

# Multiaged Silviculture

## Solutions for Today's Challenges

By Susan L. Stout

As foresters, we have at least two reasons to find multiaged and uneven-aged silviculture compelling: these alternatives to even-aged systems respond to negative public reactions to even-aged harvests, and they provide the wildlife, recreation, and diversity benefits that come with complex forest structures.

This issue of the *Journal of Forestry* presents perspectives from all regions of the country, from both traditionalists and pioneers of new approaches to multiaged systems. We find many ideas for foresters seeking to develop tools to meet the increasingly complex demands placed on forests and silviculture. We read about using stand density index and leaf area index to create desirable structures and forest floor lighting conditions. We read about the utility of traditional tools like the Arbogast guides for northern hardwoods and the BD<sub>q</sub> approach. As these articles remind us, successful tools—new or old—must provide desirable stand structures and be practical enough for use by markers in the forest, as well as promote regeneration that sustains diverse and desirable species compositions.

That puts foresters in some parts of the country between a rock and a hard place. As new methods are developed, serious conflicts can arise. What if the species favored by traditional uneven-aged silviculture are favorite browse for white-tailed deer in regions where these herbivores are overabundant? How do we handle hemlock and beech, also favored by uneven-aged silviculture, in regions where exotic insects make those species vulnerable to sudden loss? How should the managers of Douglas-fir proceed in the Pacific Northwest, from which Emmingham writes his appeal for the development of new tools?

Several initiatives are under way to design and test creative approaches to multiaged silviculture in the face of these challenges. Both O'Hara and Long suggest that residual structures based on stand density index or leaf area index may provide structural diversity while allowing enough light to reach the forest floor to ensure regeneration of shade-intolerant species. Seymour and Kenefic report real progress on new ways of describing and analyzing stand structure in multiaged spruce-fir stands. Miller and Kochenderfer report that two-aged systems in West Virginia appear to preserve the species diversity of even-aged systems while providing additional structural complexity.

Most public agencies, some industrial foresters, and some consulting foresters are experimenting with various forms of two-aged silviculture, featuring retention of overstory trees from all species and crown classes at final harvest. Silviculturists design these systems to ensure both species diversity and vertical structure while sufficient light is passed to the forest floor to allow regeneration of diverse species in the new age class.

But the biggest challenge for all of us is learning how to communicate the importance of diverse regeneration to citizens who too easily believe that uneven-aged silviculture is a panacea for all they fear on public lands managed for multiple use.

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# Silviculture for Structure

Movement away from even-aged silviculture and toward maintenance of continuous cover and structural diversity has generated renewed interest in two-aged and uneven-aged silvicultural systems. New approaches for multiaged stands suggest managers can achieve many goals with systems that integrate the structural features associated with natural disturbance processes with systems that are simpler than the uneven-aged silviculture of the past. The result is flexible systems for designing and implementing diverse stand structures for many objectives, including biodiversity. An understanding of forest stand dynamics and landscape ecology is a prerequisite.

