CHAPTER 15

SILVICULTURE OF PURE UNEVEN-AGED STANDS

Uneven-aged stands, like pure plantations, have staunch adherents and scornful critics. Patchy regenerative disturbances have commonly created them both in natural forests and in forests that have been subject to partial cutting. It is often better and easier to preserve the preexisting age-class structure than to attempt to change it. Where some management objective requires that a stand always have some large trees, it is necessary to develop or maintain some sort of uneven-aged structure. It is claimed by some that uneven-aged stand structures are essential to the well-being of forest ecosystems.

There are several kinds of uneven-aged stands, and conflicting ideas about how to manage them. Some foresters have devoted much attention to quantitative methods of molding these stands into self-contained units that will supply sustained yield of timber. Others have been content simply to develop stands with several age classes and to let yields of timber fluctuate in varying degree. Sometimes the quantitative methods are used to mold stands into arrangements of diameter classes that some believe to be characteristic of old-growth stands.

In order to simplify the initial presentation of these ideas, this chapter deals with comparatively simple, pure uneven-aged stands; discussion of more complex stands that are mixtures of species or are both uneven-aged and mixed is postponed until a later chapter.

The term **selection system** applies to silvicultural programs that are used *to maintain* uneven-aged stands; **the selection method** is employed to *regenerate* such stands. An uneven-aged stand contains at least three well-defined age classes; ''well-defined'' means differing in total height and age, not just in stem diameter. It is not necessary that it be a self-contained sustained-yield unit or even an approximation of it.

As far as the discussions in this book are concerned, the even-aged aggregations of which uneven-aged or multicohort stands are composed are small patches. This qualification is applied because there is not, in the strictest sense of the term, any such thing as an uneven-aged stand. Even when a single large tree dies, it is replaced not by one new tree but by many that appear nearly simultaneously. This is true even if the new trees are from advance regeneration.

The uneven-aged stand is an artificial entity invoked to help understand what might otherwise be a chaos of little "stands." The question of how large an even-aged aggregation must be to represent an individual stand depends entirely on the particular context in which the forest is viewed at the moment. Someone concerned about silviculture or logging, for example, may see many little even-aged stands. In contrast, someone concerned about forest administration, wildlife, or watershed management may see these same stands as a homogeneous entity characterized by much internal variation. Whereas the first party would map the little units separately, the second would regard that as a useless complication.

An essentially ecological definition would make the minimum size of a stand equal to that of the largest opening that was fully under the microclimatic influence of adjacent mature trees. An opening of this critical size would, at the very center, have the same temperature regime as that which prevailed over a large clearcut area. Such an opening would be about twice as wide as the height of the mature trees. The effects of shade and root competition with adjacent older trees would be significant.

Some observers believe that application of the selection systems requires that each stand be made into a self-contained sustained-yield unit. This condition is one that can be approached but is almost never attained in practice; even approximations of the condition are difficult to maintain. In fact, single-minded efforts to mold stands into sustained-yield units often produce results that are illogical in the light of other considerations. Nevertheless, the essentially mathematical manipulations involved in these efforts are introduced in this chapter because they have a powerful appeal to many and also because, as also described in Chapter 17, they provide one means of monitoring programs for achieving sustained yield in whole forests.

In the selection method of reproduction, the mature timber is removed either as single scattered trees or, more often, in small groups at relatively short intervals to open growing space for regeneration. Such cuttings are repeated indefinitely; the cuttings may be at regular intervals or carried out whenever the condition of the stand or other considerations dictate. The whole flowing process depends not only on periodically establishing reproduction but also on making it free to grow so that the continuing recruitment of new age classes is achieved. The method is usually associated with natural reproduction but can also be used with planting or artificial seeding. True reproduction cutting is typically accomplished by cutting the oldest or largest trees, *and, if necessary, enough smaller trees to ensure that enough trees of needed age classes are free to grow.* The seed and any protection necessary for natural reproduction come from the trees that remain around the openings.

The regeneration can arise from any source—that is, from new seedlings, advance regeneration, sprouts, planted stock, or combinations of all of these. In a certain sense, all of the methods of regeneration previously described can be applied in small units of area. In some patches, all the trees can be eliminated and replaced by planted trees or new seedlings as with clearcutting. The equivalent of shelterwood cutting can be used to establish advance regeneration. Reliance on sprouts emulates the coppice method. There can also be mixtures of species as described in Chapter 16.

Intermediate cuttings may be made among the younger trees at the same time that the older or larger trees are removed. Each immature even-aged aggregation is treated essentially as if it were a stand by itself. Within the whole uneven-aged stand, the periods of regeneration and intermediate cutting may thus extend through the entire rotation and be indistinguishable from one another.

The Place of Uneven-aged Stands

There are two common reasons for developing such stands. The first is simply that the stands were inherited in that condition and cannot be replaced with even-aged or double-cohort stands without prematurely cutting too many young trees.

The second is the existence of management objectives requiring that a stand always have some large trees. Not the least important are aesthetic considerations, especially in roadside strips and parts of forests that are in public view. Any approach, even a crude one, to achieving sustained yield within small holdings requires that trees arrive at mature size at short intervals even if they are sporadic. The juxtaposition of old trees with younger ones is frequently important in wildlife management or for other purposes that require diversity of habitats and of the species of plants and animals therein. If natural regeneration is difficult, as on adverse sites, there may be reason to maintain a permanent source of seed. Uneven-aged stands may be essential on steep slopes that are either geologically unstable or subject to avalanches.

The selection method is often said to favor regeneration only of shade-tolerant species or to be unusable for intolerant ones. This really is not true. As has been pointed out before, tree seedlings are small, and their survival is governed by characteristics of microenvironments with dimensions measured in centimeters. The shelterwood methods can be modified to regenerate even the most shade-requiring species in even-aged stands; the selection methods accommodate intolerant ones in large openings. However, the single-tree selection method, which is described next, is associated mainly with shade-tolerant species or stands on sites so dry that crown closure is incomplete.

Single-Tree Selection System

In the classic form of the selection system, each little even-aged component of the uneven-aged stand occupies a space equal to (or somewhat less than) that created by the removal of a single mature individual (Fig. 15.1). Theoretically, single mature trees are harvested at short equal intervals of time, and each group is thinned artificially or naturally so that only one tree is left at the end of the rotation. The development of even-aged groups of trees in the very small, scattered openings thus created is the main characteristic. The only reason for making the cuttings at equal intervals of time would be to make the stand into a perfect sustained-yield unit.

The species most likely to be perpetuated are those that are very tolerant, although the opening left by the removal of a single large tree will, if site conditions are otherwise favorable, allow the establishment of a few seedlings representing early successional stages. However, if the opening is not soon enlarged, the crowns of adjacent older trees will almost certainly widen and overtop all the new regeneration. The difficulty of carrying out light harvests often enough to accomplish this has usually made the single-tree selection system very difficult to conduct.

The removal of single trees in thinnings or the choice of trees to harvest on the basis

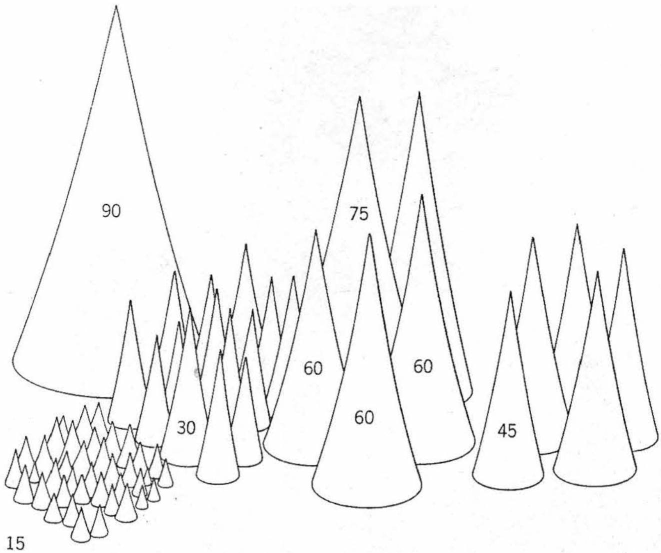

Figure 15.1 Schematic oblique view of a 1/10 hectare segment of a balanced uneven-aged stand being managed by the single-tree selection system on a 90-year rotation with a 15-year cutting cycle. Each tree is represented by a cone extending to the ground; the numbers indicate the ages. Each age group occupies about 1/60 hectare. The 90-year-old tree is now ready to be replaced by numerous seedlings while the numbers of trees in the middle-aged groups are appropriately reduced by thinning.

of individual analysis constitutes use of the single-tree selection method only if it results in the establishment of regeneration that is free to grow.

