reliable and prompt method for regenerating forestland and also allows stands to be upgraded with genetically improved seedlings available across the South. Even though planting may be more expensive than either natural regeneration or direct seeding, it is easier to economically justify on better quality reforestation sites. The current trend is to use direct seeding and natural regeneration on sites that will be less intensively managed.

Container stock should be used on especially difficult (e.g., droughty) sites and for species such as longleaf pine whose survival has typically been low. Planting container stock in these situations usually improves field performance significantly. The increasing availability of good-quality container stock should increase its use across the South.

3.7 Comparisons of Natural and Artificial Regeneration Methods

Because some southern pines can be regenerated with a variety of natural and artificial methods, the choice of method should largely depend on production and economics (see chapter 2 for details on economics). The following comparisons of two natural regeneration methods

(selection and shelterwood cutting) and one artificial method (planting) are based on case studies for loblolly pine growing on average sites and where site index equals 27 m (90 ft) at 50 years in southeastern Arkansas [3], assuming a 50-year sawlog rotation. If rotation length, cutting cycle, or site were different, the results of the comparisons would change. In addition, had genetically improved stock been used, production values for the plantation would probably be higher.

For the selection method, an uneven-aged pine stand was developed and maintained at a relatively high stocking level – 108 m^3/ha[1] (9,000 fbm/ac) of sawlog volume immediately before 5-year cyclic harvest cuts. Overstory and midstory hardwoods were eliminated early in the rotation, and hardwood brush was controlled with herbicides at 10-year intervals. Production volumes are from the "Poor Farm Forty" on the Crossett Experimental Forest [33].

For the shelterwood method, pine seedlings originating from a shelterwood were managed as a natural, even-aged stand. The overstory was removed at the beginning of the rotation, and the regenerated stand was thinned to 20 m^2/ha (85 ft^2/ac) basal area at 5-year intervals beginning at age 20. Overstory and midstory hardwoods were eliminated at the time of the shelterwood cut, and hardwood brush was controlled periodically with prescribed burns. Production volumes are from a thinned 50-year-old natural stand subjected to the above treatments [10, 29].

For the planting method, a pine plantation was established following clearcutting and site preparation. The planted stand was thinned to 20 m^2/ha (85 ft^2/ac) basal area at 5-year intervals beginning at age 15. Hardwoods were controlled periodically with prescribed burns. Production volumes are from a thinned 50-year-old plantation subjected to the above treatments. (Data on file, Forestry Science Laboratory, U.S.D.A. Forest Service, Southern Forest Experiment Station, Monticello, Arkansas).

[1] Cubic-foot and metric conversions of measurements expressed in board feet should be viewed as estimates because of the assumptions involved in the conversion process. Board-foot volumes are in Doyle measure.

3.7.1 Production

Plantation management produced only 9% more total merchantable volume than shelterwood but 44% more than selection (Table 3.7). Thus, in terms of pulpwood or fiber production, even-aged plantation or natural stand management was clearly superior to uneven-aged. However, selection and plantation management produced about 28 to 30% more total sawlog volume than shelterwood and considerably more average annual volume [about 5 m^3/ha (420 fbm/ac) for selection and plantation vs. 3.9 m^3/ha (328 fbm/ac) for shelterwood; Table 3.7].

3.7.2 Economics

On the basis of the production values in Table 3.7 and current cost [37] and return [30] values, three different economic analyses were performed for each of the three management systems:

(1) Net Present Value (NPV): The sum of all discounted returns from a management system minus the sum of all discounted costs. Thus, NPV represents the earnings associated with the system after all capital and interest expenses have been repaid. Net present value, frequently used by forest industry firms, is an appropriate analysis where investment capital is not particularly limiting or for comparing investments of approximately equal amounts.

(2) Benefit-Cost Ratio (B:C): The value of all discounted returns from a management system divided by the value of all discounted costs. Thus, B:C represents the present value of the return per dollar invested in the system, or its economic efficiency. Benefit-cost ratio is appropriate where capital is limiting (for example, with nonindustrial private landowners) or for comparing investments of unequal amounts.

(3) Cost Efficiency (CE): The yield from a management system divided by the value of all discounted costs associated with the system. Because it estimates physical output per dollar invested in the system, CE can be considered a physical analog of B:C. Cost efficiency is most appropriate where the owner wishes to maximize yield of a particular product (for example, sawtimber) or where the product carries no readily identifiable dollar value.

Table 3.7. Production of loblolly pine for three management systems over a 50-year rotation (adapted from Baker [3]).

Management system	Total		Mean annual	
	Total merchantable, m^3/ha (ft^3/ac)	Sawlog, m^3/ha (fbm/ac)[1]	Total merchantable, m^3/ha (ft^3/ac)	Sawlog, m^3/ha (fbm/ac)[1]
Natural, uneven-aged (selection)	413 (5,897)	256 (21,241)	8.3 (118)	5.1 (425)
Natural, even-aged (shelterwood)	546 (7,807)	198 (16,414)	10.9 (156)	3.9 (328)
Artificial (plantation)	594 (8,488)	252 (20,956)	11.9 (170)	5.0 (419)

[1] Board-foot volumes are in Doyle measure.

Table 3.8. Economic analyses[1] of three management systems for loblolly pine over a 50-year management period at a 7% discount rate (adapted from Baker [3]).

Management system	Present net value, $/ha ($/ac)	Benefit-cost ratio	Cost efficiency, per $	
			m^3 (ft^3)[2]	m^3 (fbm)[3]
Natural, uneven-aged (selection)	163 (404)	3.71:1	1.13 (40)	0.70 (143)
Natural, even-aged (shelterwood)	219 (541)	5.40:1	1.81 (64)	0.65 (133)
Artificial (plantation)	200 (493)	3.13:1	1.05 (37)	0.44 (91)

[1] See text for description of the three economic analyses.
[2] Total merchantable volume production.
[3] Sawlog volume production.

