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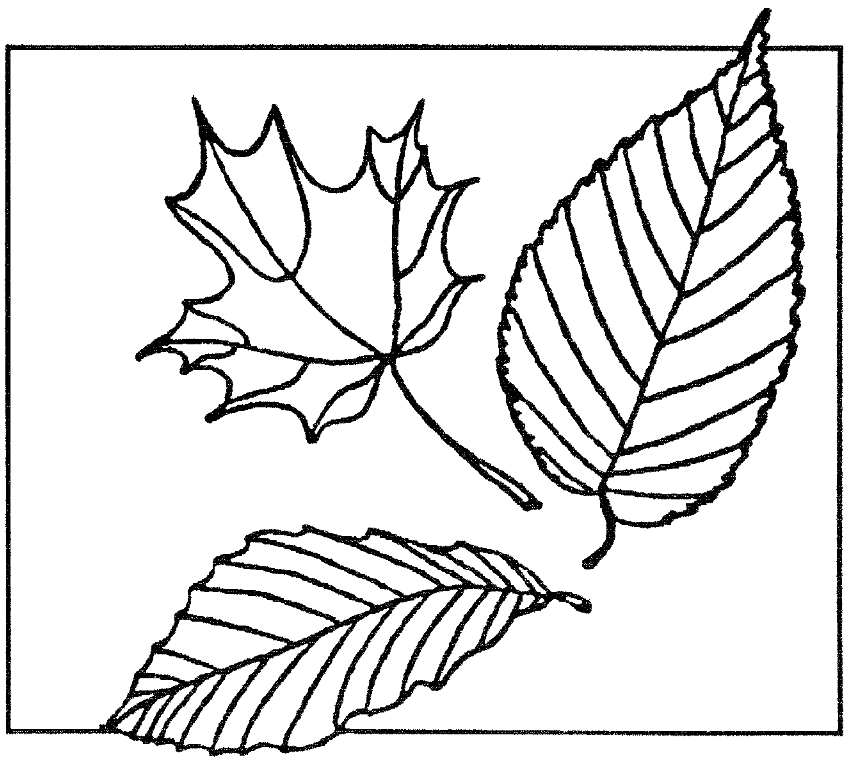
New Perspectives on Silvicultural Management of Northern Hardwoods

Proceedings of the 1988 Symposium on the Conflicting Consequences of Practicing Northern Hardwood Silviculture



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NEW PERSPECTIVES ON SILVICULTURAL MANAGEMENT OF NORTHERN HARDWOODS

PROCEEDINGS OF THE 1988 SYMPOSIUM ON THE CONFLICTING CONSEQUENCES OF PRACTICING NORTHERN HARDWOOD SILVICULTURE

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INTRODUCTION

Silvicultural guidelines developed by forestry research are widely used as the basis for stand management. After attending recent symposia, it occurred to our planning committee that foresters often receive conflicting advice from the scientific community. At a recent symposium, a silviculturalist presented a well-reasoned and well-presented case for the uneven-age management of northern hardwoods with entries into the stand every decade or so. The next day, a pathologist gave an equally well-documented paper explaining that repeated entries into the stand might lead to deterioration of the stand from harvest-related diseases within two or three rotations.

The objective of our symposium was to discuss the combined influences of sites, nutrients, pathology, entomology, equipment technology, and economics on the choice of a silvicultural system for the management of northern hardwood forests. All of these factors should be considered and should influence the prescriptions developed for the management of forest stands, However, foresters and specialists in each of these disciplines seldom have the opportunity to discuss these issues at one time and place.

Our symposium took a novel approach. In order to provide a common background for discussion, the symposium began with a paper summarizing the history, range, and present quality of the northern hardwood forest type. The next paper provided a forecast of future demands for northern hardwood forest products. Then experts in silviculture (even-age and uneven-age), site selection, nutrient cycling, pathology, entomology, engineering, and economics presented papers in their fields of expertise, stressing the advantages and disadvantages of even-age and uneven-age management. There was ample time for questions at the end of each paper. After all papers were presented, the speakers were assembled to allow the audience to question all of the participants and to foster discussions between the speakers and between the speakers and the audience.