Group-Selection System

A much more feasible way of managing uneven-aged stands is the group-selection system under which the final age-class units consist of two or more single mature trees (Fig. 15.2). If the regeneration openings are made larger, it becomes possible to accommodate the ecological requirements of almost any tree species. As previously stated, if the matter is viewed from the standpoint of ecological site factors, the maximum width of what are called "groups" could be set at approximately twice the height of the mature trees. With such a classification limit, the same environmental conditions that exist in a huge clearcut area could be made to exist but only near the center of the opening. Regeneration of some very intolerant species might thus be virtually impossible.

As indicated earlier, this semantic matter may also be viewed from the standpoint of someone making administrative maps of forests for such purposes as determining areas of different age classes. Under this interpretation, the smallest areal unit of a given age class that one was ready to delineate on a map would be the smallest recognizable "stand." Anything smaller would be deemed a "group" and part of a larger "stand" with two or more age classes. With aerial photographs and satellite-referenced position locators, it is

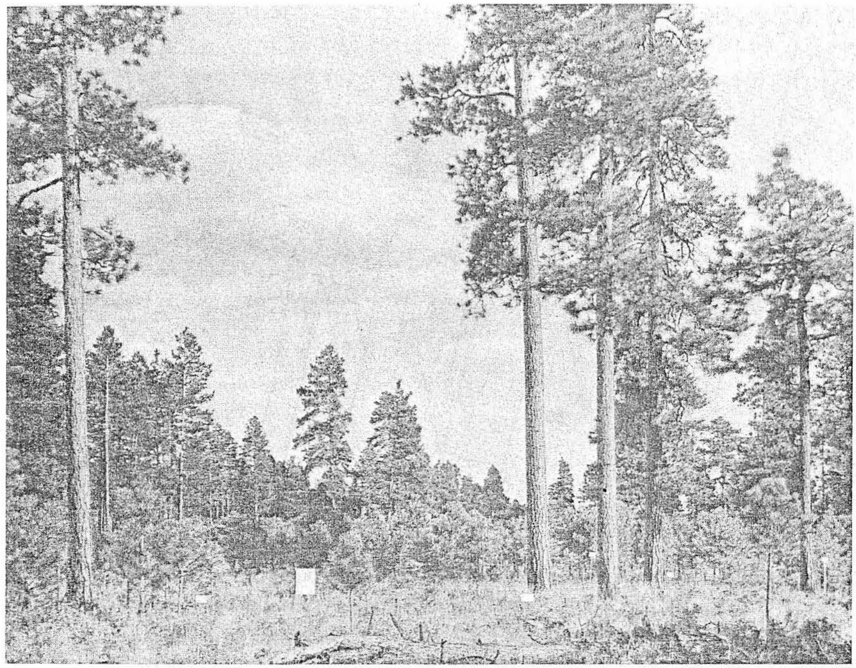

Figure 15.2 A stand of ponderosa pine in the Fort Valley Experimental Forest, Arizona, managed under the group-selection system. The saplings form a group that resulted from one unusually favorable regeneration year. The group that occupies the foreground has been thinned twice to favor trees of best bole form such as the ones now remaining. The small cards mark the stumps of medium-sized trees cut 32 years earlier; the large card marks the position of a large member of the group harvested 2 years ago. *(Photograph by U.S. Forest Service.)*

possible to identify ''stands'' very much smaller than was the case when foresters could map stands only by measuring distances on the ground. In other words, it is now much easier to recognize small even-aged stands, and there is less reason to lump them into larger uneven-aged stands.

The group-selection method has other advantages (Roach, 1974) over single-tree selection cutting. The older trees can be harvested more cheaply and with less damage to the residual stand. The trees develop in clearly defined even-aged aggregations; this characteristic is of substantial advantage in developing good form in many species, especially in hardwoods.

This modification is also more readily applied to stands that have become uneven-aged through natural processes because such stands are more likely to contain even-aged groups of mature trees than a mixture of age classes by single trees. Furthermore, the openings created are large enough that the progress of regeneration and the growth of younger age classes are more readily apparent.

It is important to consider the significance of the effects involved in having trees growing on the edges of even-aged aggregations. The total perimeter of such edges is greater the smaller the size of the groups. The effects are both beneficial and harmful but vary according to the circumstances. Influences on reproduction are beneficial to the extent that side shade protects young seedlings. However, the competition from the older trees for soil moisture can be serious. The roots of the older trees are capable of spreading out into the newly created openings. They may even do so automatically if they are already attached to the roots of the cut trees through intraspecific root grafts.

On the other hand, this lateral expansion of the roots and crowns of older trees along the edges of groups may make it possible to allocate more area to the growth of large trees than is the case with forests of even-aged stands (Fig. 15.3). This enables slightly more of the total production of the stand to be shifted to the larger and more valuable trees, thus at least theoretically increasing the yield of the stand in terms of merchantable volume added to such trees. The smaller the groups, the greater would be the advantage. However, because of the uncertainties involved in studies of forest yield, this advantage is not known to have been verified experimentally.

The juxtaposition of different age classes provides an opportunity to release the young trees along each edge once during each rotation when the older adjoining groups are harvested. This takes the place of one heavy thinning and is of some advantage when ordinary thinning must be long delayed or is not feasible. The effects of this phenomenon on the form of the edge trees vary considerably depending on the species and circumstances. The development of large branches is forestalled as long as there are larger trees at the side, but the effect is reversed when the larger trees are removed. Distinctly phototropic species, such as most of the hardwoods, do not fare well because the stems tend to bend outward toward the light or to become crooked if the terminal shoots are battered

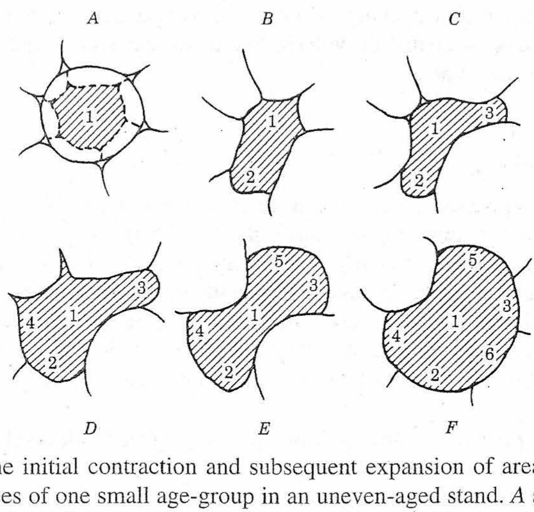

Figure 15.3 The initial contraction and subsequent expansion of area occupied by the trees of one small age-group in an uneven-aged stand. *A* shows the circular outline of the area previously covered by a single mature tree that has just been removed; the smaller cross-hatched area 1 is that to which the new age-group of seedlings is confined by expansion of the older adjacent trees. Sketches *B* to *F* show how this group of trees would re-expand as periodic, sequential cutting of areas 2 to 6 successively removed adjacent trees during the remainder of the rotation.

by the crowns of taller trees. This is not so true of distinctly geotropic species like conifers, which tend to grow straight under all circumstances. However, in climates subject to wet, clinging snows, any trees growing beside taller conifers are likely to be damaged badly when accumulations of snow suddenly slide off the higher crowns. Some wildlife species profit from the combination of environmental conditions existing along the boundaries between very young groups and older trees, but it is harmful to others. If the advantages outweigh the disadvantages, an effort may be made to increase the length of group perimeter per acre by creating smaller groups.

The simplest kinds of group-selection cutting create definite gaps in the forest canopy. Some ecologists regard ''gap-phase'' regeneration as the common way that forests are renewed without departing from the ''climax'' or late-successional kinds of species composition. The gaps are construed as being caused by wind or maladies associated with old age. If the gaps are large enough, they will, for the reasons described in Chapter 7, provide microenvironmental conditions suitable for the regeneration of species from almost the whole spectrum of local vegetation. This may help explain why climax vegetation is regarded as having much higher species diversity than that of earlier successional stages. If so, this is because the environment of the gap is not uniform but covers a wide range of microclimates. Neither the forester nor the ecologist should regard the entire area of small openings as conducive to only one category of vegetation.

