Balance and Sustainability in Multiaged Stands

A Northern Conifer Case Study

Classical silvicultural concepts of balance and sustainability in selection stands are examined using a 40-year case study in a mixed hemlock-spruce-fir stand. Although the stand initially conformed well to the target structure, deficits of poletimber and surpluses of sawtimber have since developed. Viewing stand structure in terms of area occupied by 10-year age classes, in addition to the diameter distribution, reveals important structural and species imbalances and suggests future management directions.

By Robert S. Seymour and
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Foresters in the Northeast are both blessed and cursed by the inherent complexity of the region's forests. Thousands of years may pass between natural stand-replacing disturbances, though partial disturbances, such as blowdown, defoliating insects, and various forms of partial cutting, are common (Seymour 1995). Foresters in the region typically deal with multiaged stands and often seek to maintain or enhance structural diversity through selection cuttings. Selection forestry is complicated and prone to misapplication, however, especially in the mixed-species stands that dominate this landscape.

One classical justification for multiaged silviculture is to mold individual stands into sustained-yield units. Such stands are considered "balanced" when harvest equals growth and structure remains relatively stable over a period much shorter than a typical even-aged rotation. Natural disturbance regimes rarely, if ever, confer such balance over small areas or short time frames; the classical balanced selection stand is thus largely a human construct. Unfortunately, the strong historical link between selection silviculture and balance has tended to obscure the fact that *irregular* multiaged stands—in which individual cohorts and their yields may ebb and flow in an "unbalanced" manner—commonly have a strong ecological and economic basis (Hawley and Smith 1954; O'Hara et al. 1994; Seymour 1995). Rigorous application of irregular multiaged silviculture has not flourished, however, largely because the procedures used to regulate selection cuttings (e.g., negative exponential diameter distributions) are preoccupied with the goal of stand-level balance.

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Nine selection cuttings were made on a five-year cutting cycle in this multiaged hemlock-spruce-fir stand on the Penobscot Experimental Forest in east-central Maine. Note the diversity of tree heights and sizes and the high degree of horizontal overlap.

O'Hara (1996, 1998) deserves much credit for questioning traditional concepts of balance and, more important, for developing methods based on canopy leaf area that can apply quite generally to any multiaged stand, including ones with intentionally irregular structures. His arguments may not be self-evident, however, to foresters familiar only with traditional approaches. We offer this discussion, based on experience and examples from our region, in an attempt to link traditional and new concepts, and to elucidate some of O'Hara's arguments in a way that encourages innovative foresters to explore their application.

Age versus Size

Even though precisely balanced multiaged stands are rare, the concept is nevertheless valuable as a point of departure for discussing, formulating, prescribing, and understanding the consequences of a vast array of possible structures. Modern American silviculture texts stress the importance of two factors in achieving balance: (1) an equal distribution of growing space among age classes—referred to here as the equal area model, and (2) age classes separated by cutting cycles of equal length (Nyland 1996, p. 201; Smith et al. 1997, p. 371). Beyond its obvious rationale from sus-

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Bob Frank, a retired research forester, takes silviculture students on a tour of multiaged stands on the Penobscot Experimental Forest in east-central Maine. This forest is one of the few sites in the Northeast where long-term research on the selection system has been done.

tained-yield timber management of large landscapes, the basis of the equal area concept is unclear and, we believe, tenuous.

The equal area model essentially assumes that growing space is not shared among cohorts over their entire life, just as in a fully regulated forest of even-aged stands *(fig. 1, p. 14)*. Although this may be true in multiaged stands regenerated by group or patch selection methods where individual cohorts occupy relatively large contiguous areas, it is demonstrably ***not*** true for stands treated with single-tree selection cuttings. In the single-tree case, growing space can be shared in two ways. First, there is the simple fact that small trees do not need nearly as much room as large ones; if some of the growing space that the young tree will eventually occupy at maturity can be used by older cohorts before this time, then we effectively obtain ***temporal*** sharing of the same growing space during the "rotation." O'Hara (1996) argues convincingly that young cohorts in single-species stands of intolerant ponderosa pine expand to occupy space freed by older cohorts after they are cut, thus sharing growing space at different points in time.

