SILVICULTURAL PRACTICES AND MANAGEMENT OF HABITAT FOR BATS

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The twenty-first century has seen a shift in the philosophy and practice of forestry. Historic assumptions that prevailed as recently as three decades ago have been challenged in light of new concepts and practices, developed through advances in research and lessons from practical experience. The goals of forest management today encompass a wider array of resources than in the past, and managers are using a wider range of tools and techniques to provide them.

For example, consider the evolution in wildlife management. The old prevailing wisdom held that good forest management, which was focused on timber objectives, was also good wildlife management (Bissonette 1986). This reflected the perceived benefits of using clearcutting to harvest stands, and the resulting response of plant species that provided soft mast and browse for deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*). These game species were of special interest to state wildlife management agencies and to outdoor enthusiasts who enjoyed hunting. Today, in general, it is understood that a particular forest management strategy is desirable or undesirable for wildlife, depending on how the habitat for the wildlife species or community of interest is affected (Bissonette 1986; Hunter 1990). Thus, if a harvest creates early successional conditions, it will favor wildlife species that use early successional habitat, but will not favor species that depend on older forests.

The practice of silviculture has evolved as well. Three decades ago, it was socially acceptable and a matter of public policy to maximize timber production through intensive forestry that involved clearcutting followed by the planting of fast-growing trees (Behan 1990; Kessler et al. 1992; Swanson and Franklin 1992). As a result, silviculture came to be associated primarily with intensive forestry for timber production, especially by the public. That view is too narrow by today's standards, where demands of society for forest resources go beyond timber production. Contemporary forest management goals include health, diversity, productivity, and sustainability of ecosystems and the diverse elements they contain; those goals are achieved through silviculture. This view has conceptual advantages beyond those of multiple use, especially if those multiple uses are in conflict (Behan 1990; Franklin 1989; Kessler et al. 1992; O'Hara et al. 1994; Swanson and Franklin 1992).

The value that a given society holds for forests and forestry depends on the availability and abundance of forests, whether forests are or have been exploited, and whether people are concerned about the sustainability of forests and forest resources into the future. The views of the society at large regarding forest management typically mature through four stages (Kimmins 1991, 1992): (1) unregulated exploitation of local forests and clearing of forests for agriculture and grazing; (2) institution of legal and political mechanisms or religious taboos to regulate exploitation; (3) development of an ecological approach to timber management with the goal of sustainable management of the biological resources of the forest; and (4) social forestry, which recognizes the need to manage the forest as a multifunctional resource in response to the diverse demands of modern society.

In North America, steps 1 and 2 can often be seen on private forestlands where owners are unfamiliar with the concepts of forestry and simply cut trees when they can be profitably sold. In many areas of the country, urban sprawl might be classified as step 1 if the definition included clearing for urban development. Industrial forestlands that support intensive management to provide sustainable harvests would be classified at some intermediate stage between steps 2 and 3. Forestry on public lands is generally at step 3, but changing attitudes about public forestry in North America (Kessler et al. 1992) suggest a transition into the fourth step in Kimmins' hierarchy.

It is the fourth step of Kimmins' hierarchy that holds the most promise for managers and biologists to work together. As more demands are placed on forests, the resource attributes needed to meet those demands expand and often conflict. These conflicts can quickly overwhelm managers (Farrell et al. 2000; Kessler et al. 1992). Perhaps the greatest hope for resolving such conflict is to manage forests for patterns and processes that restore and maintain ecosystems (Kessler et al. 1992). Management recommendations could then be related to how they are integral to essential ecosystem function.

In this chapter we seek to familiarize people interested in the ecology and conservation of bats with silvicultural practices used by foresters, and comment on the implications of those practices for forest-dwelling bats. We hope to dispel old notions that equate silviculture exclusively with timber management, to broaden the definition of silviculture to include nontimber habitat management, and to facilitate communication between biologists and foresters about practical modifications of existing silvicultural practices to promote habitat for bats in forests.

SILVICULTURE: AN OVERVIEW

Both the old forestry and the new are implemented using silviculture. Silviculture can be defined as the science and art of manipulating a stand of trees toward a desired future condition. For example, a desired future condition could be old growth forest, foraging habitat for the Indiana myotis (*Myotis sodalis*), pulpwood destined for a mill, or nearly anything someone could describe using quantitative or qualitative descriptions of the stand of forest under management.

There are two main elements to silviculture: the individual treatment practices that make a short-term change in the conditions of a forest stand, and the systems or prescriptions developed by arranging individual treatments over time through the life of the forest stand. The individual practices can often be quantified in great detail and, in general, are based on current scientific literature, experimentation, and implementation. The systems or prescriptions are based less on science and more on creativity, experience, and adaptation, elements that are perhaps better described as art rather than science.

Silvicultural practices are designed to indirectly manipulate supplies of water, nutrients, and incident solar radiation by removing undesired plants that usurp resources from desired plants. A silviculturist sees a forest stand as a collection of individuals of different species, each of which uses resources according to its size and species attributes. Some individuals are to be retained to meet the goals of the forest owner. Other individuals that unduly compete with those to be retained are then removed. Removal can be through felling, girdling, use of herbicides, top-killing with fire, or any other practice that effectively reduces or eliminates the ability of undesirable plants to compete with desired individuals. If the removal of undesired trees can be accomplished by having someone else pay the landowner for them, cut them down, and haul them away to a mill, so much the better for the landowner. But this is a secondary outcome to the primary silvicultural objective of redirecting the flow of resources on a site to the trees that are to be favored.

Increasing growth rates is fundamental to the goals of most forest landowners, whether these goals are economical, social, or ecological. Human longevity is a fraction of the timescale required for forest development to occur; thus, landowners and foresters do not have the luxury of waiting for a desired stand condition to develop on its own. Silviculture enables trees to grow faster, so that desired stand conditions can be achieved more rapidly. For example, suppose a stand with old-growth structural attributes is needed to satisfy a desired future condition. Foresters could wait the requisite centuries for that structure to develop, or silvicultural practices could be used to accelerate development of the desired structural features in a shorter time frame.

Often, a silviculturist must choose among several ways to implement a practice to achieve a certain objective. For example, if the objective is to remove small midstory hardwoods in a mature pine stand, many different treatment alternatives exist such as the use of herbicides, prescribed fire, or manual chainsaw felling. Each alternative will achieve the intended effect, but will result in slightly different conditions following treatment, and those posttreatment differences will be accentuated over time. Moreover, each alternative varies in the costs and human resources needed to implement the treatment.

Silvicultural systems and prescriptions are designed to meet the long-term objectives of the forest owner. In light of the expected changes in stand age and condition, a prescription is little more than a list of the silvicultural practices planned for the stand over time. Prescriptions typi-

Table 7.1. An example of a silvicultural prescription for managing even-aged, naturally regenerated loblolly-shortleaf pine stands under the seed-tree silvicultural system in the upper West Gulf Coastal Plain

	Stand		Starting condition		Expected results		
Step	age (yr)	Operation and probability of event	N	BA	N	BA	D
	0	(seedfall from seed trees)	–	–	–	–	–
1	0	prescribed burning	–	–	–	–	–
2	3	removal cut, harvest seed trees	10	2	0	0	0
3	4	precommercial thinning (with rolling chopper)	>8,000	8	4,000	4	3
4	4	precommercial thinning (with brush saw)	4,000	4	1,500	2	3
5	4	pine release (with brush saw)	1,500	2	1,100	1	3
6	14	prescribed burning	–	–	–	–	–
7	14	pulpwood thinning (long pulpwood)	1,100	25	600	14	18
8	15	salvage cut after ice storm (~10% in any given year)	600	15	500	13	18
9	20	prescribed burning	–	–	–	–	–
10	20	pulpwood thinning (long pulpwood)	500	22	300	14	23
11	26	prescribed burning	–	–	–	–	–
12	26	salvage cut after ice storm (~10% in any given year)	300	22	220	16	30
13	31	prescribed burning	–	–	–	–	–
14	31	thinning (sawlogs)	220	22	160	16	36
15	36	prescribed burning	–	–	–	–	–
16	36	thinning (sawlogs)	160	21	125	16	41
17	41	prescribed burning	–	–	–	–	–
18	41	thinning (sawlogs)	125	18	100	16	43
19	45	prescribed burning	–	–	–	–	–
20	45	seed cut, seed-tree reproduction cutting method	100	17	10	2	48

Source: From Zeide and Sharer 2000.
Note: The overall system consists of 20 separate silvicultural treatments imposed over a 45-year period (N, stem density, trees/ha; BA, basal area, m2/ha; D, average stem diameter, cm).

cally include the time frame for which the system is being developed, the treatments that are planned, the expected time when each treatment will be applied, technical details about how each treatment will be applied, and the conditions expected before and after each treatment (table 7.1). In essence, the prescription is a detailed long-term plan for the forest stand being managed.