Another ecological attribute of small openings that must be anticipated is their tendency to become pockets of hot air by day and of frost and dew by night. This is because they are not well ventilated by the wind but are open to the sky and, if large enough, to the sun. At night plant surfaces cooled by radiational heat loss may not be adequately reheated by contact with warm air wafted down from above; dew or frost may form on the plants. This may cause risk of damage by frost or increase the risk of infection of leaves by fungus spores, such as those of the stem rusts of conifers. The frost effect has been suggested, along with deer browsing, as a means of controlling unwanted true firs in the regeneration of pine forests in the Sierra Nevada (Gordon, 1970).

The effects of hot-air accumulation in sunlit openings on plants are more obscure; humans find them very pleasant in winter and oppressive in summer. Studies of German spruce forests have shown that the risk of frost is most extreme in openings that are one and a half times the height of the surrounding trees (Geiger, Aron, and Todhunter, 1995). Wider openings are better ventilated and smaller ones more shaded, especially at high latitude. If these effects are undesirable, one can wholly or partly substitute the effects of more diffuse cover of the kinds associated with, but not limited to, shelterwood cutting. Partial cover combines some shade with more opportunity for ventilation by the wind, which may be thought of as entering the forest from above in the degree that canopy openings allow.

Not all the mature trees of a group need be cut at a single time. If desirable because of ecological requirements for reproduction, the need to leave some trees for additional growth, or some other consideration, the groups can be reproduced by small-scale applications of the shelterwood and seed-tree methods. There is no necessity that the individual groups in one stand be uniform in size, shape, or arrangement, nor that one age class be represented by a single group. In fact, if proper advantage is taken of the existence of groups of different ages when an irregularly uneven-aged stand is placed under management, such regularity is unlikely. A systematic arrangement of individual groups would be convenient but is usually almost impossible to secure.

Strip-Selection System

The components of an uneven-aged stand can be created in slowly advancing strips. This arrangement enables the transportation of logs through the next strip to be harvested. There is opportunity to obtain advance reproduction in the side-light adjacent to the most recently cut strip. Similarly, if the progression of cutting is directed toward the equator, regeneration of species that require partial shade may be encouraged. If successive cuttings advance against the direction of the most dangerous winds, the stand gradually becomes streamlined so that the main force of strong winds is diverted up and over the stand (Fig. 19.1). Strip and patch selection cutting have sometimes been effective in creating snowdrifts and thus improving the yield of water from snowmelt (see Chapter 18).

Quantitative Methods of Managing Uneven-aged Stands

This section starts with a discussion of the concept of the perfect sustained-yield stand as a series of little even-aged stands representing all age classes. It then considers another theory, driven by a simple mathematical assumption about numbers of trees in diameter classes, that proposes somewhat different structures that are claimed either to be more efficient in timber production or to simulate some perpetual equilibrium alleged to characterize old-growth stands. It concludes with accounts of more flexible quantitative methods of regulation that are not based on simplistic rigid assumptions about desirable stand structures.

The Concept of the Balanced All-Aged Stand

One of the most attractive and idyllic concepts of forestry is that of the theoretical, balanced, all-aged stand (Davis and Johnson, 1987). It continually yields benefits and regenerates itself steadily; it is a dynamic system that is always the same and always in equilibrium. The adjective "balanced" means that every age class up to that of rotation age is represented by an equal area so that the stand is a perfect sustained-yield unit. If these conditions are met, *and only if they are met,* one could annually cut whatever amount of wood the stand produced in a year and count on doing so indefinitely if the cutting was done every year and the schedule was not disrupted by unplanned destructive disturbances.

Even though this condition has a powerful naturalistic appeal, it does not come into existence in nature but would have to be an essentially artificial creation. Some foresters and ecologists take it as axiomatic that virgin or old-growth forests are in a state of self-maintaining equilibrium. Even if such stands have several cohorts and biomass production is perfectly balanced by decay and mortality, this does not mean that stand even approximates a balanced all-aged stand. One would have to regenerate the same amount of forest area each year for about a whole rotation to create the condition exactly. It is a simple encapsulation of good ideas toward which foresters strive by various means but should not expect to achieve perfectly, even in whole forests.

The theoretical all-aged stand would have trees of every age class from one-year seedlings to veterans of rotation age, but there is no clearly good way of specifying how many there should be in each age class. The idea that each age class should have foliage covering an equal area has always provided the soundest theoretical basis for sustained-yield management of forests. Unfortunately, it is not feasible to regulate a balanced uneven-aged stand directly on this basis because the necessary measurements of areas of small aggregations of trees and determinations of their ages would be too intricate. Therefore, it is necessary to employ surrogates for foliage area and resort to modifications and approximations of the idea.

Simplifying Approximations

The simplest modification has to do with the impracticality of operating in each stand every year. Instead, it is presumed that the stand would be treated periodically, with each period being called a **cutting cycle**. The uneven-aged stand would have as many age classes as there were cutting cycles during the rotation. If the result were a stand with an arrangement of age classes that approximated the all-aged stand, it would be regarded as a balanced uneven-aged stand. Figure 15.4 is a schematic map of such a stand, and Fig. 15.5 shows how such stands might be combined into a whole forest managed on the basis of some perfect selection system.

In order to avoid direct determinations of tree ages and the areas occupied by each age class, it is commonly assumed that tree diameter can be taken as the index of age. The distribution of diameters in the stand is used to assess and control the allocation of area of growing space to each age class. Total tree height, which has a much higher correlation with effective age, would be better but is more difficult to measure or even to estimate.

Much confusion and error can be avoided if it is recognized that the best indicator of the rate of future growth of a tree is the amount of foliage that it bears. Just because the

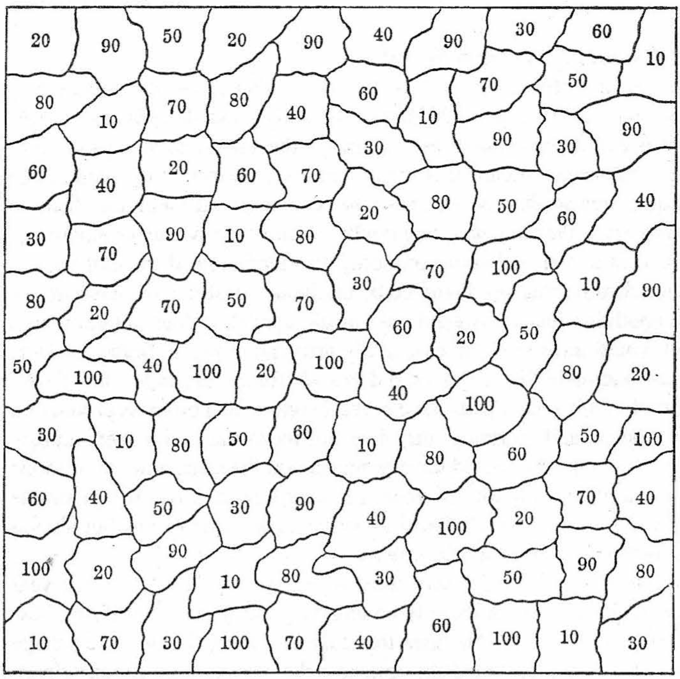

Figure 15.4 A 1-acre portion of a fully balanced selection stand managed on a rotation of 100 years under a 10-year cutting cycle. Ten age classes are represented, each occupying approximately one-tenth of the area. The numbers indicate the ages of the individual groups of trees.

Stand 1 contains age classes: 1, 11, 21, 31, 41, 51, 61, 71, 81, and 91	*Stand 2 contains age classes:* 2, 12, 22, 32, 42, 52, 62, 72, 82, and 92	*Stand 3 contains age classes:* 3, 13, 23, 33, 43, 53, 63, 73, 83, and 93	*Stand 4 contains age classes:* 4, 14, 24, 34, 44, 54, 64, 74, 84, and 94	*Stand 5 contains age classes:* 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95
Stand 6 contains age classes: 6, 16, 26, 36, 46, 56, 66, 76, 86, and 96	*Stand 7 contains age classes:* 7, 17, 27, 37, 47, 57, 67, 77, 87, and 97	*Stand 8 contains age classes:* 8, 18, 28, 38, 48, 58, 68, 78, 88, and 98	*Stand 9 contains age classes:* 9, 19, 29, 39, 49, 59, 69, 79, 89, and 99	*Stand 10 contains age classes:* 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100

Figure 15.5 Diagram of a selection forest managed on a rotation of 100 years with a cutting cycle of 10 years. The forest contains ten stands, one of which is cut through each year, thus giving equal annual cuts. Each stand contains ten age classes, and together the age classes in the ten stands form a continuous series of ages from 1 to 100 years.

diameter of a tree is used as a surrogate for its total leaf area does not mean that the diameter of the tree controls the rate of future growth; it is a result of growth and not a cause of it. Neither can it be assumed that every 9-inch shortleaf pine will increase in diameter at the same rate as others of the same diameter in the same stand on the same soil, especially if the positions in the crown canopy are different.

