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# EFFECTS OF VARIOUS HARVESTING METHODS ON FOREST REGENERATION

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# EFFECTS OF VARIOUS HARVESTING METHODS ON FOREST REGENERATION

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## ABSTRACT

Available literature indicates that for most forest types and species on most sites, foresters have wide latitude in choosing regeneration cutting methods insofar as ecological requirements of tree species are concerned. Few species or sites require uneven-age management under a selection system, and necessary conditions can be provided usually by some form of even-age management. Likewise, there is no ecological necessity for large patch or continuous clearcuttings to regenerate most types, species, and sites including Douglas-fir; shelterwood or strip clearcut systems appear equally suitable for regeneration of most species on most sites. Selection systems can be used successfully for some major species, including certain southern pines. They also could be used for many others, provided that a change in species composition is acceptable. Ecological constraints do limit use of clearcuts on more severe sites, that is, those where moisture and temperature are major problems. With these exceptions, economic and social rather than ecologic considerations appear to be the most important factors controlling selection of cutting systems.

## INTRODUCTION

Preparing a comprehensive paper on effects of even-age management on vegetation has proved a laborious task! Because time and resources were insufficient to consider the total effect on all elements of plant communities, we decided that we must confine ourselves to effects of cutting systems on forest regeneration. We then proceeded to examine the research and experience recorded in each of the major forest types of the United States—the silvicultural systems being used or under study and their successes and failures in terms of regeneration.

We soon became aware that the paper we were producing on a type-by-type basis was going to be unwieldy, incomplete, and repetitious—not to mention boring. Patterns emerge and repeat themselves in type after type. Almost all major types can be regenerated successfully by a variety of silvicultural systems. Few species or types have such limited tolerances that only a single harvesting method will suffice.

We altered our original intentions, therefore; instead, we have prepared a paper on the patterns or generalities that are apparent and illustrated them in selected types. We will try to point out the latitude silviculturists typically have in choosing regeneration techniques and some of the biologic and environmental factors that constrain them. We will illustrate these principles with examples of some of the species, types, and circumstances that necessitate either uneven- or even-age management, or a particular even-age system, to obtain prompt regeneration. Finally, specific conditions will be discussed for two major forest regions—the Douglas-fir and the southern pine and bottomland hardwood.

## SILVICULTURAL SYSTEMS

Before proceeding, let's examine and define the different silvicultural systems used to achieve regeneration cuts. We will make the general presumption that the objective of regeneration cutting is a replacement stand within a certain time limit and of a desired composition and vigor. According to Smith (37), four major systems are used in regeneration cutting although each has numerous variants–the clearcut, seed-tree, shelterwood, and selection systems. Three of the four systems lead to the creation of a new, even-age stand regardless of the form of the original stand. The only exception is the selection system and its variants, which are used to create or maintain uneven-age stands–stands with "at least three well-defined age classes" (37).

In the **clearcutting** system, the entire stand is removed in one cutting. This method produces the most drastic changes in environmental conditions–providing full exposure to light and minimal protection of the site from climatic extremes. Foresters may depend on either artificial or natural regeneration or both in establishing the new stand after clearcutting. In coniferous forests, clearcutting (that is, **continuous** or large **patch clearcuttings**[1]) usually is associated with artificial reforestation by planting or seeding. Natural regeneration is an alternative with coniferous species that are consistent and prolific seed producers such as loblolly pine. Clearcutting of hardwood forests relies primarily on natural regeneration. Modifications of the clearcutting system over much smaller areas are designed specifically to enhance regeneration by providing a more protected site and, if natural regeneration is sought, an abundant seed supply. The most common modification is the **alternate strip clearcutting** where long, narrow clearcut areas are interspersed with uncut strips. Another is the small **group** or **patch clearcutting** on, perhaps, 1 to 5 acres, rather than the much larger areas typically referred to as clearcuttings.

[1]One can argue at what size (acreage) areas logged by group selection are sufficiently large to be considered small group or patch clearcuttings. To clarify our terminology in this article, we offer the following admittedly arbitrary size definitions:

| | |
|---|---|
| Continuous clearcutting | 100 acres or more |
| Large patch clearcutting | 10 to 50 acres |
| Small patch (or group) clearcutting | 1 to 5 acres |
| Group selection | Two trees to ¼ acre |
| Selection | Single tree |

Also, we use the term clearcutting to refer to **biological** clearcuttings, where all trees over a certain size are removed, in contrast to **commercial** clearcuttings, where culls and otherwise defective and unmerchantable trees are left standing. We thank Dr. David Smith for his advice in arriving at these definitions.

In the **seed-tree** system, all of the forest stand is cut except for a few selected trees (perhaps from 2 to 12 per acre). These trees are left to provide seed for natural regeneration and have only a minor protective function. The success of the method depends upon leaving enough seed trees to produce adequate seed for regenerating the stand when seedbed conditions are optimum. Release of seed trees before harvest cut sometimes may be required to stimulate seed production and insure coincidence of the seed crop with favorable seedbed conditions.

In the **shelterwood** system, the old stand is removed gradually in from two to several stages. Sufficient trees are left to protect the site from environmental extremes until regeneration is established, generally by natural seeding. As Smith (37) stated, "Within the framework of the shelterwood method, it is possible to achieve wide variation in the relative degrees of shelter and exposure.... Adjustments can be made to meet the environmental requirement of almost all species."

In the **selection** system, mature trees are cut, either as individuals (**single tree selection**) or in small groups (**small group selection**), throughout the entire stand. This procedure is repeated indefinitely at relatively short intervals. Reproduction thereby is established continuously and an uneven-age stand structure is maintained. This system results in the least disturbance and is therefore the most pleasing from an esthetic viewpoint.