In general, foresters make a distinction between the practice of silviculture and that of forest management. The usual domain of silviculture is the forest stand, whereas that of forest management is the forest as a whole, containing all stands under a given ownership (Baker et al. 1996; Smith 1986; Wiersum 1995). Under the old paradigm, forest management plans were based primarily on the sustainable yield of timber over the long term (Baker et al. 1996; Behan 1990; Farrell et al. 2000; Kessler et al. 1992; Wiersum 1995). As modern ideas of sustainability expand to embrace all the values that forests provide, the practice of silviculture has grown to reflect an understanding of how landscapes function, and how the treatments conducted within each of the individual forest stands affect that function. This means that a silviculturist planning a treatment in a given stand must take into account the activities occurring in adjacent stands, not only within an ownership but across ownerships as well (Baker et al. 1996; Farrell et al. 2000; Franklin 1989). This is often easier to do in landscapes dominated by public lands than in those that consist of numerous private landowners.

Finally, although some may find it counterintuitive, the modern perspective on silviculture is dramatically enhanced if active markets for timber within a region are present (Kessler et al. 1992). Owning, staffing, and managing a forest are not cost free (Hunter 1990). Because trees have commercial value as lumber and pulp, the costs of conducting silvicultural treatments often can be partly or completely defrayed by selling the harvested trees.

An example of managing for ecosystems and ecosystem attributes on a landscape scale is found in the restoration of the shortleaf pine-bluestem (*Pinus echinata-Andropogon* spp.) ecosystem in the Ouachita Mountains of Arkansas and Oklahoma (Bukenhofer et al. 1994; Bukenhofer and Hedrick 1997; Guldin and Guldin 2003; Hedrick et al. 1998). At the time of European colonization, these forests were much more open than today. Fires no doubt contributed to that openness (Foti and Glenn 1991; Mattoon 1915). Seventy years of fire suppression resulted in denser stands with more trees in the smaller size classes (fig. 7.1), which had detrimental effects on a host of flora and fauna adapted to open understory conditions, including the endangered red-cockaded woodpecker (*Picoides borealis*). To restore the desired historic condition, a silvicultural prescription was developed to thin overstory and midstory pines using commercial timber sales, to remove midstory hardwoods by mechanical treatment, and to reintroduce surface fires on a one- to three-year interval. Funds generated by the timber sales helped defray the cost of the midstory removal and the prescribed fire treatments. As a result, treated stands now support many plant and animal species adapted to open Ouachita woodlands (fig. 7.2), including expanding numbers of the red-cockaded woodpecker. Thus, a desired ecological outcome was achieved using classical silvicultural treatments and existing timber markets.

SILVICULTURAL PRACTICES

Silvicultural treatments can be divided into three categories that are correlated with tree size: reproduction cutting methods (large trees), regeneration treatments (seedlings and saplings), and intermediate treatments (small or immature trees larger than saplings) (Smith 1986). The goal of reproduction cutting is to harvest mature trees to favor the establishment and development of new trees; the species composition, desired spacing, and tolerance to shade of the species being managed determine what kinds of reproduction cutting methods might be effective in the forest

Figure 7.1.
A shortleaf pine (*Pinus echinata*) stand in the western Ouachita Mountains after 70 years of fire exclusion and before restoration treatment.
Photo by J. Guldin

Figure 7.2.
A shortleaf pine (*Pinus echinata*) stand in the western Ouachita Mountains after thinning in the overstory, removal of encroaching midstory hardwoods, and initiation of cyclic prescribed fire.
Photo by J. Guldin

type being managed. The goals of regeneration treatments are to prepare a site for seed or seedlings of the desired species, to either plant seedlings, scatter seed, or encourage natural seedfall of desired species, and to promote proper development of young trees. The focus of intermediate treatments is to reduce competition to levels that favor continued growth of the desired trees.

REPRODUCTION CUTTING METHODS

Reproduction cutting methods are used when a decision is made to harvest all or part of the mature trees in a stand, and to establish new trees to perpetuate a succeeding generation of trees. Even-aged methods are characterized by one or two age classes of the desired species, and operate over a length of time called a "rotation," which lasts from establishment of regeneration to final harvest. Clearcutting, seed-tree, and shelterwood methods are the cutting practices typically used for even-aged systems (Smith et al. 1997). Uneven-aged methods are characterized by three or more age classes of the desired species of trees. Single-tree selection and group-selection methods are used for uneven-aged systems (Baker et al. 1996; Smith et al. 1997). The methods vary by the number and distribution of trees retained on the site and by the ecological conditions for regeneration that are created.

CLEARCUTTING METHOD

In the clearcutting method, all or most of the trees are removed from the stand. Timber sales typically are used to harvest trees of commercial value, and subsequent treatments are used to remove the remaining trees. Depending on ownership objectives, some snags and living trees can be left standing to enhance visual qualities, meet habitat objectives, or provide structural elements that would otherwise be missing from young stands.

In more intensive applications, clearcut stands are generally reforested by plantings. If timber production is an important goal, stands are often planted using genetically improved planting stock of fast-growing species such as Douglas-fir (*Pseudotsuga menziesii*), loblolly pine (*Pinus taeda*), or cottonwood (*Populus deltoides*). In some situations, clearcuts can be reforested by use of direct seeding, although spacing uniformity is often sacrificed. Additionally, because of the cost of genetically improved seeds, direct seeding does not have the same opportunity for genetic improvement as planting does.

Clearcuts also can be reforested through natural regeneration. The most common applications of this are in hardwood stands in eastern North America, where the succeeding stand originates from saplings previously existing in the stand prior to the clearcut and from stump sprouts from harvested trees. In upland oak stands, for example, considerable effort is made to encourage development of regeneration of desired species of suitable size before the clearcut occurs (Sander et al. 1983). In other forest types, such as aspen stands in the Lake States, harvested stands sprout vigorously and little supplemental effort is required to obtain abundant regeneration (Perala and Russell 1983).

It is more problematic to rely on natural regeneration following clearcutting of species that do not sprout, such as pines. One successful approach is to depend on seed fall from adjacent stands. This will work only if the clearcut is sufficiently narrow or otherwise oriented such that all parts of the clearcut are within the effective seeding distance of mature trees in adjacent stands. Harvesting can be relied on to scatter seeds throughout a stand if mature seeds are present within the crowns of trees to be harvested. This approach works well in species that retain mature seeds in their crowns for an extended time, such as jack pine (*Pinus banksiana*), sand pine (*P. clausa*), and lodgepole pine (*P. contorta*). Otherwise, the precise timing required for initiating and completing the clearcut between seed maturation and dispersal is rarely attainable.