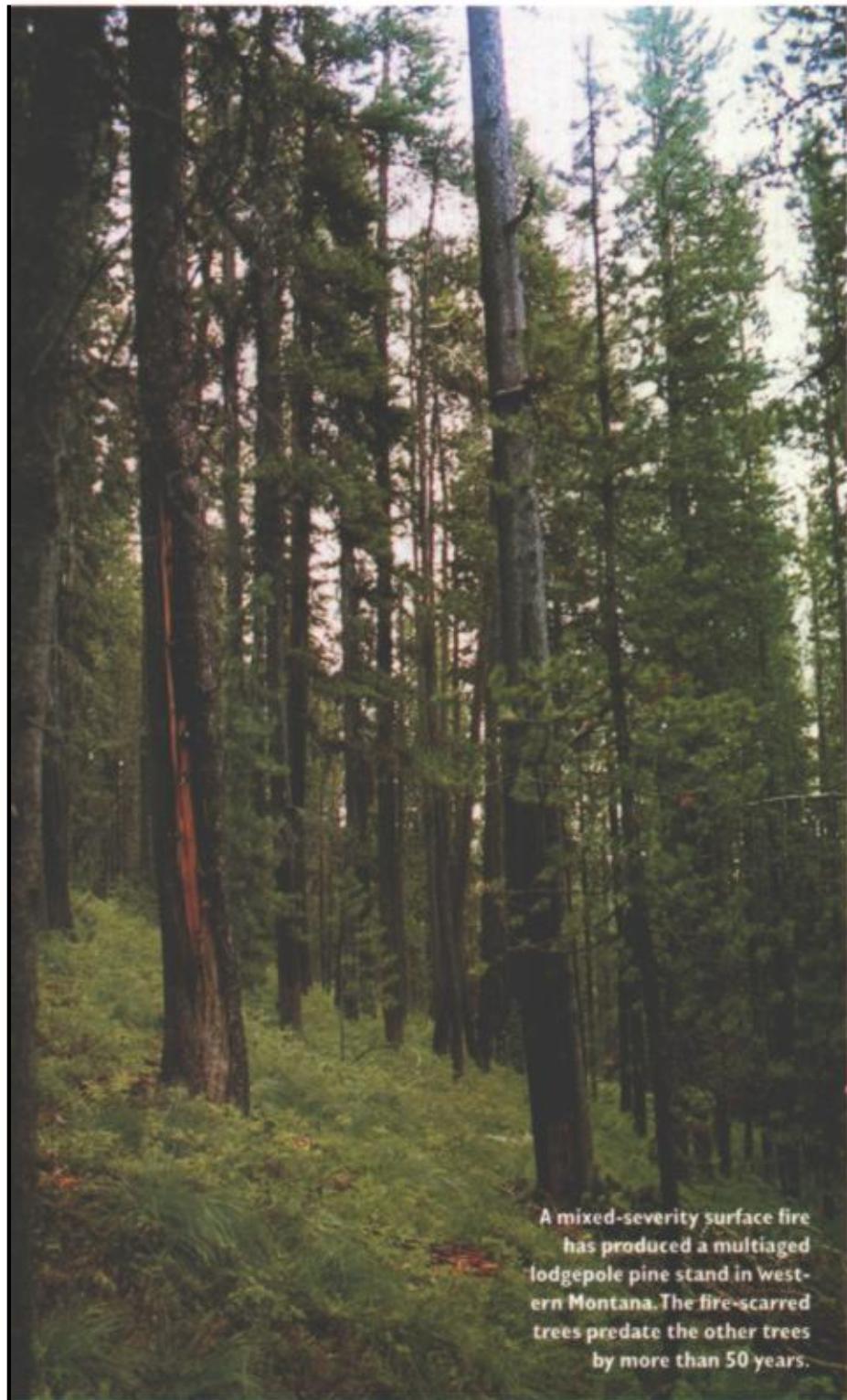
By Kevin L. O'Hara

Rapidly changing forest management paradigms emphasize creating and maintaining structural diversity at the stand level to provide for biodiversity and assure long-term sustainability. Maintaining continuous vegetative cover over time and avoiding obtrusive treatments are additional concerns. To meet the challenge, various forms of uneven-aged, or selection silviculture are being advocated here and abroad.

The new stand management strategies, and the structures they create, have assumed several names: continuous cover forestry (Yorke 1992; Garfitt 1995), ecological silviculture (Benecke 1996), near-natural forestry (Benecke 1996), close-to-nature forestry (Mlinsek 1996), pro silva (Pro Silva 1996), green-tree retention (Franklin 1989; North et al. 1996), multiaged (O'Hara 1996) and multicohort (Oliver and Larson 1996) forestry, as well as such traditional labels as *Dauerwald*, or roughly, "continuous forest" (Helliwell 1997), selection silviculture (*Plenterwald*), and uneven-aged silviculture. In philosophy these forms of silviculture are all designed to create multiaged stands (stands with two or more age classes) but are as varied as their names. Some are attempts to manage forests in ways that resemble natural processes under unmanaged conditions (ecological silviculture). Others describe a structural condition (multiaged) or an objective (continuous cover).