Over the 50-year rotation, the two even-aged systems, although at very different investment levels, had a more favorable NPV, at $200 to $219/ha ($493 to $541/ac), than the uneven-aged system, at $163/ha ($404/ac) (Table 3.8). The results of this comparison indicate that landowners should select the plantation management system if they desire one of the peripheral benefits associated with it – such as maximum total production, the opportunity to plant

Table 3.9. Guide to regeneration alternatives for the southern pines (adapted from Williston et al. [41]).

Management situation	Pine species	Alternatives
Well-stocked stand to be managed in even-aged units with frequent periodic cuts.	All	Starting at leeward side of stand or management unit, clearcut strips approximately 90–120 m (300–400 ft) wide, or small patches or blocks of approximately 3.3–4.0 ha (8–10 ac). Burn clearcut area after fuel is cured and before next seedfall. Treat midstory and overstory hardwoods > 2.5 cm (> 1 in.) dbh with herbicide. Precommercially thin stand, if > 12,350 stems/ha (5,000 stems/ac), between ages 3 and 5. Use strip or block shelterwood for longleaf. Use block clearcuts; regenerate artificially following appropriate site preparation. Periodically thin residual stand to maintain growth and production of high-value products.
Well-stocked stand to be managed in even-aged units; periodic cuts not required in the immediate future. or Mature, slow growing stand.	All	Use clearcutting, seedtree, or shelterwood method with seed or seedlings in place; only the shelterwood method is suitable for longleaf. With seedtree or shelterwood, use a prescribed burn about 1 year before the reproduction cut. Clearcutting with seed in place should be done after cones mature, but before seeds germinate. Clearcutting with seedlings in place should be done during summer after a good seed year. Following any of the reproduction cuts, hardwoods > 2.5 cm (> 1 in.) dbh should be treated with herbicides. Regenerate artificially by clearcutting, followed by suitable site preparation and either planting or direct seeding.
Well-stocked stand to be managed in uneven-aged units with periodic cuts.	Loblolly, shortleaf	Harvest groups of trees at 3- to 5-year intervals to create openings for seedlings. May be able to prescribe-burn for seedbed preparation in some cases. Treat hardwood brush as needed with herbicide to free young pine from competition.
Understocked or cutover stand [< 7 m^2/ha (< 30 ft^2/ac) merchantable basal area] with some seed-bearing trees present.	Loblolly, shortleaf, Chocta-whatchee sand	Use seedtree or selection cutting methods as previously described. Control hardwoods if stocking is high. Regenerate artificially by clearcutting, followed by suitable site preparation and either planting or direct seeding.
Understocked or cutover stand with no seed-bearing trees present.	All	Regenerate artificially by planting or direct seeding. For loblolly or shortleaf, attempt to rehabilitate stand with selection cutting and hardwood control if some pines will become seed producers within 5–10 years.
Scattered sawlogs; heavy understory of hardwood brush.	All	Regenerate artificially by clearcutting, followed by suitable site preparation and either planting or direct seeding. Treat brush mechanically (chopping) or with herbicides; then burn before seedfall. With proper brush control and seedbed preparation, seedlings should establish naturally.

superior seedlings, or ease of management.

When B:C ratios were considered, the shelterwood method had the advantage because of its low management cost (B:C ratio of 5.4:1). Plantation management had the lowest B:C ratio (3.1:1), whereas the selection method was intermediate (3.7:1).

When cost efficiency was considered, the shelterwood method was most efficient in terms of total merchantable volume, with 1.81 m^3 (64 ft^3) produced per dollar spent. However, the selection method was the most efficient, in terms of sawlog production with 0.70 m^3 (143 fbm) produced per dollar spent. Plantation management had the lowest cost efficiency in this example. However, the length of rotation (50 years) used was more appropriate for small landownerships than larger industrial tracts.

When the landowner desires economic efficiency, investing in the management system with the highest B:C ratio would be financially best. When the owner desires a particular product, the system with the highest cost efficiency for that product should be selected. A landowner who used a system with a high efficiency measure, such as B:C ratio or CE, could manage a larger land base with the same investment or the same land base with a smaller investment. With the rotation age used, both natural-stand management methods had favorable B:C ratios. These, combined with the systems' high CE values, suggest that many landowners could enjoy cost savings by managing natural stands rather than by planting. However, once again, the examples used may be more appropriate for small landownerships than for shorter rotation industrial tracts. Artificial regeneration will usually provide simpler technical systems and reduce the number of small-volume timber sales.

3.8 Regeneration Guide

Table 3.9 provides regeneration alternatives for various management situations that may be encountered for the southern pines. The guide is intended only as a quick checklist. In many cases, more than one alternative may be available; thus, decisions must be made based on the individual site and the owner's preference.

3.9 Conclusions and Recommendations

Most landowners have several options for regenerating their forestlands. The southern pines can be regenerated naturally with clearcutting, seedtree, shelterwood, or selection reproduction cutting methods, or artificially by direct seeding or planting container or bareroot seedlings. Once the decision has been made to regenerate a stand, other important details must be considered before harvesting begins. If the area is to be regenerated from natural seeding, then an appropriate reproduction cutting method must be selected. If the area is to be regenerated artificially, then the regeneration method (direct seeding or planting) and the species must be selected. Site and stand characteristics, cost of the regeneration method, cash flows associated with the silvicultural system, and landowner objectives all affect the above decisionmaking. Therefore, landowners or resource managers should become familiar with the advantages and disadvantages of the different regeneration options so that they can fully evaluate their individual situations and choose the most appropriate system.

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