It is important to remember that clearcutting, seed-tree, and shelterwood methods are all utilized in even-age management, and only the selection method is aimed at uneven-age management. Further, among the even-age methods, the shelterwood is the most "conservative," that is, protective of the site from environmental extremes, and usually depends upon and provides suitable circumstances for natural regeneration. Conversely, patch or continuous clearcutting provides maximum exposure of the site and depends much more upon artificial regeneration for new stand establishment. Shelterwood techniques are more difficult and patch-clearcutting methods simpler to apply. Strip and small-group clearcutting and seed-tree methods are intermediate in these characteristics.

The selection silvicultural system is, of course, the most difficult to apply, and there is some doubt whether a "true" selection cut as compared to an "economic" selection (or high-grading) cut ever has been done operationally in many forest types of the United States.

## WHERE IS UNEVEN-AGE MANAGEMENT NECESSARY OR POSSIBLE?

We can begin by asking whether there are any forest types or species in the United States that are unsuited to some method of even-age management. Or, stated another way, are there types or species that **require** uneven-age management, a selection method, for their maintenance or regeneration?

From our examination of the literature, we find few situations where the selection method is **essential** to regenerate a new stand. Perhaps the outstanding example is virtually pure ponderosa pine found on sites subject to severe environmental stresses, particularly in moisture or temperature or both—climax ponderosa pine sites.[2]

Ponderosa pine stands of this type sometimes have been considered uneven or all aged. Most work indicates they consist of a mosaic of small even-age groups or patches that collectively present an uneven-age appearance (15, 30). Regeneration cuttings in these pine forests usually include some form of selection system; group selection has received greater emphasis than individual tree selection in recent years. Clearcutting does not provide suitable conditions for prompt regeneration in most stands (47), and stands and environment usually are not suited to a shelterwood cutting. Even under selection cutting, regeneration is typically episodic, awaiting the suitable combination of a good seed year and favorable conditions for germination and establishment during the next growing season.

[2]The ponderosa pine forests found on less severe sites with aggressive, more tolerant competitors, such as Douglas-fir or grand fir, are entirely different. These forests usually were created and maintained by fire, and selection forestry on these sites eventually will result in elimination of the pine. This points out the danger of generalizing about an appropriate cutting method for a widespread and variable "forest type" such as ponderosa pine, especially when that forest type is defined on an economic rather than an ecologic basis.

Although a few types **require** uneven-age management or selection forestry, we might ask whether other types **can** be managed in this way if so desired. We might also ask whether some types can be regenerated more easily by the selection system than by even-age methods. Apparently, many forest types can be regenerated by selection cutting; in fact, most of the climax forest types and very tolerant species can be perpetuated easily by selection cutting.[3] Examples of the latter include the northern hardwood types where beech and sugar maple are desired (27) and the red spruce-balsam fir type where objectives include favoring the spruce (17, 44).

Even seral or subclimax forest stands sometimes can be perpetuated by selection methods, but the landowner must be willing to accept a compositional change in the type. Examples are changes from Douglas-fir to western hemlock, ponderosa pine to Douglas-fir, and mixed hardwood stands containing an abundance of yellow-poplar to stands where oaks and hickories predominate. Sometimes, a group-selection technique may be adequate to provide for regeneration of the more desirable but less tolerant species and retard or arrest the gradual successional change in stand composition (29). Some species, however, represent very early stages in succession and probably cannot be perpetuated by any type of selection cutting. These include red alder (51), paper birch (28), aspen (16), and longleaf pine (42).

Although regeneration can be obtained by selection cutting in most forest types, even-age systems are operationally more efficient because areawide cultural treatments can be imposed. Moreover, growth rates of reproduction are more rapid when even-age systems are used. These two considerations are of prime importance if wood production is the main objective of management; however, they can be tempered with other considerations including continuity of forest cover and esthetics where other forest resources are also significant.

[3]It is essential to remember that many tree species, especially in the western United States, differ in their successional roles from site to site, as was pointed out with ponderosa pine. Douglas-fir and lodgepole pine, usually thought of as intolerant, seral species, are, in fact, climax on certain sites and therefore biologically amenable to regeneration under selection methods on these sites.

## WHERE IS EVEN-AGE MANAGEMENT SUITABLE AND WHAT FORM SHOULD IT TAKE?

If characteristics of few species, types, or sites dictate uneven-age management, then most species should be suited to some even-age method. Indeed they are. Most forest types have been grown and regenerated successfully under one or more of the even-age silvicultural systems–clearcutting, seed-tree, or shelterwood. But which of these is most applicable in a given situation? Let's begin with a consideration of the most controversial of the group–clearcutting.

Do any types, species, or sites have characteristics that necessitate the use of clearcuttings? Biologically, no types or species appear to **require large clearcuttings** for successful regeneration–by "large," we mean clearcuttings that exceed 10 acres. Even shade-intolerant species, such as yellow-poplar, can find light conditions suited to their establishment in areas of less than 2 acres (2). Tryon and Trimble (41) found that even intolerant hardwoods reproduced and grew well in areas as small as ¼ acre. The very intolerant black cherry reproduces best in small openings or narrow strips that are less than 66 feet in width (20). Red alder also appears capable of regenerating in small clearcut patches.