From an ecological perspective, the clearcutting method attempts to mimic large-scale disturbances such as crown fires, tornados, and insect outbreaks. It is well suited to tree species that cannot survive shading, such as aspen (*Populus tremuloides, P. grandidentata*), paper birch (*Betula papyrifera*), red alder (*Alnus rubra*), and most pines. It is also well suited for providing habitat for animals that use open conditions. For example, the silver-haired bat (*Lasionycteris noctivagans*) is known to use clearcuts (Patriquin and Barclay 2003).

SEED-TREE METHOD

The seed-tree method is similar to clearcutting, except a small number of mature seed-bearing trees, typically no more than 10–25 trees/ha, are retained to reseed the stand. After the new age class is in place, the seed trees are usually removed. It is not always economically feasible to do so, however, and in these instances seed trees could be used to create snags or be left as relict trees to provide roosting habitat for bats.

Many of the physical characteristics of trees vary among individuals and are highly heritable. Because seed trees are the primary source of seed for the succeeding stand, keeping seed trees that have desirable traits is important. Silviculturists frequently select for desirable economic traits such as straightness of the stem or growth form. Seed-producing ability is also a highly inherited trait, and field personnel are often instructed to evaluate candidate seed trees based on evidence of past fruitfulness. Because traits of trees that are beneficial to bats and those beneficial to timber quality may differ, biologists should seek to identify whether traits that affect bats, such as bark characteristics, are heritable. If so, field crews could be instructed to retain seed trees with those traits when marking a stand.

The seed-tree method works best with tree species that regenerate readily following major disturbance events such as fire or windstorms. These species are shade intolerant, in general, and have light, readily dispersed seeds such as aspen, paper birch, western larch (*Larix occidentalis*), and southern pines (Young and Giese 1990). In the southern United States, the seed-tree method is well suited to loblolly pine, a disturbance-adapted species that is a prolific seed producer (Cain and Shelton 2001). Heavy-seeded species, such as oaks (*Quercus* spp.), hickories (*Carya* spp.), and longleaf pine (*P. palustris*) are poorly adapted to this method because they have irregular seed production, limited seed dispersal capability, and rely on seedlings being present in the understory prior to disturbance. Wildlife species favored by the seed-tree method will be similar to those favored by clearcutting. Regardless, retaining seed trees may provide roosting opportunities for bats that are otherwise not available in clearcuts.

SHELTERWOOD METHOD

The shelterwood method retains some of the mature trees to act both as a seed source and to partially shade the ground. The number of trees retained depends on form and crown shape, but typically varies from 30–60 trees/ha. Because more trees are retained, seeds do not have to travel as far to reforest a site; thus, the shelterwood method can be used with heavy-seeded species such as oaks and longleaf pine. Shading from the residual trees helps ameliorate harsh climatic conditions (e.g., summer frost or high soil-surface temperatures) at ground level.

Smith (1986) describes three specific treatments in the shelterwood method: the preparatory cut, the seed cut, and the removal cut. The preparatory cut is a late-rotation thinning used to promote crown development in future seed trees by removing other trees that compete with them. The seed cut removes all trees except those intended to reseed the stand. The removal cut harvests the seed trees once a new stand is successfully established. This is typically done five to ten years after the seed cut. In some cases, the removal cut may be deferred for half or more of the subsequent rotation, which results in a two-aged stand (Helms 1998; Smith 1986). The shelterwood method mimics relatively small small-scale or moderate-intensity disturbances. Because the number of residual trees retained in the shelterwood method varies depending on the tree species, the method might benefit bats adapted to edges and also those species of bats adapted to open woodlands.

SINGLE-TREE SELECTION METHOD

This uneven-aged method involves periodic harvesting of individual mature trees scattered across the stand to establish new seedlings in small openings created by the harvest. In general, no more than 30% of the stand is harvested at any one time (Young and Giese 1990), and harvesting is typically done every 10 to 20 years. One aspect unique to single-tree selection is that if careful attention is paid to the size distribution of trees, a continuous yield of timber products can be generated from a single stand. This method is particularly well suited to the forest landowner whose ownership is of limited area.

The single-tree selection method imitates conditions caused by the death of an individual tree in an unmanaged mature forest (fig. 7.3). When a tree dies, the sunlight, water, and nutrients that were used by that tree become available for other plants in the immediate vicinity. Shade-

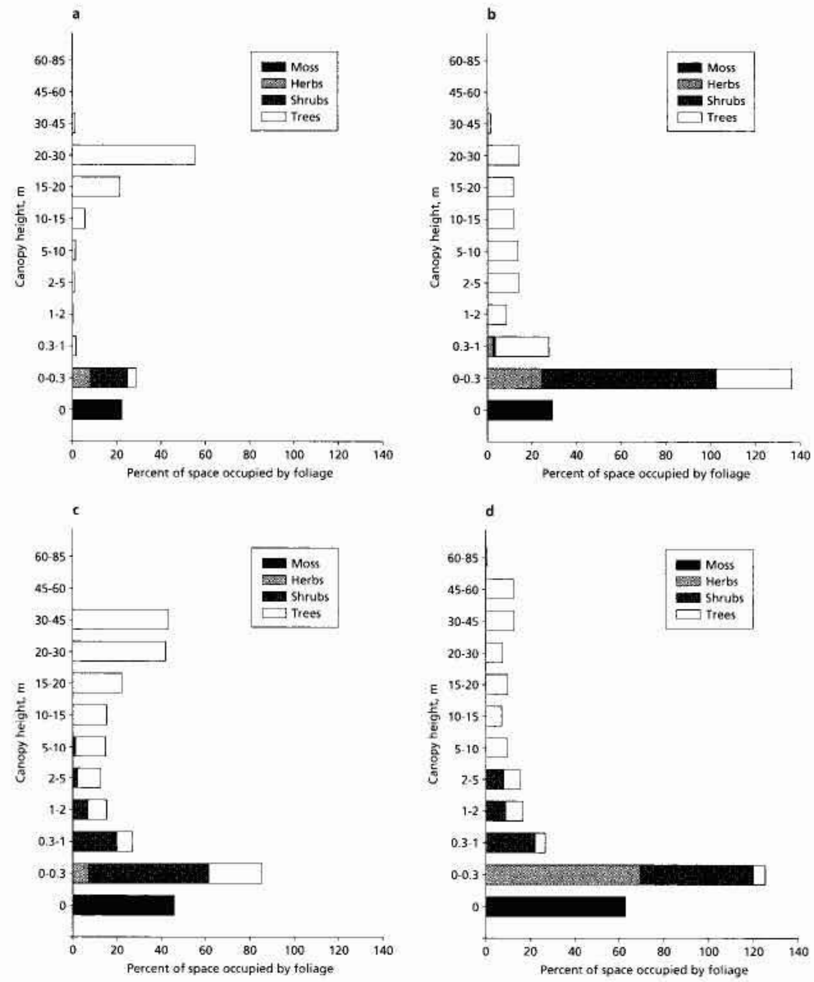

Figure 7.3. Percent of space occupied by foliage of four different types of vegetation at different heights: (a) a managed even-aged stand; (b) a managed uneven-aged stand; (c) an unmanaged even-aged stand; (d) an old-growth stand. Sample stands are in the Douglas-fir (*Pseudotsuga menziesii*) forest type in the western Cascade Mountains (W. Emmingham, unpubl. data).

tolerant tree seedlings, saplings in the understory and lower canopy of the forest, and trees whose crowns are adjacent to the space that the dead tree occupied in the upper canopy, all respond with faster growth. As this process continues over time, forests of shade-tolerant species are naturally maintained with individual trees in many size classes.