Second, as long as the upper canopy is open enough to allow seedlings and saplings to develop in the understory, trees can physically share the same ***horizontal*** growing space at the same time. Smith et al. (1997) characterize this condition as an advance regeneration effect, in which younger cohorts grow beneath older ones and thus do not need to exclusively occupy the horizontal area that would be needed in an even-aged stand. Although there is an upper limit to the amount of growing space available, and thus a limit to the amount of leaf area in a stand, trees frequently exist in overlapping rather than mutually exclusive arrangements in mixed-species stands.

The apparent advantages of single-tree selection suggest alternatives to the equal area model, in which older cohorts are allocated relatively more space than younger trees. Conceptually, this might be shown as a linearly increasing area from young to old cohorts *(fig. 1)*. The benefits are immediately obvious: a greater proportion of valuable sawlog-size stems and greater availability of old, large trees for wildlife use. Furthermore, recent work suggests that these older trees may actually be more efficient (i.e., produce more stemwood per unit of leaf area) than their younger counterparts (O'Hara 1996).

Although O'Hara's results contradict other studies of growth that show a decline in growth efficiency with increasing tree age (Assmann 1970; Long and Smith 1992), they suggest that stand productivity may improve by increasing the proportion of older trees, at least in some forest types. Unlike the equal area model, this structure assumes that some of the growing space vacated by cutting older cohorts is not immediately occupied by regeneration, but rather by crowns of adjacent trees

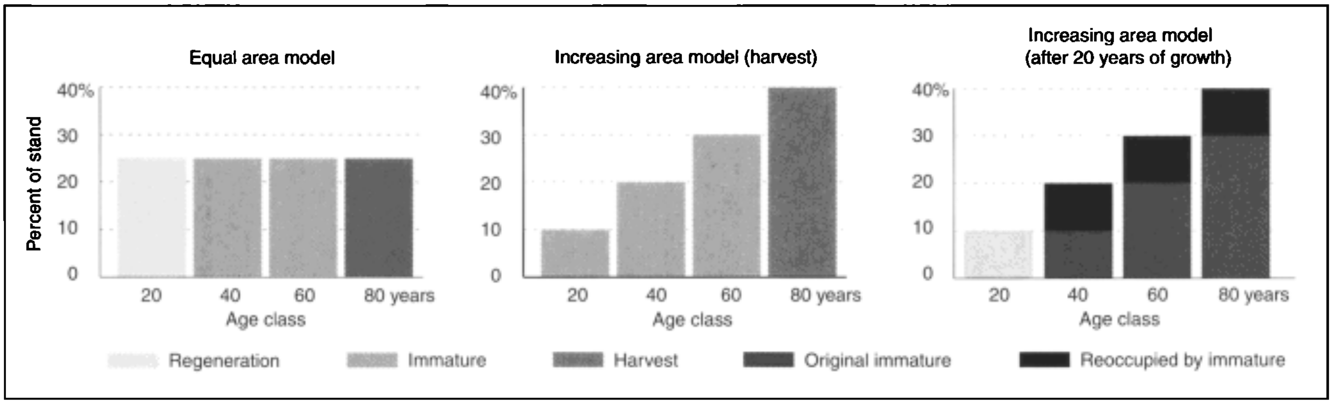

Figure 1. **Alternative models of growing space allocation in a hypothetical four-aged stand managed on a 20-year cutting cycle. In the equal area model (left), each age class shares growing space equally. Note that all area removed from the oldest age class becomes regeneration. In the increasing area model (center), older cohorts occupy relatively more growing space than younger trees. After 20 years of growth (right), only one fourth of the harvested area is reoccupied by regeneration.**

in immature cohorts *(fig. 1).*

The possibilities for shared growing space, at least in the single-tree selection case, suggest that achieving balance between growth and harvest does not necessarily depend on creation of a stand structure that is balanced by area. As O'Hara (1996) has suggested, other structures may well be feasible, sustainable, and even more productive.