We hope this approach will have several results: 1) to make foresters aware of ramifications that they may not have considered, 2) to help specialists to think in broader terms, 3) to discuss these combined issues and to make recommendations that will be new and useful to the practicing forester as well as the scientific community.

These proceedings contain the invited papers presented at the symposium and contributed poster papers. The invited papers have been reviewed by at least two peers. The final chapter is a summary of the sense of the meeting.

THE NORTHERN HARDWOOD RESOURCE: SOME SILVICULTURAL IMPLICATIONS OF ITS HISTORICAL DEVELOPMENT AND CURRENT STRUCTURE

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The historical development and current structure of the northern hardwood resource in the northeastern and north-central United States is reviewed. New analyses of previously unpublished data obtained by the USDA Forest Service for Maine illustrate that this resource is diverse in species composition and is dominated by less-than-fully stocked, irregular stands. The most common type of harvesting activity has been heavy partial cuttings, nearly half of which leave residual stocking below the C level. It is postulated that most northern hardwood stand structures have resulted from neither the classical even-aged nor the balanced uneven-aged silvicultural systems, but rather are consistent with an irregular shelterwood system in which stand structures contain two overlapping age classes.

Scope

The purpose of this paper is to review the current status and recent trends in the development of the northern hardwood resource from the standpoint of its past and future silvicultural treatment. For the purpose of this paper, the "northern hardwood type" is the USDA Forest Service's "maple-beech-birch" type in the Northeast or the "maple-birch" type in the Lake States region. This definition agrees closely with the most recent compilation of forest types by the Society of American Foresters (Eyre 1980), in which "northern hardwoods" include six regionally important sub-types: sugar maple; sugar maple-beech-yellow birch; sugar maple-basswood; black cherry-maple; beech-sugar maple; and red maple. Leak et al (1987) recently developed a different sub-type grouping for the Northeast, which is adopted for some analyses presented below. In all cases, the most distinctive feature of this type throughout its range is the presence of the maples, especially sugar maple as an important component of stand composition. The "aspen-birch" type, considered by Eyre (1980) to be in the "boreal hardwood" category, is excluded, even though this type is often an earlier successional stage of the maple-dominated northern hardwood association, especially in the Lake States. Emphasis is on the northern hardwood type in the Northeast; readers seeking additional details on the Lake States should consult the recent review of Spencer (1986).

Resource Characteristics

Area

In 1977 (the date of the most recent national timber assessment) the northern hardwood type occupied over 36 million acres, or 10% of all forest land in the eastern United States (USDA Forest Service 1982). Recent surveys (Considine and Frieswyk 1982; Frieswyk and Malley 1985a, 1985b; Hahn and Smith 1987; Powell and Dickson 1984; Raile 1985; Raile and Smith 1983; Smith and Hahn 1986) suggest that northern hardwoods have increased significantly in area in many northern states; Michigan and Wisconsin gained a total of over 1.3 million acres (a 16% increase) between 1966-68 and 1980-83. Northern hardwood is the most abundant type in the Northeast, and is second only to aspen-birch in the Lake States. Together, these two regions include 89% of all northern hardwood stands in the U. S. Northern New England (Maine, New Hampshire and Vermont) and New York alone contain over half of the total type area; much of the rest is located in Michigan and Wisconsin (Figure 1).

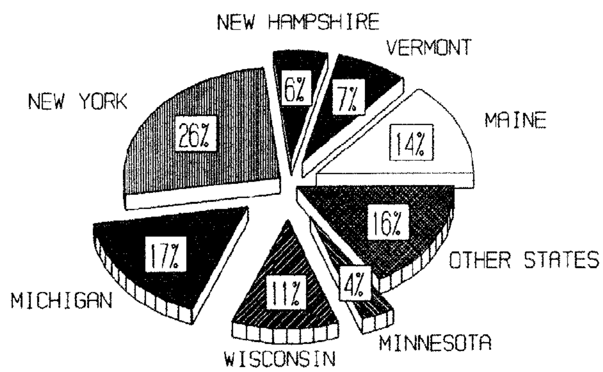


Figure 1. Distribution of the northern hardwood forest type by state. [Total area = 36.246 million acres in 1977 (USDA Forest Service 1982)].