Regulation of Cut by Diameter Distribution

A series of little stands, each of the same area, conforming to a yield table for pure stands of the same species, is the fundamental basis for defining the mathematics of development of a balanced uneven-aged stand. It is because the yield tables represent observational evidence that predict how pure even-aged aggregations of trees, if they are free to grow, actually develop over time. They show the decline in numbers from competition or thinning as well as the increase in the average diameter of each age class with the advancing years. The second column of Table 15.1 shows an appropriate diameter distribution for a pure, unthinned, balanced, uneven-aged stand of loblolly pine grown on a 40–year rotation and based on a yield table of Meyer (1942) that presents diameter distributions for even-aged stands. It is very important to note that trees of a given diameter class will not grow at the predicted rates if their crowns are shaded from above.

The characteristics of the proper diameter distributions are depicted in Fig. 15.6. Because it requires many saplings to cover the space eventually occupied by a single mature tree, the distribution should approximate the smooth, "reverse-J-shaped" curve of Fig. 15.6*A*. This curve represents the collective total of the diameter distributions of a series of little even-aged, pure groups of trees covering equal areas and separated by equal intervals of age, as shown in Fig. 15.6*B*. The objective is to harvest and replace trees in such patterns that this diameter distribution is the same either just before or just after each harvesting operation.

Assuming that the appropriate distribution of age classes has been converted to a

Table 15.1 Diameter distributions exemplifying the results of different criteria[a] used to determine these distributions for various kinds of pure uneven-aged stands

D.B.H.	Yield table	BA 128 $q = 1.7$	BA 80 $q = 1.3$	BA 80 $q = 1.7$	BA 60 $q = 1.7$
(in.)	(1)	(2)	(2)	(2)	(2)
6	138	90	35	76	57
8	84	53	27	44	33
10	44	31	21	26	20
12	22	18	16	15	12
14	10	11	12	9	7
16	7	6	10	5	4
18	2	4	7	3	2
20	1	2			
Total	308	215	128	178	135

(1) Based on a series of even-aged stands in a yield table for old-field stands of loblolly pine in northern Louisiana managed on a 40-year rotation; site index of 90 feet, and total basal area of 128 ft^2; based on Meyer, 1942.

(2) Derived entirely from chosen values of q, basal areas per acre, and maximum D.B.H.

[a]See discussion in text for explanation of these criteria.

diameter distribution and created in a stand, it is necessary to consider the small but crucial changes that will be made in the distribution at the time of each cutting (Fig. 15.7). Selection cuttings in such stands involve successive harvests of the largest trees in a stand. A diameter limit (point x in Fig. 15.7) is established as an indication of age, with the understanding that trees below this size are in general to be reserved and those above cut. This diameter limit should be regarded as a flexible guide rather than as a rigid dividing line. Depending on their silvicultural condition, especially capacity for further increase in value, a few trees above the limit should be left and some below the limit should be removed. Trees that are surplus in a given diameter class are usually harvested, except where they are needed to compensate for deficiencies in the next higher or lower classes. Commonly, there are surpluses in many diameter classes larger than the smallest that are measured; this is clear evidence of deficiencies in seedlings or other small trees.

True thinning may also be conducted simultaneously with the harvest cutting. Such thinning must be distinguished from the harvest of the oldest trees and should take place in clumps of trees that are too young for final harvest cutting. The thinnings should be guided by the estimates of required numbers of trees shown in a graph such as that of Fig. 15.7 with surplus trees removed if they are not needed to remedy deficiencies in other diameter classes. The methods of thinning followed are the same as those employed in even-aged stands. Unlike the final harvest cuttings, the thinnings should not remove the largest trees in the various clumps, unless they are of undesirable form or species. The primary objective of the thinnings should be to anticipate the inevitable reduction of numbers denoted by the steep slope of the J-shaped curve (Fig. 15.7), so as to salvage prospective mortality and allow the remaining trees space for more rapid growth.

The whole program of thinning and stand-density regulation is the key to the crucial question of how rapidly the growing and aging trees flow through the diameter distribution. The process also depends on the continual regeneration of stands.

It has been said that a forester cannot cut more than is grown or grow more than is cut. If, and only if, the stand is of one species, has the perfect balanced diameter distri-

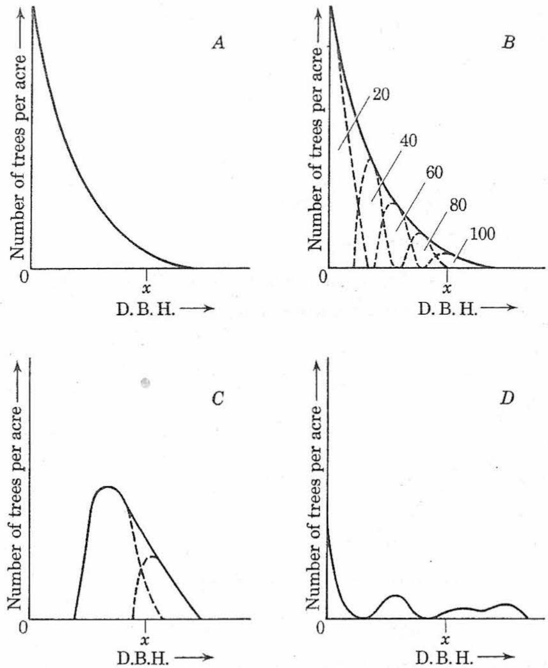

Figure 15.6 Several types of diameter distributions found in uneven-aged stands. *A* shows the distribution curve of an all-aged stand of 1 acre containing sufficient trees in each diameter class to produce an unvarying number of trees of optimum size (of diameter *x* or larger) at rotation age. *B* indicates how a balanced uneven-aged stand of the same diameter distribution may be composed of five age classes, each occupying an equal area, with a 100-year rotation. *C* represents a stand with two closely spaced age classes and no advance reproduction. Uncritically supervised selection cuttings in stands of this kind will produce abnormally high yields of timber until all existing trees reach optimum size; thereafter they will yield nothing until the new growth reaches merchantable size. It is difficult to create the balanced distribution in such stands in one rotation period, especially if the smaller trees do not respond to release after selection cuttings. *D* shows one of the many kinds of irregular uneven-aged distributions that may be found in virgin stands. This one contains four well-distributed age classes, one of which is well beyond optimum age for an economic rotation. Such a stand could be gradually converted to the balanced form provided that the intermediate age classes did not deteriorate after partial cutting.

bution, and is cut on the precise schedule just described, the allowable annual cut under sustained yield is equal to the *periodic* annual increment in the same unit of measure. It seems logical that one should safely be able "to harvest the annual growth every year," but this is true for a stand or forest only if the stated conditions of perfection have been created and are rigidly maintained. It is prudent to regard the *mean* annual increment at rotation age for an otherwise similar even-aged stand as the best estimate of the allowable

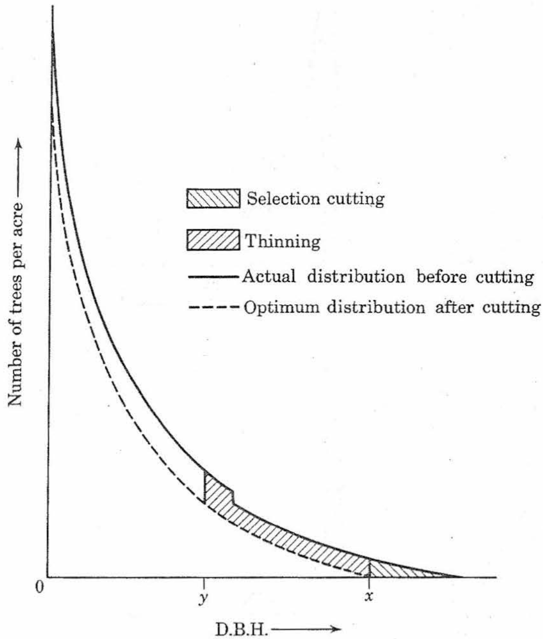

Figure 15.7 Diameter distribution of a balanced uneven-aged stand under intensive management, indicating the number of trees of different diameter classes theoretically removed in a single cutting. All trees larger than diameter x, which has been set as the index of rotation age, are removed. The trees of smaller diameter may also be reduced in number by thinning, provided that they are larger than the tree of lowest diameter (y) which can be profitably utilized. Under extensive practice there would have been no cutting of trees less than diameter x and most of those represented above as being cut in thinnings would have been lost through natural suppression.

annual cut in a balanced uneven-aged stand. It must also be kept in mind that the appropriate diameter distribution is not the cause of the desired regime of growth and harvest but an indicator and result of the process.