Diameter Distributions

Readers should not conclude that area-based structures have reached common application in American silvicultural practice, or even that they have achieved strong research support. In practice, multiaged stand structures have been regulated by their diameter distributions, based on either of two assumptions: (1) that dbh and age are generally related, so that one can use the easily measured dbh as a surrogate for age, which is much more difficult to assess (Tubbs 1977); or (2) that trees, particularly shade-tolerant species, respond to treatments based on their size and that their chronological ages are thus largely irrelevant. Creating and maintaining the characteristic reverse-J diameter distribution using mathematical BDq (with basal area level (B), maximum diameter (D), and a q factor) (Guldin 1991) or empirical (Arbogast 1957) approaches are the hallmarks of this system.

Diameter-based methods rely on number and size of trees and thus control age structure and allocate growing space indirectly. Often, no attempt is made to control the regeneration process quantitatively; ingrowth is simply assumed to occur as long as the stocking level is appropriately low. Additionally, the use of a single q factor assumes constant mortality and growth across all size classes. Empirical structures do have the advantage of demonstrated short-term sustainability, but very few trials have been monitored over the equivalent of an entire even-aged rotation. With the notable exception of the Crossett Research Forest (Baker et al. 1996; Guldin and Baker 1998), our history of forest management in North America is simply not long enough for a meaningful assessment of multiaged stand dynamics and yield in many forest types.

If each cohort within a multiaged stand is viewed as a "ministand" with its own diameter distribution, each occupying an equal area, then the sum of these distributions for the entire stand takes on the reverse-J shape (Smith et al. 1997, p. 375). This does *not* mean, however, that all reverse-J distributions are multiaged, nor does it imply that other distribution forms, such as the rotated sigmoid, could not also characterize legitimately balanced multiaged stands. For example, it is very common for even-aged stands of mixed species to assume a reverse-J shape. In this case, the diameter classes reflect vertical canopy strata and shade tolerance, not age (Lorimer 1985; Marquis 1992; Smith et al. 1997, chapter 16). Repeated selection cuttings based on the overall diameter distribution alone, without accounting for species differences, can eventually result in a degraded stand of the most shade-tolerant species originally in the lower stratum. Such misapplication, often exacerbated by poor markets for small trees or low-value species, is a major reason why selection forestry became equated with highgrading and was discredited during the 1950s (Seymour 1995).

Learning from the Past

One of the motivations for defining new approaches to uneven-aged silviculture is dissatisfaction with past and current practices. Rigidity and apparent lack of biological rationale are common criticisms of the BDq method, and empirical structures exist for only a few forest types. Nevertheless, structures based on trees per hectare or basal areas by diameter class are relatively easy for practicing foresters to understand and apply. Before we discard traditional practices, we should step back and assess what we have learned.

One of the few long-term documented applications of the selection system in the Northeast is on the Penobscot Experimental Forest in the Acadian region of Maine—a transitional forest zone characterized by eastern hemlock *(Tsuga canadensis),* red spruce *(Picea rubens),* and balsam fir *(Abies balsamea)* in a mixture with hardwoods and other softwoods. The three major conifers are all very tolerant of shade and do not form obvious canopy strata, but they differ in other important respects that affect their management in mixture. Fir reproduces prolifically and grows somewhat faster than the others but is limited to a pathological rotation of 50 to 70 years because it is highly susceptible to decay. In contrast, spruce and hemlock are very long-lived—300 to 400 years. Spruce is an infrequent seed producer. Hemlock seed crops are frequent and abundant, and deer browsing is insufficient to inhibit hemlock regeneration, as in other parts of the Northeast. Fir is a major host of the spruce budworm *(Choristoneura fumiferana),* although hemlock and spruce are also defoliated.

The Penobscot Experimental Forest was established in the 1950s when industrial landowners purchased the property and leased it to the USDA Forest Service for long-term silvicultural research. The Forest Service installed replicated even- and uneven-aged silvicultural experiments and continues scheduled harvests and remeasurements. All silvicultural treatments follow a long-term study plan, and there are permanent fixed-radius sample plots in each compartment to record dbh, species, and condition of numbered trees at five-year intervals. The study reported here was managed by silviculturists Tom McLintock, Art Hart, and Bob Frank from 1952 through 1995.