Forestry seems to cycle from one extreme to the other but rarely occupies the middle ground, and so it is with uneven-aged silviculture in North America and in Europe (Schütz 1994; Smith 1994; Weetman 1996). O'Hara et al. (1994) described the silviculture of the preceding 25 years as simple treatments in pursuit of simple objectives. Today, there appears to be a movement to the opposite extreme,

# Diversity A New Look at Multiaged Systems



A mixed-severity surface fire has produced a multiaged lodgepole pine stand in western Montana. The fire-scarred trees predate the other trees by more than 50 years.

particularly in countries where environmental pressures are severe; treatments can be as "unnatural" as some of their even-aged predecessors and are apparent attempts to micromanage forests so that all management is imperceptible. It is important to recognize the values and shortcomings of previous experience and the hazards of extreme reactions to public pressure over silvicultural practice.

In North America there remain many relatively untouched forests that allow reconstruction of prehistoric stand and landscape conditions and disturbance regimes. The natural history of our forests reveals patterns and processes that occasionally formed uneven-aged stands, or more accurately, stands with two or more age classes. This information can be used to determine how to maintain these multiaged structures and suggests ways to manage forests in patterns and structures that resemble the conditions under which some plant communities have evolved and on which native diversity depends.

## Stocking Control and Assessment

First, foresters need new methodologies and tools to design and assess uneven-aged stands that form a variety of structures. Since stocking control in uneven-aged stands generally involves allocations of growing space to age or size classes, the tools must be flexible enough to permit the design of a variety of structures.

Long and Daniel (1990) suggested allocating stand density index to diameter classes in uneven-aged stands. This system provides flexibility to design stands of a variety of structures for virtually any species. Long (1996) demonstrated the potential of this method for two-aged ponderosa pine; otherwise, guidance on allocations of stand density index to diameter size classes is scarce.

Keynote  
O'Hearn

A new method developed for pure ponderosa pine and lodgepole pine stands in western North America and mixed Norway spruce–Scots pine stands in Finland (O'Hara et al., in press) is useful for uneven-aged stocking control. This methodology recognizes the potential for leaf area index to represent occupied growing space in forest stands (see "Leaf Area Allocation: How Does It Work?" p. 11). By dividing growing space among age or size classes, the silviculturist can design structures with different numbers of age classes, canopy strata, densities, and levels of occupied growing space. An additional advantage is that the strong relationship between individual tree leaf area and volume increment allows the consequences of a desired structure to be assessed as the structure is being designed. For example, one can estimate volume increment of the stand, individual age classes, or canopy class groups, then use the growth rates to evaluate whether these stand components will sustain a structure, or to estimate vigor of one component. Such methods are particularly applicable to designing relatively simple two- or three-storied stands.

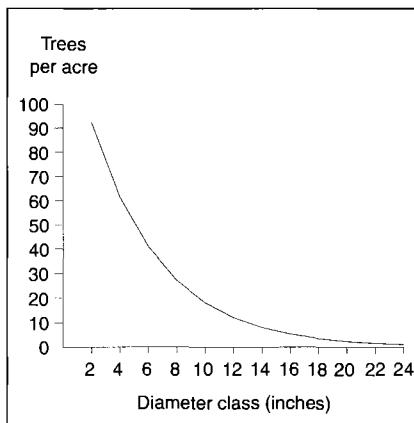
### Traditional Practices

Reverse-J-shaped diameter frequency distributions have been observed in forests for several centuries. H. Arthur Meyer is generally credited with developing the  $q$  factor (the ratio of trees in a diameter size class to the number of trees in the next larger diameter class) as a means to quantify the reverse-J curve for stocking control in uneven-aged stands in the United States (Meyer 1943, 1952). If the development of the reverse-J curve is traced back to its origins with Gurnaud, deLiocourt, Biolley, and others in central Europe (Troup 1952; Schütz 1994), the negative exponential slope of the reverse-J diameter distribution has always been most constant when applied to large areas—apparently why early writers in central Europe referred to a constant  $q$  factor in *forests* instead of *stands*. The distinction is important because when the age structure of Meyer's "uneven-aged" forests in Penn-

sylvania was measured, the stands were found to be *even-aged* (D.M. Smith 1995 pers. commun.).

Nevertheless, the  $q$  factor was largely adopted as the primary means of stocking regulation in uneven-aged stands in North America. Further development led to the BD $q$  approach, in which stocking is controlled by a basal area level (B), maximum diameter (D), and a  $q$  factor (Guldin 1991). Other developments included the concept of the "balanced" uneven-aged stand, which has essentially been equated with a stand defined by the  $q$  factor. Hence a stand whose diameter distribution strayed from the smooth negative exponential distribution was considered unbalanced.