Negative Exponential Distributions of Diameters as Guides

A different hypothesis about the proper diameter distribution uses a mathematical distribution that has a general resemblance to reverse-J-shaped curves but was not based on ideas about having all age classes equally represented. Late in the nineteenth century, deLiocourt (1898) observed that some very old forests in Europe often had diameter distributions in which the number of trees in each diameter class was some multiple of that of the next larger diameter class. Meyer (1952), in some very old natural stands (usually of mixed species) in North America, concluded that this situation prevailed and that the multiple, termed the ***q*-factor**, might vary from 1.2 to 2.0. In a stand with a factor of 2.0, each diameter class would have twice as many trees as the next larger class. They assumed *(but never verified)* that any stand with any value of q had arrived at a stable equilibrium and would remain the same perpetually if the effects of periodic harvests or mortality kept returning the diameter distribution to that defined by the same *q*-factor. This assumption of a stable dynamic equilibrium was taken as justification for assuming that the periodic annual increment was the amount that could be harvested under sustained yield forever or at least into some indefinite future. They also assumed that appropriate numbers of new seedlings would materialize at the right times.

Diameter distributions based on *q*-factors fit negative exponential curves; these convert to straight lines if numbers of trees are converted to logarithms and they are plotted over arithmetic tree diameters; the appropriate value of *q* defines the slope of the straight line. The allure of this neat mathematical relationship has led many foresters to conclude that *q*-factors define mathematical "laws" governing the growth of trees and stands, although no biological basis has been advanced for the idea. The relationship does at least define some kinds of reverse-J-shaped curves.

The *q*-factors that are chosen depend on the species and the assumptions that are made about rates of growth and mortality as well as stand basal area and the sizes to which trees are to be grown (Fiedler, 1995). Some choices of the slopes and intercepts of the lines are shown in Fig. 15.8. The slope of each line is the *q*-factor. In customary usage, if the *q*-factor is 1.4, the number of trees in a given 2–inch D.B.H. class is 1.4 times that of the next larger 2–inch class.

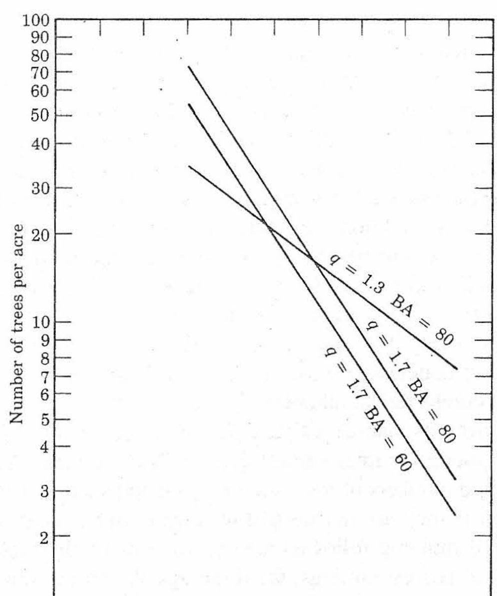

Figure 15.8 Diameter-distribution curves converted to straight lines by plotting logarithms of numbers of trees over arithmetic values of D.B.H., showing the effects of some changes in values of the *q*-factor and stand basal area (sq. ft. per acre) that are also shown in Table 15.2. The values of *q* are for 2-inch classes and the stands defined would have no trees larger than the 18-inch class.

Table 15.2 Table from Tubbs and Oberg (1978) showing values of a coefficient, *K*, for determining the number of trees to be grown in uneven-aged stands with diameter distributions with different amounts of basal area per acre and various *q*-factors

Maximum D.B.H.	*q*-Factor						
(in.)	1.1	1.2	1.3	1.4	1.5	1.6	1.7
24	18.5	24.8	34.3	48.1	68.0	97.3	139.3
22	14.0	18.2	24.0	32.1	43.4	58.9	80.1
20	10.3	13.0	16.4	21.1	27.2	35.2	45.6
18	7.4	9.0	11.0	13.5	16.7	20.6	25.5

Divide the chosen value of stand basal area by the *K*-value for the desired combination of *q*-factor and maximum D.B.H. to determine the number of trees in the largest diameter class. To determine the number of trees in each 2-inch class, multiply the number of trees in the next class with larger D.B.H. by the *q*-factor, as has been done for Table 15.1.

Table 15.2 by Tubbs and Oberg (1978) can be used to guide the calculations, which are based on the fact that basal area, tree numbers, and diameters are all perfectly related. Table 15.1 shows examples of the effect of some of the choices on diameter distributions with different values of *q*, maximum D.B.H., and basal area. For comparison, as previously mentioned, it also shows a diameter distribution for a balanced uneven-aged stand constructed from diameter distributions for known even-aged stands of loblolly pine.

Possibilities with More Large and Fewer Small Trees

Diameter distributions defined by the *q*-factor do not fit those distributions deduced from yield tables for pure even-aged stands, as shown in Fig. 15.6*B* and Table 15.1. The discrepancy lies in the fact that, if the relationship specifies the logical numbers of trees in the larger sizes, then there seem to be far too few in the smaller diameter classes. For some, this casts doubt on the validity of using this mathematical relationship in managing stands or forests for sustained yield. Sometimes provision is made to increase the number of small trees by having the *q*-factor high in the small diameter classes and lower in the middle and upper ranges.

For advocates of *q*-factors, the small numbers of small trees are regarded as evidence of some advantages deemed to be inherent in the uneven-aged arrangements defined by *q*-factors. As a consequence, efforts to deduce appropriate diameter distributions for sustained yield have been diverted into schemes for allocating large amounts of growing space to trees in the middle and large sizes that increase in *merchantable* volume rapidly (Cochran, 1992; Adams and Ek, 1974). Allocation of space to seedlings, saplings, and other submerchantable trees is reduced either deliberately or unwittingly, with or without use of *q*-factors. Some of the advocates of such action contend that sustained yield is not an objective or that somehow the use of any sort of *q*-factor magically takes care of it.

The surest way to maximize *short-term* periodic annual increment of board-foot volume would be by having whole forests with nothing but *even-aged* stands in the diameter classes around 13 inches where such volume approximately doubles with each 2-inch increase in diameter. Unfortunately, if one harvested trees continually from such a forest, the recruitment of new 13-inch trees would soon collapse while the large trees were whittled away. Trees have to be small before they can be large.

There are ways, consistent with sustained yield, for shifting production onto large stems by diminishing the proportion of small ones. Low and crown thinning are the most important ways.

If the regeneration units of a selection stand are small, the area that was previously occupied by one or two mature trees is not recolonized fully by seedlings. Some is taken over by the horizontal expansion of the crowns and roots of adjacent trees. When they are cut in their turn, the regeneration group can, in its turn, take over part of the newly vacated growing space. In this way, as shown in Fig. 15.3, the amount of area used by a given age-class group increases each time an adjacent older group is removed. This effect must have some reality in stands with small age-class groups and, therefore, much area of boundary zones between groups. The effect is negligible if the groups are large.

Another potential source of gain of efficiency lies in the "advance regeneration effect" described in connection with shelterwood cutting in Chapter 14. If small trees can be grown under large ones, it is not necessary to allocate the space to them that would be required if they were grown in the open. As will be described in Chapter 16, this same general effect can be obtained by releasing species of the lower strata of stratified mixtures, including those that are of single cohorts.