Foresters use the single-tree selection method to improve upon this process, primarily by trying to manage a balance of trees of different sizes and age classes. Size, rather than age, is generally used to describe such stands because age and size are poorly correlated in shade-tolerant species. Typically, individuals will grow until resources are limiting, and then persist with little additional growth until some minor disturbance frees up additional resources to allow the tree to resume growth. In a managed, single-tree selection stand, reproduction cutting is sufficiently frequent to maintain acceptable growth rates over time. Foresters use mathematical models of stem density versus diameter class as a target to regulate harvests in single-tree selection stands, so that the proper numbers of trees of different size classes can be maintained. Several quantitative and ecological approaches exist to determine the appropriate ways to regulate harvests (Baker et al. 1996; Marquis 1978; O'Hara and Gersonde 2004).

Single-tree selection is most appropriate for shade-tolerant trees, such as sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*), hemlocks (*Tsuga* spp.), some cedars (*Thuja* spp. and *Chamaecyparis lawsoniana*), and most firs (*Abies* spp.) and spruces (*Picea* spp.). Shade-intolerant tree species generally do not survive in the heavy shade of single-tree selection, and implementing single-tree selection on a stand of shade-intolerant trees generally converts the stand to one comprising shade-tolerant species.

The method has been successfully adapted to intolerant loblolly-shortleaf pine stands in the western Gulf region (Baker et al. 1996). In that region, silvicultural practices feature frequent harvests and retention of relatively low levels of residual basal area, which leads to optimal growth in sawtimber-sized trees. The frequent cutting and low basal area also ensure that midstory and understory trees maintain relatively uniform growth rates over time (Baker et al. 1996; Guldin and Baker 1998).

GROUP-SELECTION METHOD

The group-selection method is similar to the single-tree selection method, except that groups of trees are removed and new age classes are established largely within the group openings. These openings are designed to imitate disturbance events that remove small groups of trees, such as a localized insect infestation, a spot where a surface fire becomes hot enough to kill a few overstory trees, or where a localized gust in a windstorm blows down a small part of the stand. As in single-tree selection, foresters use the group-selection method to balance stem density in all the size classes of the stand, but recognize that the size classes will be aggregated in the group openings created at different times during the life of the stand.

Group openings can range in size from a few trees to a hectare or more. Ecologically, the upper size limit for a circular group opening on level terrain is found when the radius of the opening equals the height of the surrounding trees in the stand (Helms 1998). In openings of this size or smaller, the trees surrounding the opening cast a significant amount of shade; hence, smaller openings favor shade-tolerant species. In openings larger than this, the shade cast by the surrounding trees does not alter regeneration development in the center of the opening; therefore, larger openings are thought to favor species that are intolerant of shade. However, in a large 1-ha group opening (radius, 56.4 m) with surrounding trees 17 m tall or taller, most of the area within the opening still lies within one tree height of the edge of the opening, a zone within which shade-intolerant species would not compete well. Thus, group selection is inefficient relative to even-aged methods for managing shade-intolerant species.

Harvests are regulated in the group-selection method in the same way as in the single-tree selection method (Baker et al. 1996; Marquis 1978; O'Hara and Gersonde 2004), with one notable exception. It is increasingly common for the group-selection method to be implemented with an area-based approach. This is done by harvesting a percentage of the stand equal to the number of years between harvests divided by the average age of a mature tree. For example, in a stand where mature trees are harvested on average at age 50 and harvests are done every 10 years, 20% of the stand would be cut at each entry (10/50 = 20%). However, if the group openings are large, of uniform size within the stand, and placed in a geometric pattern within the stand rather than as dictated by stand conditions, this method is more appropriately identified as variation of the clearcutting method called patch-clearcutting (Smith 1986).

EVEN-AGED VERSUS UNEVEN-AGED METHODS

In general, even-aged cutting methods cause more site disturbance than uneven-aged methods, and the scale of effect is correlated with the intensity of harvest. Thus, the clearcutting method creates the greatest degree of site disturbance, followed in rank order by the seed-tree method, the shelterwood method, and the group-selection method; the least site disturbance occurs using the single-tree selection method. This same gradient generally applies to erosion, fire hazards from slash, and aesthetics. Conversely, uneven-aged systems often require greater care on the part of loggers to prevent damage to the residual trees. To a lesser degree this is true of even-aged management during thinning operations and in implementing seed-tree and shelterwood cuts.

Converting a stand to even-aged structure can be accomplished rapidly by clearcutting and reforesting the site by any of the methods described above. If the desired species occur within the original stand, the seed-tree or shelterwood method can be used to convert the stand. In either case, conversion is accomplished within a few years. However, converting a well-stocked, even-aged stand to uneven-aged structure is a slow and challenging process (Nyland 2003). At least two cutting cycles are needed to obtain the three age classes that minimally define an uneven-aged stand (Smith 1986). If harvests are conducted every 10–20 years, a minimum of several decades may be required and it may take even longer to configure a stand so that it is capable of providing a sustained yield. As a result, uneven-aged methods are often imposed in formerly unmanaged stands, because multiple size classes are often present, and the smaller size classes are in general comprised of shade-tolerant species. Uneven-aged methods can also be applied to rehabilitate understocked stands or stands that were high-graded in the past, provided that some stocking of desired species still remains in the stand (Baker et al. 1996).

Even-aged methods, especially clearcutting, are often favored over uneven-aged methods for timber management because it is easier to regulate harvests and because more wood fiber can be produced especially under intensive plantation practices. However, uneven-aged methods are effective in producing large trees of high volume, value, and quality per tree. Because of the added expenses of site preparation and intermediate treatments typically used with even-aged management, this system is not always more profitable than uneven-aged management (Young and Giese

1990). Nonetheless, the bias that uneven-aged methods are costly and inefficient still persists and may be a hurdle to implementing these methods where they are ecologically appropriate.

REGENERATION TREATMENTS

Regeneration treatments are intended to promote the germination, establishment, and development of seedlings and saplings of the desired species. Two classes of regeneration treatments are generally recognized: artificial regeneration and natural regeneration.

Artificial Regeneration

Artificial regeneration includes planting seedlings, planting cuttings, or sowing seeds. Seedlings and stock for cuttings are typically produced under controlled conditions in a nursery. Planting seedlings is the most common artificial regeneration technique, and the most widespread application is reforesting clearcuts with conifers. Hardwood planting is becoming increasingly popular, however, especially as a way to reforest abandoned or highly erodible agricultural land in the eastern United States.

Planting techniques typically involve raising seedlings for one or more years in a nursery, then transplanting them to the field during the dormant season. For species important to the wood products industry, such as Douglas-fir, loblolly pine, or eastern cottonwood, planting stock has often been selectively bred for desirable attributes such as growth rate or disease resistance (Namkoong et al. 1988). For a host of other species, however, especially heavy-seeded hardwoods such as the oaks, nursery production depends on collection of wild seed, with no control over genetic quality.

The mid-twentieth century was the heyday of direct seeding in North America. It was used to reforest large tracts of abandoned agricultural land that at one time supported forests. It continues to be applied in western North America to reforest areas affected by forest fires. Direct seeding is effective in such circumstances because few trees remain as seed producers and the areas requiring reforestation are vast. Also, these sites are often subject to severe erosion, making it impractical to wait the year or more required to raise seedlings in a nursery. Because no nursery is needed to produce seed for direct seeding, one can reforest large areas at far less cost than by planting. The major disadvantages of direct seeding are that a large number of seeds must be sown to obtain acceptable stocking, opportunities for gain from genetic improvement are less likely to be realized, and there is little control over spacing. Moreover, the need to reforest vast areas of abandoned agricultural land was largely met by the end of the twentieth century.