Later, an interpretation was added that a balanced stand had equal growing space allocated to each size class (Smith et al. 1997). Assuming, for example, 2-inch-diameter classes, each class is allocated the same amount of growing space. Hence the 2- to 6-inch classes are assumed to occupy the same amount of growing space as the 20- to 24-inch classes. For this to occur, each successively smaller-size class must have more trees.



**Figure 1. A reverse-J curve defined with a  $q$  factor of 1.5- and 2-inch diameter classes. Note that this distribution has only 275 trees per acre, but 71 percent are in the 2- to 6-inch diameter classes. Only five trees are greater than or equal to 20 inches. Instead of being constrained by diameter distributions with this form, foresters should be able to design a variety of stand structures, including structures with greater numbers of large trees.**

Applying the balanced-stand concept to uneven-aged stands was analogous to the area-control forest regulation procedure. Each size class in uneven-aged stands was allocated equal growing space in the same way that the total land area occupied by stands of any given age was equal in the fully regulated, even-aged, area-control forest. Sustainability is theoretically achieved in both systems because wood is produced consistently over time and a relatively constant stand or forest structure is maintained. Younger even-aged stands in a regulated even-aged forest typically have many trees, and therefore the younger and smaller classes of the uneven-aged stand should theoretically have many trees (O'Hara 1996). This gives the  $q$  factor distribution its characteristic reverse-J or negative exponential shape (fig. 1)

### Misinterpretations

It now appears that the  $q$  factor is an arbitrary distribution of tree sizes, mathematically convenient but with little ecological foundation. Very many uneven-aged stand structures are sustainable. The balanced-stand concept was created by humans to justify certain management directions they believed were sustainable.

Several research studies have demonstrated that reverse-J diameter distributions could be maintained over long periods. These include single-tree selection systems with southern pines (Reynolds et al. 1984) and group selection systems in northern hardwoods (Leak and Filip 1977). However, these studies have generally not tested alternative models for stocking control they have tested whether a reverse-J distribution was sustainable rather than whether it represented an optimal stocking solution. Others (Leak and Filip 1977) have questioned whether the rotated sigmoid curve (see Goff and West 1975) might be a more appropriate model than the reverse J. Additionally, simulation efforts (e.g., Adams and Ek 1974; Haight et al 1985) that attempt to identify optimal stocking regimes have also not shown the reverse-J distribution to be optimal (O'Hara 1996).

In North America, the adherence to



**Five distinct cohorts are represented in a multiaged ponderosa pine stand in western Montana, including one that predates European settlement and several that resulted from selection system harvests.**

the reverse-J curve has led to problems:

- Managers have focused almost exclusively on maintaining a diameter distribution instead of more significant structural features, such as distributions of foliage, canopy strata, or crown occupancy. Managers have also typically ignored the ages of trees, and in many cases cutting amounted to highgrading, thereby giving uneven-aged silviculture a bad reputation (Smith 1994).

- The high numbers of small trees required by higher  $q$  factors are often justified by the expectation of high mortality in smaller-size classes. For the distribution depicted in *figure 1* that has a  $q$  of 1.5, the 195 trees in the  $\leq 6$ -inch-diameter classes eventually replace the five trees in the 20- to 24-inch classes. The remaining trees are assumed to die, be thinned, or not increase in diameter. However, in the United States, density management guidelines for even-aged conifers generally prescribe relatively low densities that rarely let a stand go beyond about 60 percent of maximum stocking (Drew and Flewelling 1979; Long 1985; Dean and Jokela 1992). When

similar limits on density are applied to uneven-aged stands (Long and Daniel 1990; O'Hara 1996), mortality in small-size classes occurs because of the high levels of competition within them. It becomes a self-fulfilling prophecy: many small trees are needed because some will die, and some will die because there are so many small trees.

The root cause of such misinterpretations may be general confusion about all-aged versus uneven-aged stands. Managers using the  $q$  factor frequently assume that by creating an all-sized stand, they are creating an all-aged stand. Very few ecological studies have observed stands in which nearly all age classes are present (Oliver and Larson 1996). More common are stands with several distinct age classes that originate after unique regeneration events. The diameter distribution of a natural stand is more likely to have several peaks rather than the smooth shape defined by the  $q$  factor. Where fires are frequent but of low severity, the diameter distribution might be bell-shaped even though the stand is uneven-aged.