In fact, large-scale clearcutting methods are not justified by biological requirements for regeneration of the type or species but for rather different reasons. One is that early growth rates of established seedlings are often most rapid in clearcuttings–less "edge" per unit area is involved and therefore a smaller proportion of the new stand is retarded by "edge" effects. Disease or insect problems may be another reason. The prime reasons for large-scale clearcutting, however, are those related to efficiency and economics in harvesting and managing the stands. As Duffield (10) has pointed out, clearcutting often "... makes the least demand on other valuable resources, such as energy and labor, and on road mileage, transportation, and supervision." Certain treatments used in intensive culture–for example, fertilization and control of weed species–can be applied most efficiently to large areas. At times, landowners may wish to liquidate an economically unproductive stand or convert a stand from one species to another. With such objectives, large-scale clearcutting may be the best, if not the only, alternative available.

Given that regeneration of forest species never requires large-scale clearcuttings, perhaps a better question to ask is "Which forest types, species, or sites cannot be regenerated successfully by a clearcutting system?" At the risk of being accused of saying all methods are suited to all types, we must suggest again that most truly productive forest land can be regenerated after clearcutting–provided that a dependable method of artificial reforestation is available. Some serious constraints exist, however, and not all forests suited to even-age management necessarily are suited to clearcutting, particularly on an extensive basis. Let's consider some of the factors essential for regeneration and how they can influence its success or failure.

The regeneration triangle of Roe, Alexander, and Andrews (32) contains three groups of elements that must be present for a successful natural regeneration–adequate seed, suitable seedbed, and a favorable environment for establishment and growth. Artificial regeneration, particularly planting, largely circumvents two of these elements–seed and seedbed. Favorable environment remains as a requirement for either natural or artificial regeneration, however, and herein lies the chief difficulty with extensive clearcutting.

Environmental elements that influence regeneration success usually can be reduced to temperature, moisture, and light. Lack of nutrients may limit regeneration on some sites (for example, phosphorus-deficient soils in the southeast), but these are exceptions. Temperature and moisture tend to be problems on one type of site and light on another. Unfavorable light conditions are most commonly a consequence of competing vegetation, and therefore problems are greatest on the most productive sites where growth of competing vegetation is rapid. Any silvicultural system will tend to stimulate development of competing vegetation on such habitats. Although clearcutting often produces the most favorable circumstances for development of competing vegetation, a variety of chemical and physical methods are available for control, and areas of regeneration failure can be corrected by planting or seeding. Such control methods are difficult or impossible to use on areas cut by shelterwood or selection methods. Less common are problems associated with excesses of solar radiation, such as those encountered after clearcutting Engelmann spruce at high elevations in the Rocky Mountains (33).

Unfortunately, adverse conditions of moisture or temperature are much more difficult (or impossible) to ameliorate, and large-scale clearcutting almost invariably aggravates these problems. Consider, for example, the distribution of western forest types in an "environmental field" of relative moisture stress and temperature (Figure 1), and then recall the specific situation in which problems have arisen in regeneration after extensive clearcutting. Usually, regeneration failures have occurred where either moisture or temperature are controlling or overriding environmental factors. Clearcutting has aggravated these conditions sufficiently that they are near or beyond tolerances of the species we wish to regenerate. Furthermore, conditions are often not only beyond the tolerances of natural seedlings, but also beyond the range for dependable artificial regeneration, that is, for survival and growth of planted trees. Some form of "protection" cutting, such as shelterwood or the strip clearcutting, can maintain these stresses within the tolerance levels of the regenerating trees.

Problems also have been encountered after clearcutting on very wet sites in the southeastern coastal plain–these will be discussed in more detail later.

Extensive clearcutting becomes increasingly undependable as environmental conditions become more and more limiting. Consequently, using such a technique on severe sites is unwise, particularly if no dependable method of artificial regeneration is available. This is generally true in the forest habitats that are extremely dry, wet, hot, or frost susceptible. On such sites, and they are numerous, even-age management using shelterwood or strip or group clearcutting methods often has proved successful.

Perhaps one can recognize a range from the most severe sites where shelterwood or selection methods are essential to