Natural Regeneration

Natural regeneration occurs when trees grow without people having planted them. This includes trees growing from recently fallen seeds, from seeds stored in the forest floor, and from root and stump sprouts. Natural regeneration occurs in both managed and unmanaged stands. In managed stands this includes regeneration that has occurred both before and after a harvest. With the exception of most clearcutting, all of the reproduction cutting methods rely on natural regeneration. Although people do not actively plant these trees, management affects the species composition, density, and growth potential of natural regeneration. Achieving the natural regeneration goals of a stand requires attention to the timing of treatments, understanding the regeneration biology of the desired species, and the competitive interactions among associated species.

Site Preparation

After a stand is harvested, few sites are well suited for the establishment of regeneration, be it artificial or natural. This is particularly true for the even-aged reproduction methods, and especially for clearcutting. Site preparation is how silviculturists modify the site to make it suitable for regenerating the desired tree species. These modifications include removing slash (branches and crowns of trees left over from harvesting), exposing bare mineral soil and enhancing soil nutrition, and controlling competing vegetation, including any undesirable trees that remain following the harvest. In upland oak stands, treatments can also include cutting stems of desired oak-advanced growth so that a fast-growing seedling sprout is produced. In general, site preparation is implemented through mechanical treatments, prescribed fire, herbicides, or fertilization. Many refinements are associated with each of these, depending on the reproduction cutting method, the species being regenerated, the site conditions, and whether natural or artificial regeneration is being used. The balance of how much and what kinds of site preparation to conduct varies between good and poor seed years in a given species, and is complicated by the timing of reproduction cutting relative to seed dispersal.

Precommercial Thinning

As seedlings of desired species become saplings, they face increasing levels of competition from individuals of both desired and undesired species. If left unchecked, this competition will often compromise tree growth and health and ultimately lead to mortality of desired species. This is particularly true for shade-intolerant species. Precommercial thinning is used to alleviate intraspecific competition, or competition among desired species. In precommercial thinning, stem density is typically reduced through mechanical felling, although herbicides and prescribed fire are also used. This type of thinning is termed "precommercial" because the trees being removed are not commercially valuable and cannot be sold.

Release Treatments

Release treatments are used to control competition between desired and undesired species, and are applied when the desired species are saplings or smaller. These treatments generally aim to control undesirable species that possess faster growth rates than desired species, such as unwanted fast-growing sprouts that are competing with desired slow-growing seedlings. Release treatments can be divided into two categories: liberation cutting and cleaning. Liberation cutting is the removal of undesirable trees that are taller than the desired species. Cleaning is the removal of competing vegetation that is about the same height as the desired trees, but is expected to overtop them. A common scenario in which release is necessary occurs in the maintenance of early successional and midsuccessional stands. In this scenario a stand of early or midsuccessional trees develops a midstory of later successional species. If the overstory is harvested but the understory is not immediately treated, a liberation treatment will become necessary to allow the original overstory species to develop through the taller and more shade-tolerant midstory. Liberation treatment can be avoided if the midstory is also removed when the overstory is cut.

Cleaning becomes important when the midstory species have the ability to stump sprout. They will generally be able to grow faster than seedlings of the desired species because of energy reserves stored in their undisturbed roots. Cleaning frees these desired species from the competing stump sprouts. In the northeastern United States, cleaning is a common treatment used in upland oak and northern hardwood stands, in which sprouts of the ubiquitous red maple (*Acer rubrum*) can, if left untreated, effectively suppress the favored species.

INTERMEDIATE TREATMENTS

Intermediate treatments traditionally involved removing immature trees that were of some commercial value to reinvigorate growth of the remaining trees to hasten a harvest. As the goal of modern forestry has moved from harvesting trees to achieving a desired stand condition, however, the role of intermediate treatments has changed as well. Intermediate treatments might better be defined as treatments that redistribute resources within an established stand to move the stand toward a desired future condition. Intermediate treatments include thinning, improvement cutting, prescribed burning, and fertilizing.

Thinning

Thinning is used to reduce stem density of the desired species in the stand. Typically this is done to release "better" individuals from competition by removing some trees to enhance the growth of the trees that remain (Lundgren 1981). However, thinning can also achieve other goals correlated with reducing stem density, such as promoting understory growth, reducing clutter for bats, or creating downed woody debris. Regardless of the goal, thinning will redistribute resources to the remaining trees and stimulate their growth.

Distinctions among the different kinds of thinning relate to the relative crown positions of the trees being removed. Low thinning, or thinning from below, primarily removes smaller overtopped trees that are likely to be lost to density-dependent mortality. This type of thinning increases the availability of water and soil nutrients to retained trees, but it generally does not increase the amount of light available to the residual trees or understory, unless it is applied in a manner that removes a third or more of the stem density in the stand. Crown thinning, or thinning from above, removes larger trees that reach the upper canopy to favor similar individuals that have better form. This type of thinning increases the availability of all resources and promotes growth in both the understory and overstory.

Most thinning involves a judgment that some attribute of the trees being retained is superior to that found in the trees being cut. Traditionally, this has been associated with timber production such as straight stems, small branches, no damage in the crowns, and so on. But if branchiness, sweep, bark roughness, or crown deformation enhance habitat for bats, thinning can be adapted to favor trees with those traits.

Improvement Cutting

Improvement cutting is similar to thinning, but with the goal of removing undesirable species from a stand. It is analogous to a release treatment; both are imposed to balance competition between desired and undesired species. With improvement cutting the trees being removed are of merchantable size, but whether they can be sold commercially depends on whether there is sufficient volume to make a harvest operationally feasible for a logger. Improvement cutting is often applied in stands that were not subject to release when young. As in release treatments, improvement "cutting" can be carried out through the use of herbicides. Improvement cutting can also be adapted to favor mixed-species stands by leaving trees of different species in the residual stand, and removing trees that compete with the retained trees.

Prescribed Burning

Prescribed burning is frequently associated with its use as a site preparation tool to dispose of slash and litter, to release seeds from serotinous cones, to release nutrients stored in leaf litter and woody material, and to top-kill seedlings and stump sprouts of species not adapted to fire. However, fire is increasingly being used as an intermediate treatment in established stands to maintain attributes of fire-adapted ecosystems and to reduce fuel loads. In fire-adapted ecosystems, fire can be used like an improvement cut to eliminate competing species that are not adapted to fire-prone habitats. At the same time, this will help promote other aspects of fire maintained ecosystems, such as an open, grassy understory (Sparks et al. 1998).

The practice of prescribed burning is limited by safety constraints. Criteria for when fires can be set typically are very strict to ensure that prescribed fires do not turn into wildfires, that air quality is not compromised, and that those working on the fire are not at risk. Fires are often limited further by hunting seasons and public opinion. Because of these constraints, implementing fires on a landscape scale is not always possible.

Fertilization

Although fertilization is frequently confined to regeneration treatments, it is often used in industrial forestry in stands of all ages. The idea behind fertilization is to add a limiting resource to the stand, rather than by releasing it from use by other trees. It is most effective if the nutrients being applied are limiting; effectiveness diminishes quickly if other resources such as soil moisture are more limiting than the nutrients being applied. Fertilization done early in the life of the stand is usually intended to accelerate sapling development and reduce the length of time required to obtain trees of a given size for harvest. Mature stands that are soon to be harvested can also be fertilized economically several years prior to harvest to provide additional growth of trees that are already of large size and value.

SILVICULTURAL SYSTEMS AND PRESCRIPTIONS

A silvicultural system is an integrated combination and sequence of treatments planned over time, designed to carry an existing stand to a desired future stand condition.

SCHEDULING TREATMENTS

An even-aged system has a discrete beginning and end, starting with the establishment of the new stand and culminating in a final harvest when the stand reaches maturity at the appropriate rotation age *r* (fig. 7.4a). The reproduction cutting method initiates the new stand, regeneration treatments release desired species from competing vegetation, and intermediate treatments regulate stem density to maintain growth of desired species. Eventually the stand reaches rotation age at which time a new system is initiated. Thus, silvicultural systems in even-aged management follow a chronosequential pattern, and each treatment conducted at each point in time is generally applied across the entire managed portion of the stand.