The three selection treatments on the Penobscot vary in cutting cycle, residual basal area (BA) goal, and residual maximum diameter. These stands provide a unique opportunity to assess structure and growth in mixed conifer stands manipulated to conform to a q structure. With 40 years of data, we can now explore size and age distributions, area allocation, and sustainability as a case study in the application of q in mixed northern conifers.

Selection Cutting Experiments

The data we present are from one 6.5-hectare replicate of selection cutting on a five-year cutting cycle. The target structure has a q factor of 1.96 on 5-centimeter (2-inch) classes, a residual maximum diameter goal of 48 centimeters (19 inches), and a target residual BA of 26 m^2/ha (115 ft^2/ac). The study plan also provides for volume control, in which removals are tied to recent net periodic growth rates. Marking guidelines (in order of priority) include removing cull trees, removing poor-risk trees, thinning crop trees on three sides, and removing trees at financial maturity. Removing undesirable species and low-quality trees is also a priority. In practice, volume control took precedence over structural considerations, sometimes leading to cutting in deficit dbh classes that were dominated by high-risk fir or old, low-vigor spruce and hemlock. Creation of regeneration openings of one fourth to one third of an acre began in the 1980s, indicating a shift from single-tree to a hybrid single-tree and group selection method.

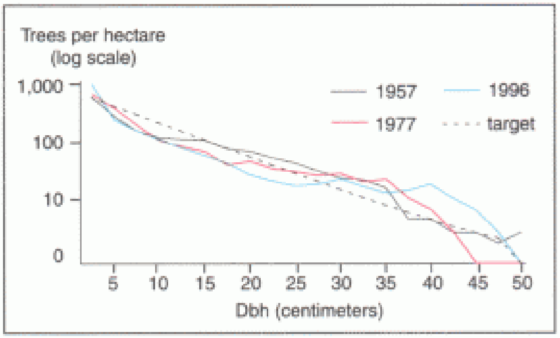

***Figure 2.* Changes in the diameter distribution from 1957 to 1996, relative to the target structure (BA = 26 m^2/ha, maximum dbh = 48 centimeters, q = 1.96). Note the developing deficits of pole-timber (10–25 centimeter dbh) and surpluses of sawlog trees.**

After 20 years of treatment, the overall stand structure was fairly close to the target, leading Frank and Blum (1978) to predict that the distribution would remain balanced thereafter. Deficits have since developed in the middle size classes, however, and a surplus of large trees has accumulated *(fig. 2).*

What Is the Problem?

Advocates of diameter-based structures could argue that the problem is not with the stand or its management, but with a target structure that is simply too steep. Indeed, reducing q to 1.66 fits the present distribution quite well. But does this really help us understand why the original structure could not be maintained or, more important, how to treat this stand in the future?

To identify the factors contributing to the imbalance, we took a random sample of hemlock, spruce, and fir. Sampling was stratified by 5-centimeter dbh classes across the range of diameters present, and age at breast height, dbh, and crown projection area were determined for each sample tree. Stand age structure and area occupied by each age class were calculated (Kenefic and Seymour, in press).

The underlying age structure, weighted by crown projection area *(fig. 3),* provides insight that is not appar-