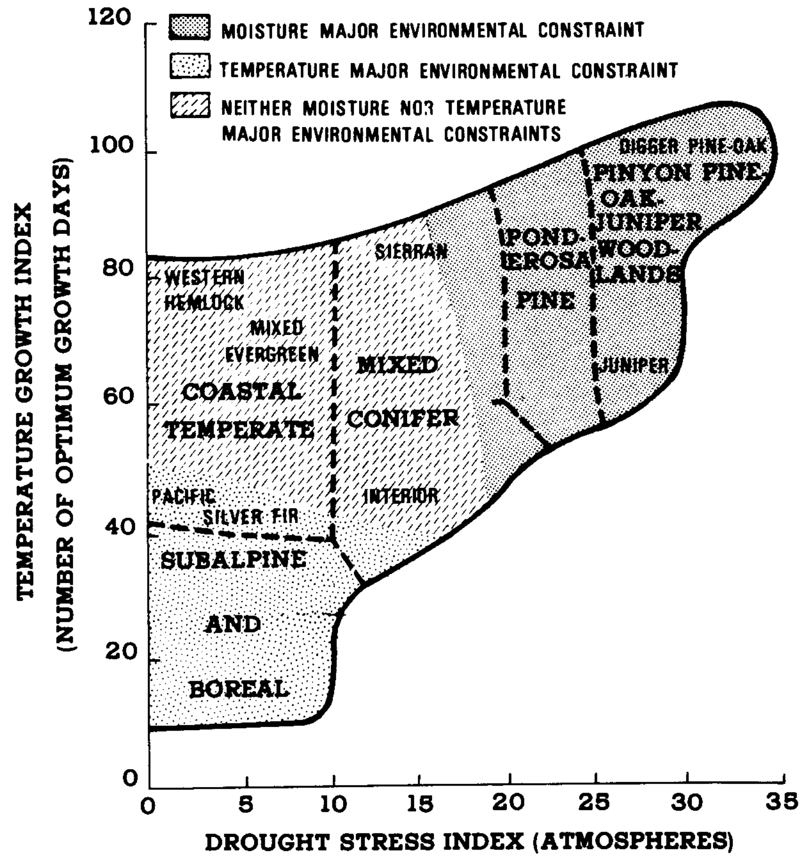


**Figure 1. Distribution of major western coniferous forest formations along temperature and moisture gradients (courtesy of R. H. Waring and the Coniferous Forest Biome, US/IBP). Temperature index is based upon number of "optimum growth days," a temperature-summing method, and the moisture index is based upon maximum night stress in conifer seedlings, in atmospheres.**

extremely favorable sites where any method will provide for regeneration, including large-scale clearcutting.

Let's now relate these generalities to conditions in two major timber-producing regions of the United States—the Douglas-fir region and the southern pine and bottomland hardwood region.

## THE DOUGLAS-FIR REGION

The Douglas-fir region encompasses western Washington and Oregon where extensive forests are dominated by Douglas-fir and western hemlock. Characteristic associates are western redcedar, Sitka spruce along the coastal strip, incense cedar, white fir, and sugar pine in southwestern Oregon, and Pacific silver fir and noble fir at higher elevations in the Cascade and Coast Ranges. In general, western hemlock is the most tolerant species present and, therefore, the major climax species except at higher elevations where it bows to Pacific silver fir. The majority of these stands have regenerated after wildfire or logging. Most stands in the region are essentially even aged.

Conditions are favorable for forest establishment and growth on most forest sites. Competing vegetation, such as red alder or salmonberry, is the major problem in forest regeneration on the moister, more productive sites. Hot, droughty habitats are encountered locally, however, in the summer-dry climate, and these become increasingly common from north to south following the regional trend in precipitation and moisture. And at higher elevations snow, short growing season, and frost become major environmental factors.

The objective of regeneration cutting in these forests is prompt reproduction of even-age coniferous stands. Douglas-fir is the most widely preferred, but western hemlock, Sitka spruce, noble fir, and others are also acceptable and sometimes preferred. Douglas-fir reproduction most often is established artificially by planting after clearcutting. Natural regeneration provides "fill-in" trees, which are often other species. Much of the cutting on public land is still in old-growth forests with all their difficulties–for example, large volumes of slash and very large logs. More and more of the cutting is in younger age classes. These stands have characteristics, such as smaller size, greater uniformity, and less defect, which permit much greater operational flexibility.

Almost all clearcutting and partial cutting methods, excepting only true selection techniques, have proved biologically suitable for regeneration of forests of Douglas-fir and western hemlock. The standard method on public land has been to clearcut patches averaging around 40 acres in a staggered-setting pattern, followed by broadcast slash burning (Figure 2). Originally, this system was believed to provide suitable conditions (open areas with adjacent seed supply) for natural regeneration of Douglas-fir, economic logging units, rapid development of access roads, and to avoid large, continuous areas of hazardous fire fuels. Fully stocked, naturally regenerated stands often failed to develop promptly or at all, however, because of infrequent Douglas-fir seed crops and high mortality of seedlings on more severe sites (36). Consequently,

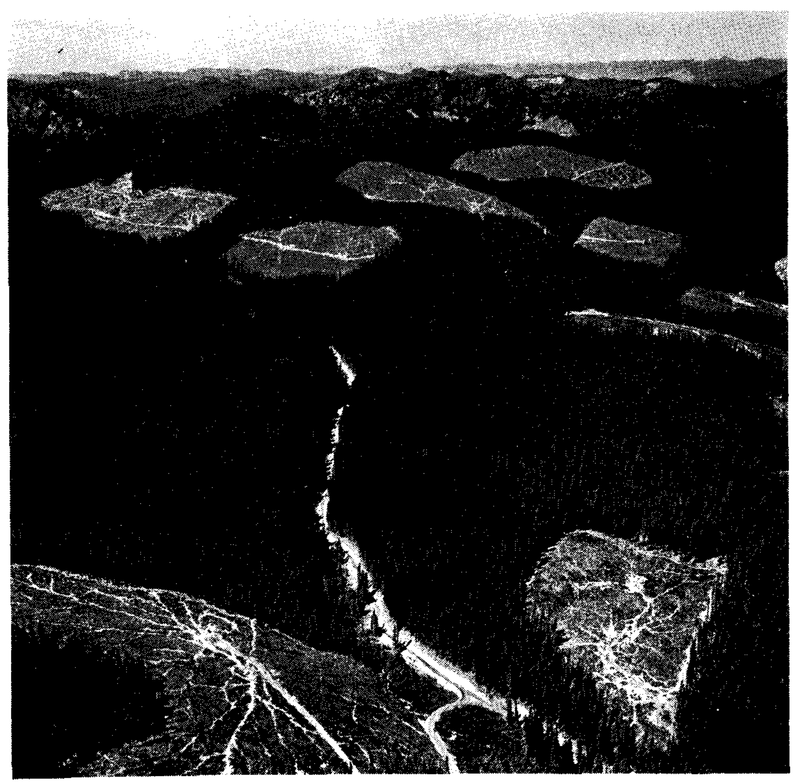

**Figure 2. Staggered-setting system of clearcut patches typically used on public lands in the Douglas-fir region.**

clearcuttings now are generally planted or seeded shortly after cutting, with good results. The system occasionally fails on moist habitats where competing vegetation or shrubs develop rapidly, or on hot, dry habitats where planted stock has difficulty surviving. Its more serious failures will be discussed later.