Conversely, uneven-aged silvicultural systems do not have a discrete beginning and end. The basic unit of management is the cutting cycle, defined as the average interval between harvests. Each cutting cycle harvest contains some elements of reproduction cutting, some elements of thinning, and some elements of regeneration treatment, all conducted concurrently within the different size classes appropriate for each (fig. 7.4b). The uneven-aged silvicultural system then becomes defined by the pattern of implementation (single-tree or group selection) and by the description of treatments required in each age cohort of the stand.

Trends in cash flow, investment, and return can also be inferred from these temporal patterns. In even-aged stands, late rotation thinning and the final harvest provide the largest financial returns, but little opportunity for financial return exists in the first half of the rotation. Some practices, such as planting and site preparation, are extremely expensive and must be capitalized over the life of the stand. This creates powerful economic incentive for managers to optimize growth and reduce the length of the rotation. On the other hand, uneven-aged stands often provide pe-

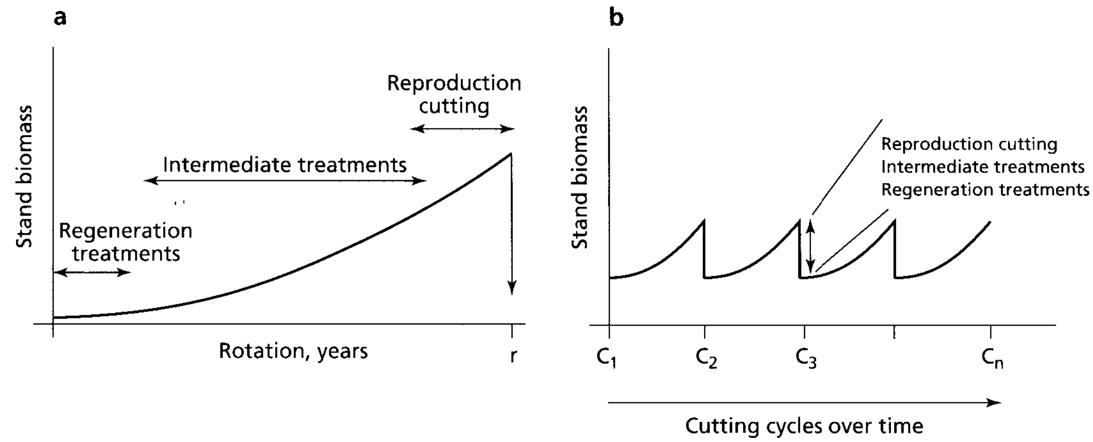

Figure 7.4. Comparison and timing of treatments conducted in even-aged (a) and uneven-aged (b) silvicultural systems over time.

riodic return for landowners and expenses are low. However, the standing volume that must be maintained in an uneven-aged stand does have value, and the compounded value of that standing inventory represents a financial risk if it were to be lost. Landowners must individually decide which cash flow model is appropriate for their respective economic situation.

The temporal patterns (fig. 7.4) also depict trends in canopy cover for each silvicultural system. In the even-aged systems, there is some time early in the rotation when canopy cover, especially cover associated with reproductively mature trees, is limited or absent. Conversely, continuous canopy cover is maintained in uneven-aged systems, especially in the single-tree selection system. If a diversity of canopy conditions across stands is sought, even-aged systems might be appropriate, especially if stands are managed to feature different age classes across the landscape. Conversely, if uniform canopy coverage across a landscape with a minimum of openings in the canopy is sought, uneven-aged systems would be better.

TIMING OF PRESCRIPTIONS

Proper timing of prescriptions is important in both even-aged and uneven-aged systems. In even-aged systems, delays in timely treatment can lead to reduced growth, reduced individual tree vigor, and greater risk of density-dependent mortality. For example, pine bark beetles (*Dendroctonus* spp.; *Ips* spp.) are more likely to cause problems in stands where individual tree vigor is low. Thinning to maintain acceptable vigor and growth rates before stands become overcrowded is an effective tool to promote forest health. In uneven-aged stands, prescriptions must consider the balance between the basal area of small trees, large trees, and the submerchantable seedling and sapling classes. Too many large trees can lead to suppression and mortality of regeneration. If the merchantable size classes become too densely stocked, either by retaining too many residual trees during a cutting cycle harvest or by failing to implement a scheduled cutting cycle harvest in a timely manner, regeneration can become suppressed.

FIELD PERSONNEL

Whether using even-aged or uneven-aged systems, training must be given to field personnel on proper marking techniques. Generally speaking, from intermediate-age classes onward, marking for thinning and reproduction cutting requires attention to the silvicultural axiom "cut the worst trees and leave the best." Describing what is worst or best depends on the ownership objective, and the description might differ if the goal is for maximum timber production versus sustaining habitat of tree-roosting bats. In general, marking in even-aged stands requires attention to uniformity of spacing and to desirable attributes sought in the trees being retained. Conversely, in uneven-aged stands, variability in spacing of overstory trees is necessary to promote openings for regeneration.

Managing even-aged stands often requires fewer visits to the site by field crews than does managing uneven-aged stands. This can be important in organizations where the number of field personnel is declining. Other things being equal, the ideal way to plan a thinning or harvest is to inventory the stand in the field, analyze the inventory data in the office to determine what is to be retained and thus what is to be cut, and then return to the field for the marking. Regardless, it is easier to skip the inventory step in an even-aged stand than an uneven-aged stand. Even-aged stands are more homogeneous in tree size, and under such conditions, the target residual basal area can be easily estimated. In heterogeneous stands, it is more important to use an inventory to develop a target residual stand and to guide operational marking. As a result, management costs are often higher in uneven-aged stands than even-aged stands.

STREAMSIDE MANAGEMENT ZONES

In most forest management applications on public and private lands, special attention is given to the areas immediately adjacent to streams. Because trees draw water from the ground, harvesting trees reduces the water storage capacity of an area. This can lead to increased water flow, which can accelerate erosion. Erosion can adversely affect water quality and aquatic habitats. To protect water quality most public and industrial forests use streamside management zones (SMZs). These are zones surrounding perennial and intermittent streams in which limited or no harvesting of trees is permitted (Wigley and Melchiors 1994).

In addition to water quality, trees overhanging streams in SMZs are important in maintaining colder water temperatures. Because water temperature dictates the amount of dissolved oxygen in water, water temperature is critical to aquatic insects and to some species of fish, such as the salmonids (Beschta et al. 1987). SMZs have also been found to be important for wildlife habitat (Dickson and Wigley 2001). Bats have been observed to use SMZs as travel corridors (Law and Chidel 2002), and may concentrate in SMZs for feeding and drinking (Grindal et al. 1999). Because SMZs have been viewed as critical for many ecological resource values, silvicultural treatments have generally been restricted within these areas. The degree to which SMZs serve as valuable landscape elements for forest-dwelling bats has yet to be clearly determined, and likely will vary among geographic regions.

IMPLICATIONS OF SILVICULTURE FOR BATS

Of all the habitat components required by bats in forests, the two most heavily influenced by forestry are roosting sites and foraging habitat (Hayes and Loeb, chap. 8 in this volume). The management of trees valuable as roosts is not intrinsic to any one silvicultural practice. Rather, most practices can be modified to manage roosting sites. In contrast, different silvicultural practices will promote different foraging habitats, which will favor different species of bats. For example, Patriquin and Barclay (2003) reported that in the boreal forests of Alberta, different species of bats use forests in different conditions; they noted that the silver-haired bat prefers clearcuts and avoids intact forests, the little brown myotis (*Myotis lucifugus*) prefers to forage along the edges of clearcuts, and the northern myotis (*M. septentrionalis*) prefers to forage in intact forests. Such reports support the impression that there is no generic habitat for forest-dwelling bats, but rather, like other wildlife species, different habitats will favor different bat species. Developing adequate forest habitat for bats will require a much better understanding of the habitat that each species prefers than is currently available.