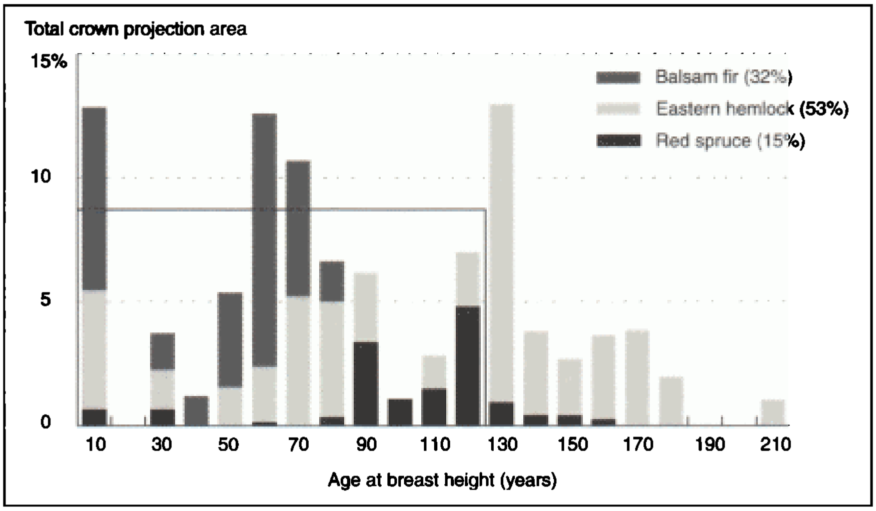

***Figure 3.* Distribution of growing space (using crown projection area as a surrogate) by 10-year age classes at breast height, by species. Total CPA = 14,315 m^2/ha, or at least 43 percent horizontal overlap. The rectangle shows a hypothetical equal area distribution, assuming trees reach the maximum dbh in 120 years.**

ent in the diameter distribution alone. Although all age classes except 20 are represented, the structure is distinctly unbalanced, with peaks at ages 10, 60, and 130. The total crown projection area is 14,315 m^2/ha, which means that at least 43 percent of the stand area is doubly occupied by tree crowns in different vertical strata. As a benchmark, we also show a hypothetical equal area age structure. This assumes that under management, spruce and hemlock can reach the maximum dbh of 48 centimeters in approximately 120 years (derived from *fig. 4*). (For simplicity we will use the same age for fir, even though it has a pathological rotation of perhaps half this age.) Each entry on a five-year cutting cycle should thus regenerate 5/120 of the stand area, or 8.3 percent per decade.

Assuming for the moment that the equal area model is appropriate, several problems are immediately evident. The most obvious is that until the last decade, insufficient space has been allocated to the regeneration of new cohorts. Although the eight entries made prior to our measurements should have regenerated 33 percent of the stand, only 18 percent of the total crown projection area (or 25 percent of the stand area, allowing for overlap) consists of trees less than 40 years old. The 20- to 50-year age classes are especially deficient, which suggests that the poletimber deficits that have materialized since the 1970s will only worsen during the next several decades. Furthermore, an inordinate amount (about 60 percent) of the young cohorts is fir, despite the intent to decrease the stocking of fir and increase the stocking of spruce.

Though very important relative to the stand's long-term sustainability, the lack of regeneration from 1955 to 1985 does not explain the increasing structural deficit in poletimber from 10 to 25 centimeters dbh *(fig. 2)*. According to *figure 4*, spruce trees of this size are 50 to 150 years old (hemlocks, 40 to 170 years old) and thus were present before the study even began. Consequently, deficits here are mainly the result of natural stand development, perhaps augmented by marking practices that quite logically emphasized tree vigor and quality over structure. Low-vigor intermediates were often cut from poletimber classes, regardless of whether they were in deficit, whereas larger, more vigorous upper-stratum trees were favored as growing stock.

Are the apparent poletimber deficit and the departure from the original *q* structure really a problem? It is interesting that the 60- to 120-year age classes collectively occupy 47 percent of the crown area (67 percent of the stand area), compared with the equal area goal of 58 percent—hardly a major imbalance *(fig. 3)*. As long as the 60-plus age classes are well tended to maintain growth, does it really matter which size classes provide this growth? In the aggregate, there appears to be sufficient area occupied by trees over 50 years old to sustain the total harvest for several decades, although an increasing proportion of it will be hemlock. We cannot plan on carrying the 50- to 70-year-old fir much longer; the question here is whether released growing space can be occupied by hemlocks of similar age.

Finally, it is worth noting that the *q* structure has *not* automatically provided for steady ingrowth into the 10-centimeter dbh class. Ironically, the most serious structural deficits (in terms of age, not size) were created during the early years, when the stand best conformed to the target. Although the ultimate consequences of this discrepancy will not become clear for several decades, it is another example of how conformance to *q* may create a false sense of stability.