There are also many well-documented cases of reverse-J diameter distributions in even-aged stands (Oliver and Larson 1996) and many examples of poor management resulting from an assumed correlation between size and age. Previous misinterpretations are

due to a failure to determine what ecological processes created the observed structure. When a reverse-J diameter distribution is observed, foresters have tended to assume—erroneously—that it is uneven-aged (Smith et al. 1997).

Silviculture must build on a solid foundation of ecological understanding. To design and manage uneven-aged stands, we must understand the events that combine to form these structures. Reconstructing stand age structure is difficult but well worth the effort if our management is to be ecologically sound and convince skeptical citizens.

Whereas traditional stocking control mechanisms based on the reverse-J curve are lacking the flexibility needed to guide design of a diversity of stand structures, new tools provide this flexibility. Additionally, these new tools can integrate concepts of stand dynamics such as natural disturbance cycles and patterns of canopy stratification through design of structural features based on age classes or canopy strata.

### New Understandings of Structure

With changes in management direction in North America toward more emphasis on what is left after harvest as compared to what is recovered, there is also a greater emphasis on structural conditions. Stands with structural diversity, such as all-sized or uneven-aged stands, generally have greater species richness than stands with less structural diversity (Hunter 1990; Hansen et al. 1991). When viewed from a landscape scale, however, species richness and biodiversity are maximized by a diversity of stands, including even-aged and multiaged structures of various ages. Biodiversity will most likely be maximized by organizing a diversity of structures over a large area, not by creating the same structure over many hectares. This is why the concepts of landscape ecology are so important for today's forestry. To maintain a desired level of diversity in forests, we must simultaneously plan over large areas.

The silviculturist thus has great opportunities to create a diversity of structures that maximize biodiversity. However, an understanding of forest stand dynamics is a prerequisite for this

type of management (O'Hara et al. 1994). New stocking tools that create a variety of multiaged structures will be useful for meeting this biodiversity.

Stand structure can be viewed as a unifying variable for forest management: most multiple-resource or multiple-use management objectives— aesthetics, hydrologic values, wildlife habitat, and even timber production— can be expressed in terms of stand structures. Inclusion of variables that describe the position and size of tree crowns can also enhance our ability to predict stand increment in both even-aged and multiaged stands (O'Hara 1988, 1996). But in describing structure, the emphasis should be on using variables that are relevant ecological structural features, not whatever is convenient to measure or easy to quantify (such as the reverse-J curve).

**Shade tolerance.** It is often assumed that uneven-aged systems work only for shade-tolerant species that can survive in an understory. This assumption may be rooted in classical succession theories that vegetation developed toward a climax type that was self-perpetuating and uneven- or all-aged, and that the vegetation consisted exclusively of shade-tolerant individuals. At present, the climax model has generally been discredited (Christensen 1988; Pickett and McDonnell 1989; Cook 1996), but assumptions concerning species composition for uneven-aged stands still exist.

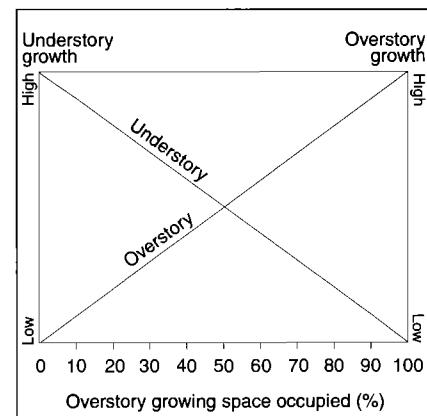
Shade tolerance can, however, be viewed as a relative ranking of a species' ability to survive beneath another species (Parker and Long 1989). In theory, a shade-tolerant species can survive under a less tolerant species, but not vice versa, and no species can survive for long in its own shade: the "leftover" light passing through a tree's crown would be insufficient to support another tree of the same species. Yet natural multistrata stands of relatively shade-intolerant species are common (see Oliver and Larson 1996 for examples), and intolerants provide some of our best examples of successful uneven-aged management (Baker et al. 1996). These stands exist because their total foliage biomass and light interception are low compared with

shade-tolerant species, and the open structure of their canopies permits considerable light to penetrate their discontinuous upper stratum.