ROOSTING HABITAT

Bats often use trees and snags for roosts (Barclay and Kurta, chap. 2 in this volume; Hayes 2003; Kunz and Lumsden 2003). Some species, such as lasiurine bats, roost in the foliage of live trees, whereas other species roost in a more protected location, such as a cavity, a split trunk, or under sloughing bark (Carter and Menzel, chap. 3 in this volume; Hayes 2003; Kunz and Lumsden 2003; Menzel et al. 2003). Typically, these kinds of roosts are found in relict trees, cull trees (trees made unmerchantable because of decay or deformities), and snags. Historically, silviculturists have not valued such trees.

Relict trees, cull trees, and snags have traditionally been considered impediments to timber production goals. Relict trees are often viewed as trees that should have been harvested earlier and that are compromising the stand by using too many resources. Cull trees, such as those with cavities or a broken crown, are viewed as taking limited resources away from better trees. Snags caused by competition indicate a missed opportunity to profit from the harvest of a tree and lost growth potential for neighboring trees. When snags are created by forces beyond the control of a silviculturist, such as wind, ice, wildfires, insects, and disease, the impulse often is to salvage as much timber as possible. From the vantage of timber production, and even with a more modern set of goals, this is often a logical management decision. For example, salvaging timber after a disease outbreak may be advisable to facilitate reforesting the site and to prevent forest fires and future outbreaks of disease. Changing these attitudes, which run strongly in the profession, may be an impediment for biologists. Nonetheless, from an ecological perspective, the value of relict trees, snags, and cull trees should not be trivialized or marginalized.

We contend that the proper way to deal with relict and cull trees is to quantify their ecological influence and account for that influence in prescription planning. Because water, nutrients, and solar radiation are limited, retaining any tree limits the growth of surrounding trees (Palik and Pregitzer 1994; Thysell and Carey 2000; Traut and Muir 2000). For example, in southern pine stands managed using single-tree selection in southern Arkansas, a typical residual basal area target is 14 m^2/ha, with a maximum diameter at breast height (dbh) for residual trees of 50 cm. A tree with a dbh of 80 cm has a basal area of 0.5 m^2/ha. Thus, if two of these trees are retained per hectare as relict trees, they represent 7% of the residual basal area of the stand (fig. 7.5). To keep the residual basal area within prescribed limits, more trees would have to be cut within other size classes. Ignoring the prescribed limits would likely lead to reduced growth, mortality in smaller-size classes, and eventual conversion of the stand to more shade-tolerant species.

Because of the influence relict and cull trees have over a stand, it may be desirable to reduce the competitive edge of these retained trees. For example, leaving individuals with poorly formed crowns will minimize the shading of regeneration. Partially girdling, pruning, or disturbing the roots could be used to reduce the competitive ability of retained trees.

Another consideration for relict and cull trees is that they have the potential to reproduce. If these trees are of an undesirable species, or if they have undesirable characteristics that may be heritable, reproduction is often unwanted. Typically this will require a cleaning or thinning to remove the unwanted regeneration, but in some instances it is possible to reduce the likelihood of such trees contributing to the future stand by retaining trees that are poorly adapted to understory conditions. For example, if a stand is being managed for shade-intolerant species, shade-tolerant species could be retained because the regeneration of these trees will likely be overtopped by the faster growing desired species. Alternatively, stands managed for shade-tolerant species could retain shade-intolerant species because their regeneration will likely not survive the shade. It may

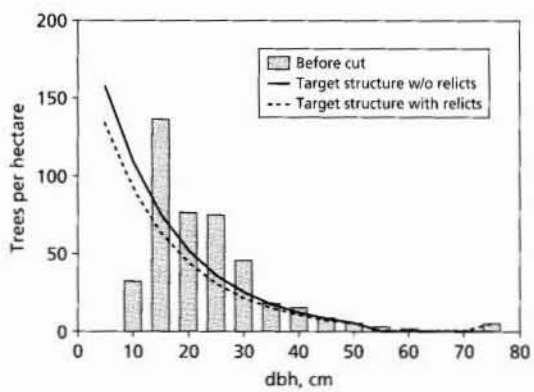

Figure 7.5.
The target, residual stand structure in the 50-cm diameter class and smaller in this hypothetical, uneven-aged stand must be reduced if two relict trees/ha in the 75-cm diameter class are to be retained.

also be possible to reduce the reproductive ability of relict and cull trees by retaining competing vegetation around these trees.

Because snags do not limit resources or reproduce they often may be more desirable to land managers than relict or cull trees. Snags can be unstable, however, and serious injuries and fatalities have occurred from snags falling on forest workers (Myers and Fosbroke 1995). Because of this safety hazard, the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor requires that, if work is to be carried out within two tree lengths of a snag, the employer must demonstrate that this will not create a hazard for the employee (Code of Federal Regulations 29, 1910.266(h)(1)(vi)). OSHA further requires all snags deemed dangerous to be felled before any other work is done within two tree lengths of the work zone. Thus, saving a dangerous snag that is 18 m tall requires no harvesting over an area of 0.4 ha surrounding this snag. If snags can be found in clusters, this could reduce the impact of retaining snags.

Additionally, snags can be retained in areas that typically are not harvested, such as SMZs and around historical sites. However, the effectiveness of retaining snags in clusters and in SMZs for forest-dwelling bats remains unknown and should be evaluated.

In any case, because of safety restrictions it is often easier to create snags than to protect them. In nature, snags are created by lightning, wind, ice, disease, and insects, but land managers have little or no control over these forces. Snags can be created by girdling the bole or by topping the tree, without compromising the growth of the stand. Creating snags from cull trees or from species that have little commercial value can further lower this "expense." Also, using cull trees may help reduce the lag time between when a snag is created and when it is of use to bats and other species of wildlife.

It should be possible to develop herbicide technology to promote living snags. A sublethal dose of herbicide injected into a tree would reduce growth and uptake of resources to a negligible level. The tree would remain alive, in a reduced state of vigor, and would essentially become a living snag with marginal effect on the trees that surround it. Assuming this approach provided the characteristics valuable for bats and other wildlife species, such an approach might significantly extend the functional presence and longevity of snag attributes in the stand.

Relict trees, cull trees, and snags are not an innate attribute of any silvicultural treatment. Most treatments can be adapted to include and manage them. Of the reproduction cutting methods, clearcutting is the least well suited to these types of legacy elements, because these trees use resources and suppress regeneration development within their zone of ecological influence. Their retention also hampers forestry operations; snags and relicts are impediments to logging, site preparation, planting, and aerial application of herbicides and fertilizers. Leaving cull trees during thinning operations will reduce the future value of timber when harvested. All of these problems can be overcome at additional expense, which landowners may or may not choose to incur.

Managing relict trees, cull trees, and snags under the seed-tree method is similar to their management in clearcuts. Seed trees can be left as relict trees, or after regeneration has occurred, they can be girdled to create large snags. Often it is only marginally profitable to harvest the seed trees, so this may be a viable alternative. Additional snags can be created at the initial harvest, in particular, if the seed trees are to be retained.

In the shelterwood method, snags can be created with any of the three harvests (preparatory cut, seed cut, or removal cut). Snags created in the first or second harvest will need to be avoided at later harvests, however. Creating snags in clumps may be useful in these situations. Relict trees can be left after the removal cut and cull trees can be left during thinning.