If this effect were perfectly achieved, one could simply allocate all of the "space" in the regulated diameter distribution to the released trees and none to those too small to release. However, trees of sufficient size to be released would have to be available and they would not grow to this size anywhere near as fast as they would in an open-grown even-aged stand. This source of efficiency, to the extent that it exists, is equally attainable with shelterwood cutting.

In stands on very dry sites, there can be another effect that diminishes the required numbers of small trees. In such cases, as in some ponderosa pine stands in the interior of the western United States (Fig. 15.2) (Baumgartner and Lotan, 1988), groups of trees can have root systems that fully occupy the soil but crowns that do not come close to touching because the possible amount of foliage is so restricted. This effect is somewhat the same as that involving tree crowns and expanding groups of trees depicted in Fig. 15.3. In such situations, it may not take many small trees to restock an area, and often the effect of root competition seems severe enough to restrict branch size and stem taper without any obvious crown competition (Pearson, 1950). It is also possible that small, slow-growing, but viable trees can be stored for long periods in small openings if they are kept alive by being root-grafted to their larger neighbors.

Other Approaches to Regulation of Stands for Sustained Yield

The various diameter distributions just discussed are best viewed as ways of relating existing stand structures to those presumed to be desirable. They are useful chiefly in determining which classes are deficient and conversely which are over-represented. They do not dictate whether to work toward the balanced structure or, if so, how fast and which trees to harvest in the process.

Techniques of predicting the development of various alternative kinds of uneven-aged stand structure by computer simulation are being developed. The soundest of these calculations are based on relationships between amounts of foliage or crown sizes on the accretion of wood (O'Hara, 1995). Although the results of such work may be translated into diameter distributions to guide partial cuttings, they are based on some fundamental ecophysiological factors and not on the idea that the diameter distributions actually control anything.

A less rigorous and reasonably successful solution to the problem is to be content with maintaining uneven-aged stands that fluctuate rather widely around the diameter distributions that are tentatively deemed to be appropriate. This process is apparently followed in long-continued management of selection stands in Europe. During the process, changes in distribution and stand volume are monitored, and all reasonable efforts are made to readjust them at harvest times. If the larger size classes seem to be over-represented and the periodic annual increment is harvested, it is recognized that the rate of cutting is faster than can be permanently sustained (Burschel and Huss, 1987; Davis and Johnson, 1987). If the periodic annual increment decreases, the diameter distribution can be examined to determine why and also to deduce what should be done to adjust the situation. If the recruitment of medium-sized trees begins to fail and the growth of the stand declines seriously, steps are taken to start over again with an irregular cohort of trees.

With any approach to uneven-aged management, it is crucial for sustained yield to keep cutting openings in the stands for the recruitment of new regeneration and to set goals in terms of the areas opened rather than the numbers and sizes of trees cut for the purpose. If the rotation is 100 years and the cutting cycle is 10 years, then the regenerated area should at least approximate a tenth of the total.

Pitfalls

Regimes of harvests in uneven-aged stands that allocate inadequate space to small trees can sometimes continue for many decades, with rates of cutting greater than can be sustained in the very long run. Forest managers who fall into this trap have sometimes done so by assuming that any diameter distribution that is reverse-J-shaped or approximates some q-factor in the merchantable size classes is *ipso facto* a balanced uneven-aged stand. The next false premise is that the conditions have been met under which the allowable annual cut under sustained yield is equal to the periodic annual increment; this harvest rate would be unsustainably high if too much space were allocated to the larger size classes.

The problem is aggravated in situations where whole forests consist of just one age class because all stands arose after a single devastating event. If one counts only trees large enough for sawlogs, a middle-aged stand can sometimes seem to have a reverse-J-shaped diameter distribution curve. One could then leap to the conclusion that the whole forest is and should be composed of all-aged stands in which the allowable annual cut is equal to the current annual increment. This expression of stand growth rate is unsustainably high in stands that are not yet at the rotation of maximum mean annual increment. If this situation is allowed to continue too long and new age classes are not recruited, some future generation will run out of trees to harvest, and it may take at least one human generation of diminished timber harvests to correct the situation.

Creation of Balanced Uneven-aged Stands

Theoretically, an absolutely even-aged stand can be replaced by a balanced uneven-aged stand during the period of one rotation. If the new stand is to have five age classes with a rotation of 100 years, all that is necessary is to conduct cuttings leading to the establishment of reproduction on one-fifth of the area at 20-year intervals. Thus some parts of the stand must be cut before or after the age of economic maturity. The disadvantages of such awkward timing of the harvests can sometimes be mitigated if any parts of the stand that mature early are replaced first and those that continue to increase in value longest are cut last. The conversion will be successful only to the extent that the cuttings are appropriately timed and heavy enough to lead to the establishment of the age classes and species of reproduction desired. It is usually a fallacy to pretend that the large trees of essentially even-aged stands are older than the small ones and to attempt to make the conversion by successive cuttings of dominants.

The creation of balanced uneven-aged stands can be carried out more rapidly and easily in stands that already contain several age classes. Ordinarily these will be in irregular distribution, having resulted from a history of high-grading or patchy natural disturbances. It will usually be necessary to make the sacrifice represented by cutting some trees earlier or later than might otherwise be desirable. Sometimes small, relatively old trees of the lower crown classes can be substituted for nonexistent dominants of the same size and younger age, thus inventing "age" classes that might otherwise take decades to grow from seedlings. This shortcut is useful to the extent that the trees involved can withstand exposure and return to full vigor. However, it would be a mistake to indulge in this procedure to the exclusion of the creation of the new age classes of seedlings that must be continually recruited and made free to grow if the balanced distribution of age classes is to be completely developed.

The age-class distribution of a stand is likely to be readjusted with least sacrifice of other objectives if the changes are made very gradually. Several rotations might well be required to transform essentially even-aged stands to the balanced uneven-aged form.

The degree of precision of regulation of the cut necessary for maintaining or creating any real approximation of a balanced, uneven-aged stand cannot be achieved without making an inventory of the stand before marking it for cutting. Usually, this involves determining the distribution of diameter classes by basal area or numbers of trees per acre. The prospective cut is then allocated among the various diameter classes on the basis of a comparison between the actual distribution and that which is assumed to represent the balanced condition. Leak and Gottsacker (1985) described an expeditious way of guiding the marking by using prism point-sample plots to assess stand conditions and having only three broad classes of tree diameter.

Irregular Uneven-aged Stands

There are many valid reasons other than sustained yield for deliberate maintenance of uneven-aged stands. These other objectives can be achieved without the balanced arrangement.

Long-continued application of the concept of financial maturity in efforts to extract optimum value from the growing stock is very likely to cause the development of uneven-aged stands. If this concept is the best key to intelligent management of an uneven-aged stand, it is as logical to use the selection system as it would be to employ the shelterwood system under similar circumstances in an even-aged stand. However, the sequences of cutting necessary for true sustained yield and those guided by the concept of financial maturity are usually compatible only in uneven-aged stands that are already balanced and composed of good trees. If the diameter distribution is unbalanced, it can be brought into balance only by cutting some trees long before or long after they are financially mature.

Most reasons that exist for having uneven-aged stands and using the selection system are not concerned with manipulating the growing stock of stands in keeping with the concepts of either sustained yield or financial maturity. Rather, they may have to do with nothing more than the preexistence of the uneven-aged condition. The purposes may be wholly or partly matters of beauty, wildlife habitat, seedling ecology, or protection of stand, soil, or site against damage. Such objectives may require uneven-aged stands but not balanced ones. In fact, the warping of patterns of harvest removals to fit some preordained diameter distribution commonly interferes with fulfilling many other logical purposes.

If an uneven-aged stand is to be allowed to remain irregular and not be refitted to some diameter distribution, it is not necessary to take the costly step of determining the diameter distribution before the stand is marked for partial cutting. It is feasible to maintain an unbalanced uneven-aged stand indefinitely and reap any benefits, other than sustained yield, that may be induced by the uneven-aged arrangement.

The distribution of age and diameter classes can be allowed to fluctuate almost at random, except to the extent that the cutting or reservation of particular classes must be adjusted to balance the books of sustained yield for the whole forest. In this kind of management, the allowable cut and its approximate distribution among diameter classes are determined for the entire forest, and then harvests are made in various stands on the basis of other considerations, silvicultural and otherwise, until the scheduled volume and kinds of trees are removed.