Continuous or progressive clearcutting followed by artificial regeneration is characteristic of many private ownerships. Advanced or postlogging natural regeneration or both may augment artificial regeneration to a surprising degree—many of the early logging operations produced continuous clearcuttings that are occupied today by fully stocked, naturally regenerated stands. The occurrence of tracts occupied by brush, low-value hardwoods, or understocked coniferous stands, however, also attests to the fact that natural regeneration cannot be depended upon.

Nor should it be depended upon. Clearcutting systems of this type are appropriate for productive forest lands suitable for intensive management. Artificial regeneration largely ensures prompt and adequate occupancy of the site by a new forest stand. Continuous clearcutting followed by artificial regeneration is, in many ways, a more logical or efficient management choice for commercial forest lands than patch clearcutting, which produces a mosaic of smaller areas of contrasting age classes.

On the majority of forest sites, these large clearcuttings have been remarkably successful. They are in no way biologically essential for regenerating even-age stands of Douglas-fir, however. As Smith (38) has pointed out:

> It is actually fortunate that the routine of clearcutting, burning, and seeding or planting of Douglas-fir has worked at all. In most instances the optimum environment for young Douglas-firs is found underneath partial shade...
>
> The widespread use of planting actually obscures the fact that complete exposure is actually detrimental to regeneration of Douglas-fir on many sites...

and finally[4]:

> ...If silviculture were a perfect imitation of natural processes leading to the ecological optimum for each species and site, a number of variants of the shelterwood method rather than clearcutting would be the most common kind of silvicultural management of the [Douglas-fir] region.

Among the more conservative silvicultural methods that have been recommended and applied successfully for regeneration cutting in the Douglas-fir region are the seed-tree (1, 12, 13, 21), strip clearcutting (12), small group clearcutting (12, 50), and shelterwood (Figure 3) methods (34, 48, 49, and Richard L. Williamson, Shelterwood Harvesting Douglas-fir in the High Cascades of Western Oregon. 1972. Unpublished manuscript on file at Forestry Sciences Laboratory, Olympia, Washington). These techniques have proved capable of providing fully stocked regeneration stands of desired species over a wide range of site and stand conditions.

On severe sites within the region, these silvicultural systems are proving essential and not simply optional to extensive clearcutting methods. Hot, dry sites found in abundance in southwestern Oregon and the frost-prone sites found on gentle topography at higher elevations are of this type. Neither natural nor artificial regeneration can be depended upon on these sites on extensive clearcuttings; some form of cutting that protects the site from environmental extremes is essential.

Selection cutting is the only silvicultural system that has not proved satisfactory for regeneration of Douglas-fir (22). Except for the occasional site where Douglas-fir is the climax

[4]We do not wish to imply that silvicultural systems should be a perfect imitation of natural processes. They are simply a means to the end specified by the landowner. Our purpose here simply is to point out that the analogy frequently drawn between conditions on a clearcutting and an area burned by wildfire is not valid; that is, clearcutting is not an imitation of natural processes, nor are conditions comparable in terms of the seedling environment.

species, single-tree selection invariably leads to elimination of the Douglas-fir and its replacement by more tolerant associates. In old-growth forests, a healthy, vigorous stand is difficult to maintain, apparently, even if the species shift is acceptable, because of damage incurred during periodic removals of individual large trees. The shift from old-growth to second-growth stands, as well as development of new logging techniques (helicopters, for example), also should make selection cuttings more practical, although maintenance of Douglas-fir still will be a problem.

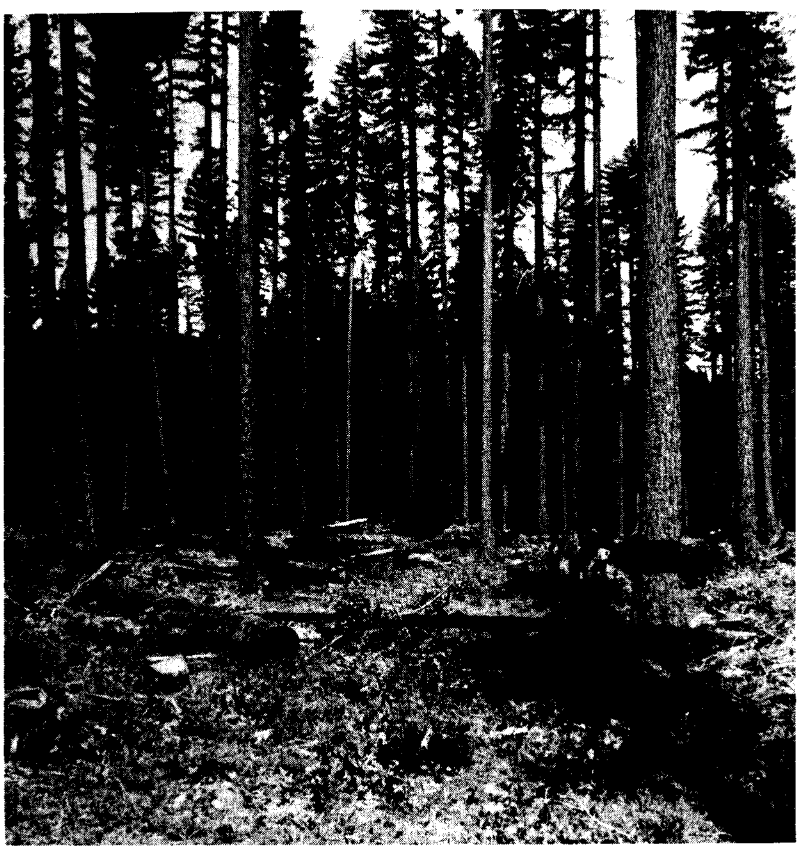

**Figure 3. Shelterwood cutting in mature Douglas-fir forest; about 25 trees were left per acre. Persons (arrow) show scale.**