There is probably no species that because of its shade intolerance could not be managed in a single-species, uneven-aged, multistrata structure. Some species may be outcompeted by other tree or shrub species (Nyland 1996), susceptible to insects or pathogens, or uneconomical to grow in uneven-aged stands. However, shade intolerance could be overcome by appropriately allocating the growing space to each species or age and canopy class. For shade-intolerant species, this would require less total leaf area, less light interception, and perhaps lower relative density than for a shade-tolerant species. Because of these lower levels of light interception, there is potential for a shade-tolerant species to invade the understory and outcompete a desired intolerant species—a significant concern for uneven-aged silviculture, since controlling invasion by undesirable trees may be expensive.

The conceptual relationship between upper-canopy trees growing in nearly full sun and lower-canopy trees growing in partial shade can be viewed in *figure 2*. The higher the overstory stocking, the lower the understory growth. The more growing space allocated to the understory, the less available for the overstory. Uneven-aged stocking guidelines should indicate the best compromise between understory and overstory growth to meet management objectives.

**Productivity.** There are many studies of the relative productivity of even- versus uneven-aged stands with no clear consensus regarding which is more productive (Lähde et al. 1994). Only a few studies were actually designed to compare even- and uneven-aged stands. Instead, researchers have simulated or found comparable even- and uneven-aged stands and used them to develop conclusions about relative productivity. The number of variables to be controlled in these studies is impressive: species, age (e.g., what type of uneven-aged stand is comparable to a 40-year-old even-aged stand?), densities (e.g., what densities are compara-



**Figure 2. Theoretical relations between overstory and understory growth and percentage of growing space occupied by the overstory. An adequate understory growth rate depends on sufficient available growing space.**

ble for the two structures?), timing of treatments, and so on.

There are few fundamental reasons why productivity might vary between structures with one age class and structures with two or more age classes. On a given site, light, moisture, and nutrient resources are constant, so potential differences in productivity related to stand structure must result from differences in use of these resources. Research comparing relative light, moisture use, or nutrient cycling efficiencies, however, is generally lacking. Recent work with ponderosa pine indicates some differences in these efficiencies, but the differences have not been separated from a confounding density effect (Valappil 1997).

Lower productivity in uneven-aged stands would probably not discourage potential use of these systems if the difference was small. Uneven-aged silviculture is already perceived to have many short- and long-term benefits; higher productivity, if verified for uneven-aged stands, might be a catalyst for more implementation of such systems. If differences in productivity were found, they would probably be small, especially compared with the effects on productivity of variations in density levels, timing and length of cutting cycles, species choice, and susceptibility to insects and diseases. For example, O'Hara (1996) found multiaged ponderosa

pine stands to have only 8 percent greater cubic volume productivity than even-aged stands in western Montana and only 2 percent greater in central Oregon; neither difference was statistically significant.

In mixed-species stands, the advance growth effect (Bourne 1951; Smith et al. 1997) suggests understory stand components might utilize leftover light passing through the overstory, allowing greater stand productivity. This would require either (1) a relatively open overstory, in which case productivity would not be enhanced because the understory productivity occurs at the "expense" of the overstory, or (2) a more shade-tolerant understory species, whose use of light would be more efficient than in a pure stand of the overstory species. Arranging these species in the opposite pattern would probably not work, however, and hence the tolerant understory species must be maintained in the subordinate position for the productivity advantage to be sustained. Mixed-species stands may present other opportunities for greater efficiency of growing space (Kelty 1992), but these efficiencies would be due primarily to species composition, not age structure.

**Costs and cutting cycles.** The costs associated with uneven-aged silviculture are generally perceived to be high because frequent stand entries are needed, with reduced volume removals and increased per-unit logging costs. Perhaps traditional uneven-aged systems have very frequent entries because of the preoccupation with maintaining "balanced" diameter distributions. Any amount of growth or change in the diameter distribution would theoretically "unbalance" the stand—something generally assumed to be undesirable, even though the consequences have never been clarified. These frequent entries in uneven-aged systems may have their origins in the *Plenterwald* system of central Europe, where entries were encouraged every five to eight years (Troup 1952).