Theoretically, the true reproduction cuttings of the selection system involve removing the oldest and largest trees, with some predetermined diameter limit being taken as a definition of the smallest trees old enough for such cutting. However, this should be only a first approximation of the characteristics of trees selected for harvest. Trees above the limit may be left because they are increasing in value with unusual rapidity or for reasons such as their capacity to provide seed and protection for reproduction. The trees designated for cutting, even though they are below the limit, are those that increase in value too slowly because of low quality or poor growth; those that interfere with logging or the growth of better trees; or those that are likely to be lost after the cutting. In other words, many of the trees to be removed are chosen based on the same principles that are followed in thinning.

The guidance of such complicated timber marking is sometimes facilitated by tree classifications. This is especially true if the various age groups are small, because the standard Kraft crown classification (Fig. 2.5) is most useful in rather large, pure, single-canopied, even-aged aggregations. In other kinds of stands, the Kraft classification must be supplemented by other information, although the matter of position in the crown canopy is always important. The other characteristics important in deciding whether trees should be cut or left are (1) age or size, (2) quality, and (3) vigor. Tree vigor is usually assessed by observations of the foliage, which is the most crucial productive machinery of the tree. The condition of the foliage can be categorized in terms of its amount, color, density, and leaf size. If attention is given to the quality of the foliage, the live crown ratio is a very useful index of tree vigor.

Evolution of Selection Methods

The first timber harvests in most forests typically involve crude, unconscious applications of the selection method in which only the biggest and best trees are removed. At the other end of the spectrum are some of the most intensive and intricate kinds of silviculture. Although one may gradually develop from the other, the early crude selection cuttings are most commonly superseded by some other method of cutting.

The extensive kinds of selection cutting are often diameter-limit cuttings. The diameter limits can be set with varying degrees of sophistication. In mixed stands, for example, it may be beneficial to set a low limit for species of little future promise but higher limits for the more valuable species. Such extensive applications may be practiced indefinitely or may be used as temporary expedients until conditions become more favorable. The cutting cycles are usually long, and there is seldom anything akin to intermediate cutting; there is little control over stand density or species composition.

In pure stands, an extensive application of the group-selection method may prove reasonably successful when the desirable species represent a physiographic or climatic climax.

Economic Selection Methods and "Selective Cutting"

In situations where landowners have no interest beyond liquidation of existing merchantable timber, foresters have used one important principle of extensive application of the selection method as a way of encouraging retention of growing stock. There is always a limiting diameter below which trees cannot be profitably utilized for a given purpose, because the handling costs exceed the sale value of the small material produced. The tree that can be harvested with neither profit nor loss is referred to as the **marginal tree** of the stand or forest in which it occurs; a cutting that removes all trees that can be utilized without financial loss is called a **zero-margin selection cutting**. If a landowner can be induced to recognize the existence of the marginal tree, it becomes clearly desirable to leave smaller trees in logging. If the presently unmerchantable trees are sufficiently large and numerous to provide the basis for another harvest in the near future, there is an additional incentive to protect the smaller trees and to shift away from a policy of short-term liquidation.

This approach is effective in getting the practice of forestry established, but is not an appropriate basis for long-term practice. In fact, as economic factors become more favorable, the size of the marginal tree often drops to the point where virtually every tree in a stand can be utilized at a profit. Under these conditions, zero-margin selection cutting may verge on clearcutting.

The primary drawback of basing the selection method on the concept of the marginal tree is that the potentialities of different trees for future growth are not taken into account. Although a tree may be logged profitably at a given time, it often can be harvested at an even greater profit at some later date. Once a landowner is committed to retaining small trees for growing stock, it becomes desirable to know which trees are best reserved to the next cutting cycle. This can be done by using the concept of financial maturity to detect those trees that will earn an attractive rate of compound interest on their own present value if left to grow. This procedure usually results in setting a guiding diameter limit that is substantially higher than the one that would apply to zero-margin cutting. If the total return to be obtained during another cutting cycle is high enough, the practicability of continuing operations at least to the end of that cycle is demonstrated. This line of financial logic is often sufficient to guide forest practice up from mere mining to a level of extensive practice likely to ensure continuity of management.

If practice can be intensified still further to secure optimum production and sustained yield, the suitability of the selection method should be reexamined. During the period 1930 to 1950, many authorities regarded extensive applications of the selection method, described as "selective cutting," as the panacea of American forest management. The times were peculiarly appropriate for such proposals. The development of trucks and tractors suitable for use in logging big timber had begun to displace railroad logging, thus making partial cutting possible in old growth. The lumber markets of that period were so badly depressed that only the biggest and best trees could be harvested profitably. Most owners were not willing to make significant investment in regeneration. In some cases, foresters were not sure that they knew how to regenerate the stands if they had funds to do so. Partial cuttings provided a means of postponing regeneration until the necessary funds and knowledge were available. Selective cutting played a highly important role in demonstrating that partial cutting was feasible and that residual stands of usable timber could be profitably left for future harvests.

Unfortunately, selective cutting also proved to be a tool that could be used for evil as well as good (Isaac, 1956). Much of it was simply high-grading that resulted in neither maintenance of the uneven-aged form, establishment of desirable reproduction, nor preservation of residual stands. Selective cutting, and indeed much of the idea of uneven-aged stands in general, fell out of fashion during the 1950s when many owners overcame their reluctance to invest in regeneration and various forms of even-aged silviculture were found to be more effective. As usual, the pendulum swung too far. It has not stopped swinging.

Examples of Management of Pure Uneven-aged Stands

Restrictive Sites

Pure uneven-aged stands are most commonly found and easiest to maintain on sites that have such pronounced seasonal deficiencies of available water that natural monocultures are favored. These deficiencies may result simply from drought or physiological dryness caused by low soil temperature or the accumulation of poorly aerated water. On such sites, conditions are only sporadically conducive to regeneration, so it helps to retain trees that can produce seeds whenever circumstances allow. In such cases, tree growth is usually too slow to justify the high cost of planting, so one is restricted to natural regeneration. Another reason for uneven-aged stands in these circumstances is the desirability of trying to keep nearly every seedling that becomes established. If they come in sparsely and infrequently, the inevitable result is likely to be an uneven-aged stand.

The evolution of this approach in the dry ponderosa pine forests of the interior of the western United States (Cochran, 1992) illustrates some of the considerations involved in maintaining uneven-aged stands of this kind. Many stands are composed of small even-aged groups of trees that have arisen when trees were killed by bark beetles, lightning, dwarf-mistletoe, or the irregular lethal effects of fires; group-selection management has long been common.

The species has a broad geographical range, and the patterns of seasonal dryness to which it is exposed differ considerably, as do the management problems. The only part of the range in which regeneration is easily secured is a region of summer rainfall that lies east of the Rocky Mountains and includes the Black Hills of South Dakota. Most of the stands in those localities are even-aged, and, because of the relative ease of regeneration, they are typically managed that way.

The widest part of the ponderosa pine range lies between the Rocky Mountains and the mountain chain formed by the Cascades and Sierra Nevada to the west. At the north there is a long, dry summer but with just enough extension of the winter rains into the spring that it is only moderately difficult to obtain regeneration. The selection system is commonly used but has evolved as conditions have allowed the intensity of practice to increase.

Before the 1940s, the old-growth forest was still ruled by *Dendroctonus* bark beetles and the limitations imposed by railroad logging. It was anticipated that this cumbersome mode of log transportation would dictate a long cutting cycle of about 30 years. Only fine old trees more than about 20 inches D.B.H. were worth cutting. The Keen Tree Classification (Fig. 19.3) was devised as a basis for predicting the survival prospects of various categories of trees for the long cutting cycles that were envisioned. It was used as the basis of financial maturity analysis (see Chapter 17), which also guided the choice of trees for harvest or retention. In fact, this approach, termed the **maturity-selection system** (Munger, 1941), was perhaps the most successful selective logging scheme of the era because it closely fit existing developmental processes in truly uneven-aged stands.