Single-tree selection allows considerable flexibility in retention of relict and cull trees. As described above, however, prescriptions must be adjusted to compensate for the presence of relict trees and care must be taken to ensure cull trees do not become a primary seed source. Because these stands are re-entered on a regular basis, creating and retaining snags can be problematic. It may be that snags created in one cutting cycle would impede operations during the following cutting cycle. However, because most stands managed under single-tree selection are shade tolerant, it may be possible to postpone harvesting around desirable snags without impacting the size distribution and species composition of the stand.

Group selection allows the greatest flexibility in the retention and creation of snags. Groups can be positioned to avoid desirable snags, or to include them within the opening. Openings created with group selection harvests are often used as logging decks, however, and snag retention within them would hinder such operations. The advantage of leaving snags in a group opening is that several cutting cycles will occur before a group opening is harvested again; thus, retained snags would be less likely to hinder subsequent harvests in the cutting cycle than if they were scattered throughout the matrix of the stand between the group openings. Relict trees and cull trees also can be retained, although, just as with snags, allowances must be made for their presence.

FORAGING HABITAT

In flight, bats must contend with physical obstructions or physical clutter (Brigham et al. 1997). These are elements of the habitat that impede flight such as foliage, branches, and tree stems. The degree of physical clutter a bat is able to negotiate depends on body mass and wing morphology (Aldridge and Rautenbach 1987). Additionally, bats must be able to detect physical clutter and prey. Differently structured echolocation calls are useful in different habitats. For example, low-frequency, narrow-bandwidth calls are effective at detecting objects at long distances, but are confounded by even low degrees of clutter. Alternatively, high-frequency, broad-bandwidth calls are effective at detecting objects at only short distances and can contend with higher degrees of clutter (Aldridge and Rautenbach 1987). As a consequence, the degree of clutter a bat can fly and hunt within depends on call structure. Some researchers have grouped bats into "ensembles" based on the degree of clutter found in the habitat they use (Aldridge and Rautenbach 1987; Grindal 1996; Patterson et al. 2003). Aldridge and Rautenbach (1987) found that bats in South Africa segregate into four ensembles: open foragers, woodland edge foragers, intermediate clutter foragers, and clutter foragers. Because silvicultural practices alter clutter, different practices should favor different ensembles.

Clutter in even-aged stands

Throughout the life of an even-aged stand, most of the foliage lies in the main canopy, which gradually increases in height (fig. 7.3a). The area within and below the canopy is typically very dense for approximately the first third of the life of an even-aged stand. During this time, such stands may be too dense for even clutter-adapted bats. As trees reach merchantable size, they often self-prune. This reduction in clutter might create a zone suitable for clutter-adapted species, but this is not always the case, as in trees that do not naturally prune or in stands that develop a midstory. Additionally, few corridors will exist through the canopy. Thinning, improvement cuts, pruning, herbicides, and prescribed fire can be used to further reduce the clutter in the understory and to open corridors through the canopy (fig. 7.6). Depending on the intensity of treatment, these silvicultural practices could be used to increase habitat use by bats (Humes et al. 1999) and create zones beneath the canopy suitable for clutter foragers and intermediate clutter foragers.

Throughout most of the life of even-aged stands, low-clutter habitat suitable for open foragers exists above the canopy. In the seed-tree method slightly less open conditions exist between the first harvest and the removal of the seed trees. Depending on the density of seed trees, these stands might be suitable for open foragers or woodland edge foragers. In the shelterwood method, foraging habitat for intermediate clut-

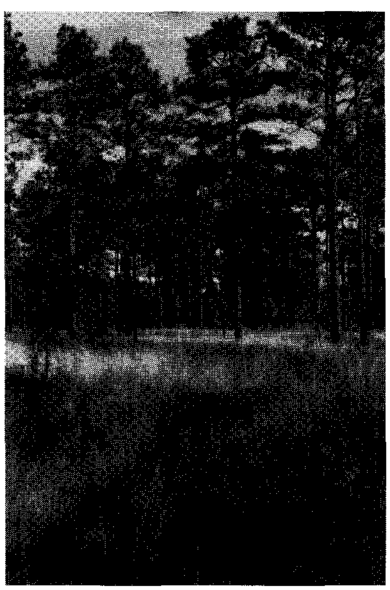

Figure 7.6. (left) Sharp transition in clutter at the base of the live crown in an even-aged stand of longleaf pine (*Pinus palustris*). Note the extensive area of low clutter beneath the canopy resulting from cyclic prescribed burning. *Photo by J. Guldin*

Figure 7.7. (right) Heterogeneous distribution of clutter within an uneven-aged loblolly-shortleaf pine (*Pinus taeda-Pinus echinata*) stand on the Crossett Experimental Forest, Ashley County, Arkansas. *Photo by J. Guldin*

ter foragers would likely be created during the preparatory cut, while the seed cut would likely favor intermediate clutter foragers and woodland edge foragers.

Clutter in uneven-aged stands

In well-regulated, uneven-aged stands, foliage is present at all strata, from the forest floor to the upper canopy (Baker et al. 1996; Lorimer 1989; Shelton and Murphy 1993; Whitmore 1989). In practice, these different strata form clusters at different heights in the canopy profile (fig. 7.7). Thus, uneven-aged stands generally have zones of low clutter within a matrix of high clutter. These low-clutter zones are larger and extend further into the canopy in the group selection method than in the single-tree selection method. Stands managed under single-tree selection would likely favor clutter-adapted species, while those under group selection might favor clutter- and intermediate-clutter-adapted species. Alternatively, because bats often use roads as travel corridors (Hickey and Neilson 1995; Limpens and Kapteyn 1991; Menzel et al. 2002; Walsh and Brigham 1998), species adapted to more open conditions may be able access stands under uneven-aged management through the road networks that are often maintained to facilitate repeated entries.

Clutter between stands

Factors other than foliage distribution can have a bearing on clutter, especially when areas larger than an individual stand are examined. Because managed and unmanaged stands differ in the distribution of clutter, boundaries between these stands might serve as a filter to exclude ensembles of bats. Similarly, boundaries between stands that differ in silvicultural treatments, management intensity, forest type, or age may also act as filters. This may especially be true of SMZs within individual stands. When managing for bats, some thought should be given to the arrangement of different stands across a landscape. For example, a mature even-aged stand with an open understory, suitable for bats adapted to intermediate levels of clutter, would be inaccessible to such species if it was surrounded by stands suitable to only clutter-adapted species. In such cases, roads may be an important means for gaining access to otherwise inaccessible areas. Thus, we suggest that management of clutter for forest-dwelling bats has both within-stand and between-stand components.

SUMMARY

In the twenty-first century, we expect that the practice of silviculture will broaden to increasingly encompass ecosystem-based goals such as restoration and enhancement of habitat for desired plant and animal species and communities. The array of reproduction cutting methods, regeneration treatments, and intermediate treatments that constitute a silvicultural system can be configured to meet the habitat requirements of bats. The choices among overall reproduction cutting methods, and between even-aged and uneven-aged methods, have implications for bats, especially with regard to roosting and the management of foraging habitat. Special attention needs to be focused on creating and retaining structural and legacy features such as relict trees and snags. Once the type, amount, and distribution of such features are known, they can be incorporated into a variety of silvicultural systems. To satisfy management objectives for species whose habitat requirements transcend individual stands, the forester should plan silvicultural practices in concert across stands and, increasingly, across ownerships.

There are some important hurdles to implementing bat-friendly silviculture. Foremost for bat biologists will be the definition and quantification of those attributes that are of value to bats. Once those needs are understood, biologists and silviculturists can work together to develop prescriptions that meet the needs of bats in forests. The challenge for biologists is to learn as much as possible about roosting, foraging, and other habitat requirements for the bat species of interest. The challenge for silviculturists working with biologists concerned about bats is to incorporate ways to satisfy habitat requirements of bats while meeting other forest management objectives.

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