## THE SOUTHERN PINE AND BOTTOMLAND HARDWOOD REGION

The southeastern and Gulf coastal plains contain some of the most productive forest land in the United States. Two major forest types are included: (1) southern pine forests (primarily loblolly, longleaf, shortleaf, and slash), which are located throughout the flat topography of the coastal plains, and (2) bottomland hardwood forests, which occur primarily on floodplains of large and small streams. Although the general topography appears uniform, sites can be rather variable—slight differences in elevation often are associated with changes in soil and can induce profound changes in soil drainage. Land-use practices also have had considerable effects on forest lands because of burning, uncontrolled grazing, and agriculture. Because of differences in silvicultural problems and management practices, we will discuss pines and hardwoods separately.

### Southern Pine Forests

Regeneration practices in the southern pinery consist primarily of even-age systems with new stands originating from natural or direct seeding and planting. Several studies and some experience indicate that pines (with the exception of longleaf) also can be regenerated satisfactorily by uneven-age or selection systems, however. The principal problem in regeneration of all southern pines is encroachment of undesirable hardwood species—especially on the better sites. In some areas and for some species, sporadic seed production, drainage problems, and frequent summer droughts also can present difficulties.

With proper hardwood control—whether by prescribed fire, herbicides, or mechanical methods—many stands can be regenerated successfully after clearcutting by natural or artificial reforestation. In much of the Atlantic coastal plain, good seed crops and seedling catches are the rule for loblolly, and stands can be reproduced easily by clearcutting after seedfall. On most industrial forest land, the accepted system is to clearcut and plant with various degrees of site preparation. The many vigorous plantations of slash and loblolly pine located throughout the South attest to its success. Clearcutting is not a good method for regenerating longleaf pine, however, because abundant seed crops are sporadic, and difficulties are associated with planting.

Seed-tree (44) and shelterwood cutting appear more or less a necessity for longleaf pine for the reasons mentioned (Figure 4). Recent evidence (4) indicates that the shelterwood system is more adaptable than the seed-tree method because it provides a more dependable seed source, less brown spot needle blight infection, and less time to obtain regeneration. Seed-tree and shelterwood methods will also work for loblolly, shortleaf, and slash pines, but probably are unnecessary except where lack of seed or summer droughts are problems.

Selection management (Figure 5) has been used to regenerate loblolly-shortleaf stands in southern Arkansas (14) and loblolly stands in the southeastern coastal plain (43). Wenger and Trousdell (45) make the following statements in their treatise on natural regeneration of loblolly pine:

> On the comparatively good sites of the coastal plain, silvical and silvicultural factors apparently present no serious obstacles to unevenaged management of loblolly pine. Regeneration is readily obtained and growth of seedlings is satisfactory in openings left by cutting mature trees. Thus, the choice between evenaged and unevenaged management depends mainly on economic factors...

According to Walker (44), selection cutting also could be used for slash pine because seedlings are not intolerant of mature trees. The extreme intolerance of longleaf pine makes selection cutting inadvisable, however.

Additional problem sites include the very wet sites of the coastal plain flatwoods. In the loblolly-shortleaf pine forests of the flatwoods, water tables may rise considerably after clearcutting. Heavy rainfall during the growing-season may result in standing water on poorly drained sites, thereby precluding successful regeneration (44). Unless artificial drainage is possible, selection or shelterwood cutting may be better alternatives on these very wet problem sites.