Instead, however, we could attempt to manage with long cutting cycles that allow structures to develop across broader ranges of relative stocking lev-

els. Lower residual densities are an expected consequence of longer cutting cycles (Buongiorno and Michie 1980; Hansen and Nyland 1987). Perhaps even-aged thinning intervals that allow stands to fluctuate between extremes of a desirable density management zone can guide the lengths of cutting cycles and residual densities.

**Regeneration.** If stands are managed with broad ranges in stand density or growing space occupancy, natural regeneration should occur, assuming adequate reductions in density and sufficiently long periods to accommodate the periodicity of successful regeneration events characteristic of many tree species. Foresters have a tendency to be overly concerned with prompt regeneration, which on most sites is likely to occur if we are patient. Perhaps our overemphasis on maintaining specific diameter distributions and the virtually nonexistent all-aged stand have forced foresters to attempt to maintain continuous regeneration over both spatial and temporal dimensions. Another legacy of the *Plenterwald* philosophy may be the disconnection between uneven-aged silviculture and artificial regeneration. Artificial regeneration offers many opportunities for species control, genotype improvement, and avoidance of delays associated with natural regeneration in uneven-aged systems.

**Sustainability.** In the past, sustainability at the stand level has been a prerequisite to an effective uneven-aged stocking control procedure. The popular use of the *q* factor was based in part on the interpretation that the "balanced" stand was a sustainable unit (Nyland 1996; Smith et al. 1997). O'Hara's (1996) analysis with *ponderosa* pine found that although distributions defined by the *q* factor appeared sustainable, other distributions that varied from a negative exponential distribution were sustainable at higher levels of production.

Similar concern over the sustainability of even-aged stocking control procedures is generally absent. Instead, sustainability of even-aged systems is typically judged by their long-term effects on productivity of the land, not on an even flow of volume production

from a single stand. The sustained yield of these even-aged systems is achieved through analysis over broad areas.

The traditional interpretation of sustainability in uneven-aged stands and the short cutting cycles inherent in the application of the *q* factor are probably closely related. Uneven-aged stands are typically assumed to be single sustained-yield units. To provide an even flow of wood from uneven-aged stands over short periods, frequent harvest entries or short cutting cycles are needed.

Perhaps silviculturists need to adapt their interpretation of sustainability of uneven-aged stands to the traditional forest management interpretation—that is, recognize the natural temporal and spatial diversity of possible uneven-aged structures, then assess sustainability over broad areas that include many uneven-aged stands rather than as a stand-level stocking regulation mechanism. At small scales, sustainability of uneven-aged stands could be evaluated by their effect on long-term site productivity.

**Growing space allocations.** Once we move beyond the constraints of the reverse-J diameter distribution and the "balanced" stand, we can allocate growing space among uneven-aged stand components (age classes, size classes, canopy strata, etc.) in many ways. Stand structures with only two or three age classes or canopy strata may provide a simple means of meeting most, if not all, objectives of more traditional and complex uneven-aged stands. These structures are simple because only two or three stand components must be managed. Additionally, we can use some of our experience with seed tree and shelterwood systems to guide growing space allocations in multiaged stands.

We can create uneven-aged stands with normal size distributions, or stands with decreasing numbers of trees with increasing size. Rather than being limited to a very few sustainable structures, we can design and implement many structures to meet management objectives. This is truly an opportunity to tap the creativity of the forester in ways traditional even-aged silviculture never has.

## Conclusions

Foresters should be wary of adopting new management practices simply because they are new. This is especially true now, when environmental, social, and political pressures are encouraging foresters to try systems that maintain continuous cover and enhance aesthetics. There will be a tendency to overreact and adopt alternatives to even-aged systems that are neither feasible nor based on sound ecological reasoning. Foresters should instead examine previous experience with both even- and uneven-aged systems for guidance.

Uneven-aged silviculture can achieve a variety of stand structure objectives other than the relatively inflexible structures represented by the reverse-J diameter distribution. New stocking control procedures that focus on multiaged stands provide the flexibility to design variations in stand structure. Information we already have—on growing space allocation in multiaged stands, on natural disturbance cycles and stand dynamics, on patterns of canopy stratification through design of structural features such as age classes or canopy strata—can be integrated into the stocking control tools. These procedures can also be adapted to other forest types, providing new options for managers to achieve a wide range of management objectives while maintaining continuous cover.

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