With the advent of tractor logging and much more favorable markets, it became possible to shorten the cutting cycles and to produce thinning effects by cutting in a broader range of diameter classes. Problems with the bark beetles subsided as large, old, susceptible trees were eliminated. It has gradually become more customary to prescribe treatments for individual stands on the basis of their prevailing condition rather than following some standard system. At one time, the term **unit area control** (Hallin, 1959) was used to denote this shift in emphasis. The ''unit'' was any homogeneous part of a large, heterogeneous stand, but it gradually came to be recognized as a small, separate stand in its own right. As problems such as dwarf-mistletoe and the need for site preparation to deal with brush competition got increased attention, even-aged systems, including those involving planting, became more prominent among the alternatives used. Concern about the invasion of tolerant conifers and increases in the amount of forest-fire fuel have also made it desirable to institute prescribed burning beneath the stands.

Farther south, in Arizona and New Mexico, severe drought in spring makes regeneration of the forest a rare event. These areas have summer showers and thunderstorms, but they do not occur in time to induce seedlings to germinate early enough to harden before frost. In 1919 the combination of an abundant seed crop, the existence of much vacant growing space from previous fires or heavy grazing, and unusual spring rains brought abundant pine regeneration to northern Arizona. The 1919 class filled so much growing space that for some decades it was logical to turn to other silvicultural management problems. Since bark beetles were not a major problem, the selection cutting could be aimed at developing trees with good bole form and natural pruning. A program for doing this, called **improvement-selection cutting** (Fig. 15.2), and many other aspects of ponderosa pine silviculture were described by Pearson (1950). The kinds of pines with small crowns and branches that he found capable of responding to release and turning into fine trees were among those that were highly vulnerable to beetle damage farther north.

In most of the ponderosa pine types, the selection system has been used to take advantage of rare regeneration episodes. In a different general case, the selection system is often used to take advantage of easy regeneration coupled with weak competition from undesirable species. Such circumstances exist on specific sites in many regions where there is good rainfall at the season of seedling establishment but such poor moisture supply at other times that only drought-tolerant species can endure. Various species of pines have this adaptation. Under just the right soil-moisture regime, the regeneration phase of silviculture may require little more than drifting with the tide of natural processes. This situation can develop on soils of deep sand, such as glacial outwash or old coastal beach deposits, in humid climates. If the stands are already uneven-aged, there is little reason to convert them to the even-aged condition. The dry soils usually make the logging easy and reduce problems with undesirable vegetation. Any large vacancies created in the growing space by cutting usually fill up promptly and almost automatically with dense regeneration. The main problem is ordinarily that the natural regeneration is far too dense and precommercial thinning may be required.

One famous and influential case involved Scotch pine on some deep sands south of the Baltic Sea. Because of the almost effortless regeneration, a mode of management called the *Dauerwald* or ''continuous forest'' developed early in the present century. This was a revolt against policies of strict regimentation of the forest, fixed rotation lengths, and plantation silviculture. Most efforts focused on tending individual trees and harvesting them only when they interfered with better trees. This policy tended to accentuate any variations in age-class structure that already existed in the stands.

This general approach is so easy that it is useful to recognize the narrow range of site conditions that make it feasible. They occur in the eastern and southern parts of the United States only on deep, sandy soils, which are often among the poorer soils for tree growth. They are, for example, the easiest places to grow longleaf pine, eastern white pine, and some other pines because hardwood competition is feeble. Such sites are more common in the western interior; examples are the kinds of ponderosa pine sites where regeneration is easy but brush competition is not serious. Another important case is the mountains of northern Mexico, which have some uneven-aged, easily regenerated forests of *Pinus durangensis* and *P. arizonica* in a summer-wet, winter-dry climate (Fig. 15.9).

Whether this dry-site regeneration is difficult or easy, it is often associated with some

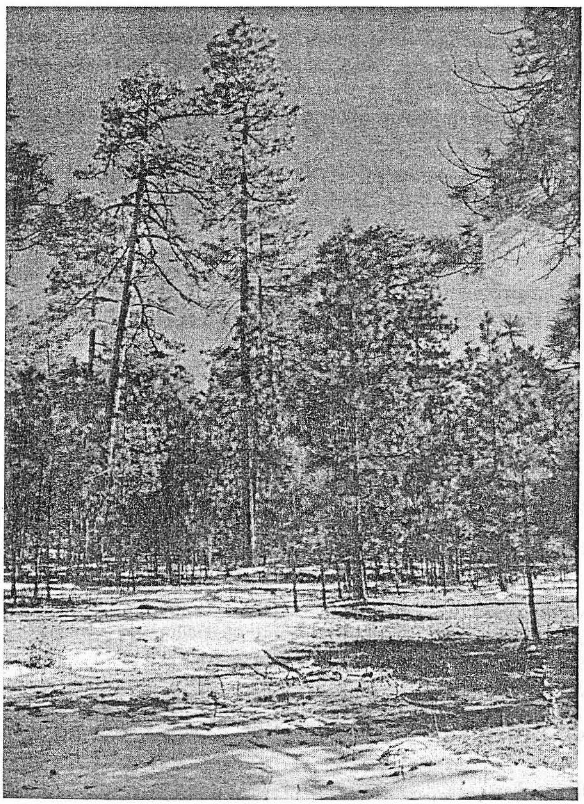

Figure 15.9 An uneven-aged stand of Durango pine on a soil in northern Mexico that is moist during part of the summer but very dry the rest of the year.

peculiar phenomena of root competition. The supply of available water is often small enough that the invisible root systems can be fully closed but unable to support a closed canopy of foliage. The stands easily develop persistent gaps that appear to be unstocked but are actually being fully utilized by the roots of adjoining trees. If root-grafting is well-developed, as it often is with pines, partial cuttings may merely donate the use of living roots of the cut trees to the remaining ones. This is good for the remaining trees but can defeat efforts to create real soil vacancies for regeneration.

Deep sands in humid climates can present an additional peculiar phenomenon. The problems with moisture deficiency may be mostly near the surface. Although trees may grow slowly at first, they can grow at accelerating rates for long periods as their roots become increasingly extensive. What may seem to be poor sites initially become much better. If the trees of crowded groups differ enough in height, the leading trees will forge ahead even without the benefit of thinning as their root systems become deeper.

In the poorly aerated peat swamps of the northern forest, regeneration of black spruce and northern white-cedar by natural layering is an important supplement to that from natural seeding and is encouraged by developing uneven-aged stands. Because the layering takes place only when the ends of live branches are overgrown by sphagnum moss, it is essential that tree crowns touch the ground in a sufficient number of places. This condition can be maintained only in uneven-aged stands (Johnston, 1977). The sites are poor enough that the stands often do not close, and the rise of water-table levels that would result from reduced transpiration after clearcutting might harm the trees. The partially cut stands are surprisingly resistant to wind because the peat is so resilient that the force of the wind tends to be dissipated in agitating the soil itself rather than in damage to the trees.

Good Sites

If enough effort is dedicated to controlling unwanted species, it is possible to grow pure uneven-aged stands of many species on any kind of site. One well-documented case history (Reynolds, Baker, and Ku, 1984) involving such stands started in southern Arkansas with loblolly and shortleaf pine. These species characteristically grow together in even-aged stands so their successful culture in uneven-aged stands is proof of the versatility of the method. The basic objective of the procedure is to develop good sawtimber growing stocks as swiftly as possible from the remnants of high-graded even-aged stands. Good new stands could be created by liquidating the remnants and replacing them with even-aged regeneration, but this might cause a temporary suspension of harvests when the old trees were gone. Furthermore, there would be needless sacrifice of many small- or medium-sized trees of good potential.

The guiding principle followed in this kind of cutting is the concept of financial maturity which is applied with careful attention to the quality of increment as well as to volume. Full advantage is taken of the excellent natural pruning of some of those remnants of earlier stands that are capable of regaining full vigor (Fig. 15.10). This procedure rehabilitates the stands and preserves enough of the irregularity of the initial stands that some intermingling of age classes remains.

This approach has helped meet the need for low-investment silviculture on small, private, nonindustrial ownerships that comprise almost two-thirds of the Southern forest (Murphy, Baker, and Lawson, 1991; Williston, 1978). The chief emphasis tends to be on manipulating existing growing stocks in order to extract optimum advantage from them over the longest possible time. Although regeneration is seldom perfect, it is often possible to get sufficient natural regeneration if fire, herbicides, browsing, and harvesting of hardwoods are used to keep the hardwoods under some degree of control.

Figure 15.10 A stand, predominantly of loblolly and shortleaf pine, being managed under the selection system in southern Arkansas. The large-branched pine in front of the man is to be cut to foster the growth of the small-branched one behind him. *(Photograph by U.S. Forest Service.)*

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