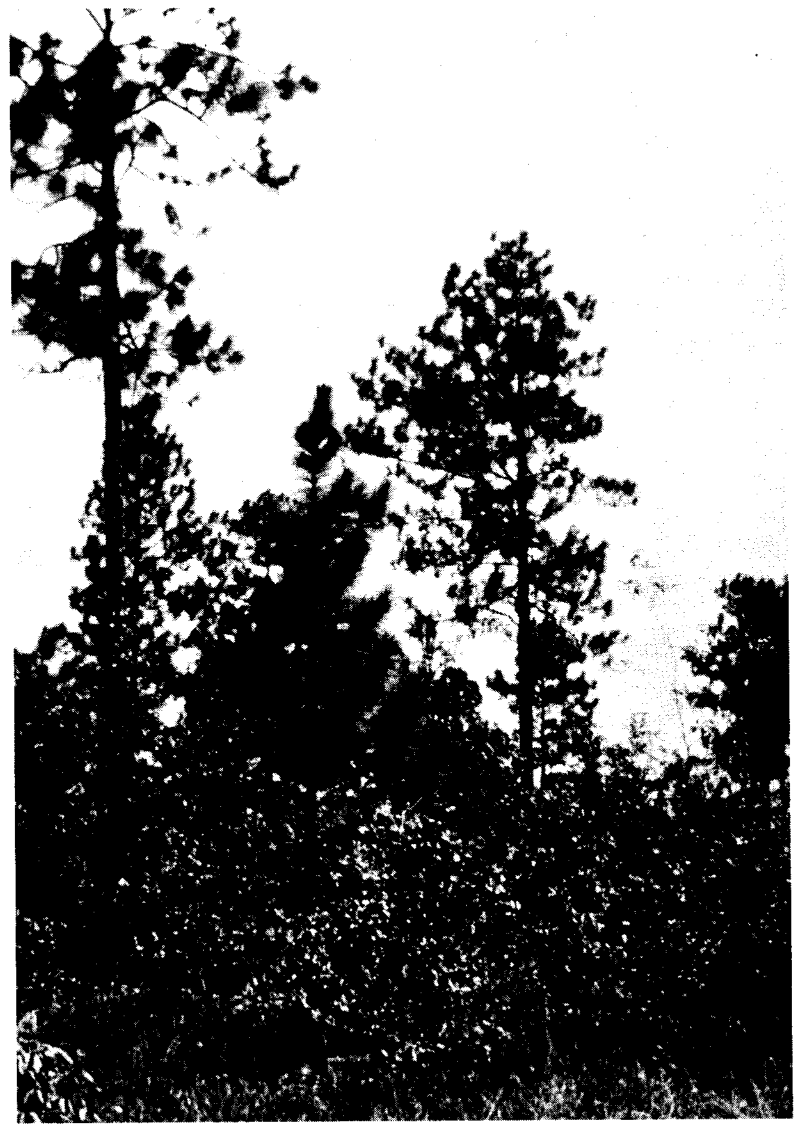

**Figure 4. Seed-tree cutting in longleaf pine.**

The foregoing discussion shows that clearcutting with natural or artificial regeneration apparently works well on the majority of pine sites. Where seed crops are infrequent or summer droughts are common, or both, seed-tree or shelter-

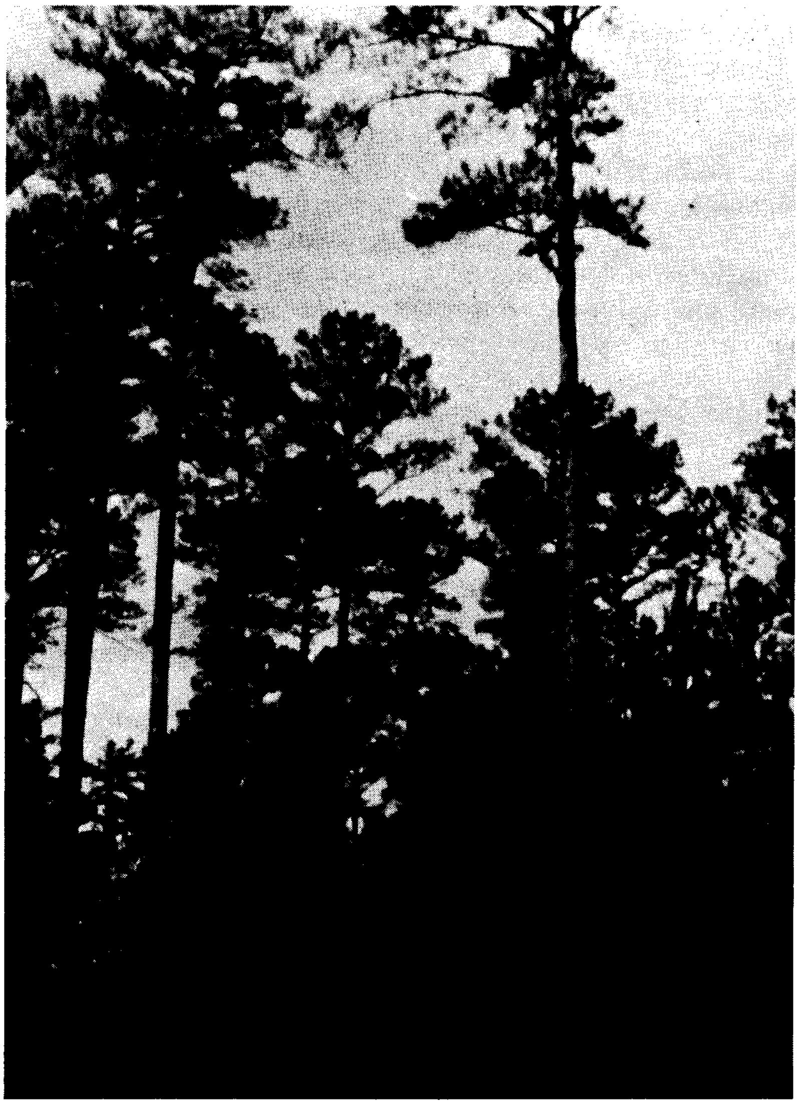

**Figure 5. Loblolly pine stand being managed under a selection system.**

wood methods are advisable and can be used successfully with all southern pines. Selection cutting may be used for the pines, except longleaf, and will not result in high-water problems sometimes encountered on poorly drained flatwood sites.

**Bottomland Hardwoods**

Except for intensively cultured cottonwood and sycamore, mixed bottomland forests are renewed primarily through natural regeneration. Obtaining reproduction after a harvest cut is no problem; in fact, a great burst of vegetative growth usually follows cutting of any kind in the bottomlands. The problem lies in securing establishment and rapid early growth of the more valuable intolerant species such as yellow poplar, sweetgum, and red oaks. For many years, selection cutting was advocated in bottomland hardwood forests (31). They thought that a continuous supply of high-quality logs to the hardwood industry would thereby be assured. Although intentions may have been admirable, actual practice often resulted in high-grading operations that took large, high-quality stems and left poorer ones to grow until another harvest (26). Today, many southern hardwood stands are in poor condition. Culls and undesirable species are all too common (24), but such results did not become obvious until supplies of high-quality logs dwindled and southern foresters began to take a close look at their hardwood forests.