We might conclude differently if a nonuniform model of allocating growing space (such as *fig. 1*) were the frame of reference. In particular, the deficits in 20- to 50-year classes would not be as severe, but the area in the 10-year class would be grossly excessive. Our purpose here is not to argue the merits of a particular area distribution model—that is a critical subject of future research—but to illustrate the value of using direct age structures to understand the dynamics of, and suggest treatments for, multiaged stands.

Future Options

In this study, major underlying imbalances in age structure did not become evident in the diameter distribution until several decades after it was too late to respond to the deficit. This point, perhaps more than any other, highlights what we see as the most significant shortcoming of *q*-based or empirical approaches to regulating multiaged stands. Our preferred approach—

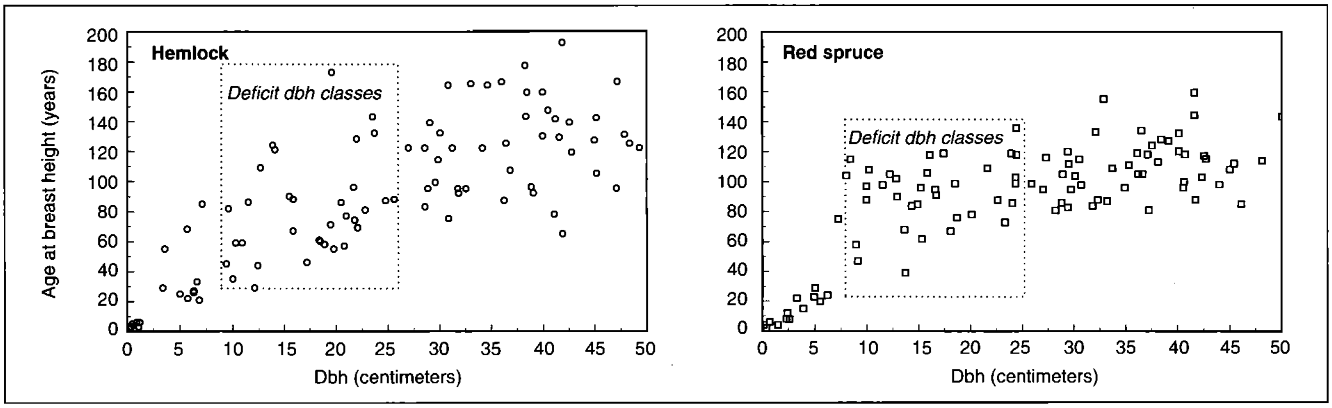

***Figure 4.* Relationship between dbh and breast-height age for eastern hemlock and red spruce, highlighting dbh classes that have developed deficits relative to the target structure.**

analysis of the age structure—shows clearly that the challenge is to continue tending the increasingly mature age classes to maintain their growth while simultaneously allocating a disciplined amount of growing space to regenerating cohorts. The first objective is arguably best achieved by continuing the past practice of thinning aging cohorts from below, even though this would continue to accumulate deficits relative to the q structure. The alternative—strict adherence to a target q structure, even one that is revised downward—could only be accomplished by cutting larger, more dominant individuals to favor weak pole-sized trees that happen to be in deficit. Short-term periodic increments would likely fall, thus reducing future harvests. It is also possible that concentrating the cut on larger trees could create excessive areas under regeneration, overcompensating for deficiencies of the past.

We are only beginning to understand the nature of multiaged stand dynamics and the response of complex forest systems to various types of selection cutting. Traditional hypotheses regarding associations between "balanced" diameter distributions and sustainability need to be reassessed, particularly in light of emerging information about age-diameter relationships and shared growing space in mixed-species stands. The challenge facing us now is to find a way to translate conceptual discussions of structural control based on age structure and crown area back into easily measured variables, such as dbh and trees per hectare, so that theoretical advances in the application of the selection system can become practical advances as well. The intricacies of simultaneously harvesting mature trees, regenerating a new age class, and releasing trees in existing cohorts ensure that the selection system will remain very much an art.

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