Studies of natural reproduction after selection cutting, seed-tree cutting, and clearcutting were made in the southeastern coastal plain during the 1950's and 1960's. Natural reproduction of both desired and undesired species was more than ample after all cutting methods. Under selection cutting, however, the more tolerant and less valuable species such as beech, hickories, and ironwood grew rapidly into large size classes at the expense of intolerant, valuable species that were not favored in the small openings (less than 1/10 acre) created by selection cutting (9, 40). On the other hand, 6 years after a seed-tree cutting in a similar stand, desirable hardwood species were abundant and growing rapidly (8). The presence of seed trees, however, was not believed to contribute importantly to success in regeneration. This belief was substantiated by evidence from a nearby clearcutting that had been planted to several hardwood species (39). Development of planted trees was not very encouraging. A survey of volunteer trees in the area 11 years later, however, revealed more than 5,000 stems per acre (7). Natural reproduction, although smothering planted trees, had resulted in a good stand of timber.

Decades of experience and a few formal studies affirm that saplings of valuable species do not develop in small openings created by the selective cutting of individual trees or small groups of trees (19). If suitable species are present in the stand to be cut, desirable new stands can be established by cutting openings of at least one-half acre (26). Maximum opening size is governed by objectives other than securing satisfactory reproduction—for example, operational costs, wildlife, and aesthetic considerations. The composition of new stands depends on advanced reproduction and seedbed conditions as well as composition of the overstory. Most yellow-poplar reproduction originates from seed; seeds can remain viable in the litter for many years (3). Exposed mineral soils and full sunlight are needed for establishment and rapid early growth. New stands of oak-hickory come from advance reproduction in the understory before harvest (35).

If advance reproduction is not present and these heavy-seeded species are desired, a series of light shelterwood cuts probably should be used to stimulate establishment and development of sturdy advance stems (35). Most sweetgum reproduction comes from sprouts and roots and stumps of cut trees (23). Ashes and maples seed readily and also are capable of sprouting. By considering these reproductive habits in pre-harvest stand treatments, the silviculturist may exercise some control over stand composition (25)

An additional problem exists in swamp forests that consist of tupelos and baldcypress. Both swamp tupelo (5, 6) and water tupelo (11, 18) are prolific seeders and sprout readily from stumps of cut trees (11). Baldcypress also sprouts from the stump and periodically produces good seed crops. Unfortunately, germination and early growth of all three species are heavily dependent upon favorable water levels—prolonged flooding during the critical establishment period can kill newly germinated seedlings. Therefore, safest methods for natural regeneration of swamp forests would rely on advanced reproduction or stump sprouts, or both. Perhaps a light shelterwood cut would provide the best conditions for establishment of advance reproduction.

For hardwood stands that have been high-graded to the point where neither overstory nor advanced reproduction in the understory contains valuable species, the only logical alternative is to clearcut and plant.

To sum up, valuable hardwood species grow more rapidly than and compete well with more tolerant, undesirable species after clearcutting. The heavy dependence on advance reproduction for success, however, indicates that, in effect, we have a shelterwood system without the initial cut. In situations where advance reproduction is lacking, light stimulatory cuts have been suggested (34). If species composition is not important, abundant reproduction also can be obtained by selection cutting, but the more tolerant and currently less valuable hardwood species can be expected to dominate.

## CONCLUSIONS

The literature shows a broad latitude in choice of silvicultural methods that will meet biologic or ecologic needs for regeneration of most types or species on most sites. Few situations require either extreme in treatment–uneven-age management using a selection system or even-age management using large clearcuttings. On the other hand, either of these extremes could be applied much more widely to regenerate forests successfully if a type or species conversion is acceptable, as in the selection system, or a dependable technique for artificial regeneration is available, as in extensive clearcutting.

Ecological considerations are major constraints on selection of cutting methods on sites where environmental conditions are severe, that is, the temperature or moisture, or both, are at or near the minimum tolerance levels for tree seedlings. Forests found in subalpine regions or on hot, dry habitats are typically of this type. Extensive clearcutting under such conditions simply aggravates the problem, and forest regeneration is best provided by use of a system that provides protection for the site–strip or small group clearcutting, shelterwood, or, in extreme cases, selection methods. Because forest productivity is typically low on stressful habitats of this type and high investments of time and money are required to assure regeneration, the question of whether commercial forest management should be attempted on such sites should be examined carefully. The decision is, of course, for the landowner and society to make, not the ecologist or forester, although both have facts to contribute.

On the majority of productive forest sites, factors other than ecological limitations of the species appear to be primary in the choice between uneven- and even-age management and among the several silvicultural systems that can be used to create even-age stands. These include: economic considerations, including efficiency in logging, growth rates, and costs and returns on investments; social considerations, such as the esthetics of cutover areas and effects on other resource values—soil, water quality, and wildlife habitat; physical considerations such as the terrain with its limitations on suitable logging methods; and other biological considerations such as presence or absence of damaging agents—dwarf mistletoe, large deer population, and some insects and fungi.

To conclude, even-age silvicultural systems can be designed that will regenerate stands of desired species successfully on most forest sites. Only on forest lands of marginal productivity do biologic considerations as such limit use of clearcuttings. On the other hand, rarely do biologic considerations necessitate large-scale clearcutting systems. Choice of harvesting methods does, therefore, depend primarily on factors other than ecological traits of forest trees. The objectives and desires of forest landowners are usually of much greater importance.

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