Species Composition

One can readily see from Figure 2 why the northern hardwoods are known as "maple-beech-yellow birch" in the Northeast; together, these species comprise 73% of all growing stock volume in this type. Compared to the Lake States, the Northeast has more red maple, beech, and yellow birch, and much less basswood and aspen. Sugar maple appears to be the only major species that is similar in abundance between regions. White ash, paper birch, and red oak also comprise a small, but economically valuable, component throughout the type.

Historical Development

Growing Stock Inventories

With few exceptions, trends in growing stock inventories for the six most abundant species in the six dominant northern

Figure 2. Species composition (based on growing stock volume) of the northern hardwood type in the Northeast and the Lake States.

hardwood states have been very positive. Since ca. 1970, the maples, paper birch, and white ash increased in all states (Fig. 3). Beech also increased in every state except Maine and Michigan, where slight declines were evident. Yellow birch increased in all northeastern states but declined slightly in the Lake States. These dramatic increases are the result of growth exceeding harvest, often by a substantial amount, and suggest that (with the possible exception of Maine, where trends are much flatter) the northern hardwood forest has been underutilized. While this may be the case, determining the appropriate growth/harvest balance is rendered more complicated by the fact that age/size-class structures are strongly unbalanced.

Forest Structure
The northern hardwood forest in the Northeast is dominated by sawtimber-size stands (Figure 4). [A "sawtimber" stand is defined as one in which poletimber and sawtimber trees (for hardwoods, 11.0 inches dbh or larger, of growing stock quality) comprise at least half of the stocking, and in which sawtimber stocking is greater than poletimber.] The dominance of sawtimber is offset by a paucity of seedling/sapling size stands, especially in the New England States. In contrast, the Lake States' northern hardwood forests are still dominated by poletimber, and have a much higher proportion of younger stands.

These structures have not been static. Between 1971-73 and 1982-83, the area of seedling/sapling stands in Maine and New Hampshire dropped by nearly half, as these stands grew to poletimber size. Sawtimber posted strong gains, as many poletimber stands matured (Figure 5). The area in poletimber (not shown) remained fairly stable in these states, but only because ingrowth of seedling/sapling stands offset development into sawtimber. This maturation is even more evident in the 1959-82 change in Maine which spans all three surveys of the State (Figure 6). Note that Maine's northern hardwood forest of 1959 is similar to Michigan's and Wisconsin's of today, suggesting that the Lake States northern hardwood forests are moving along a similar, but delayed, developmental track.

Stand Origins
The structural changes reviewed above reinforce the hypothesis that the northern hardwood forests are experiencing a maturation process similar to that in other forest types in the Northeast (Seymour et al. 1986). In effect, silviculturists are now dealing with a rapidly maturing forest that probably originated after one of several widespread phenomena that coincidentally peaked within a decade of the turn of the century: heavy cutting of the old-growth timber beginning in the late 1800's and culminating ca. 1940; cessation of fuelwood coppice cutting when coal and oil replaced wood as the dominant domestic fuel; or continual abandonment of agricultural land which has since reverted to forest. Like other forest types in the Northeast, very little of the current northern hardwood forest developed as a result of deliberate silvicultural activity.

These events which created today's forests largely pre-date the first accurate forest surveys, which have shown relatively small increases in the northern hardwood area. If the northern hardwood type had been measured in 1930, for example, a very different structure would have been found, with much more area in young, second-growth or old-field stands, little of the immature pole/sawtimber that dominates today, and some old-growth sawtimber stands in the more remote, mountainous areas that had escaped earlier cutting and land-clearing. Forest inventories that

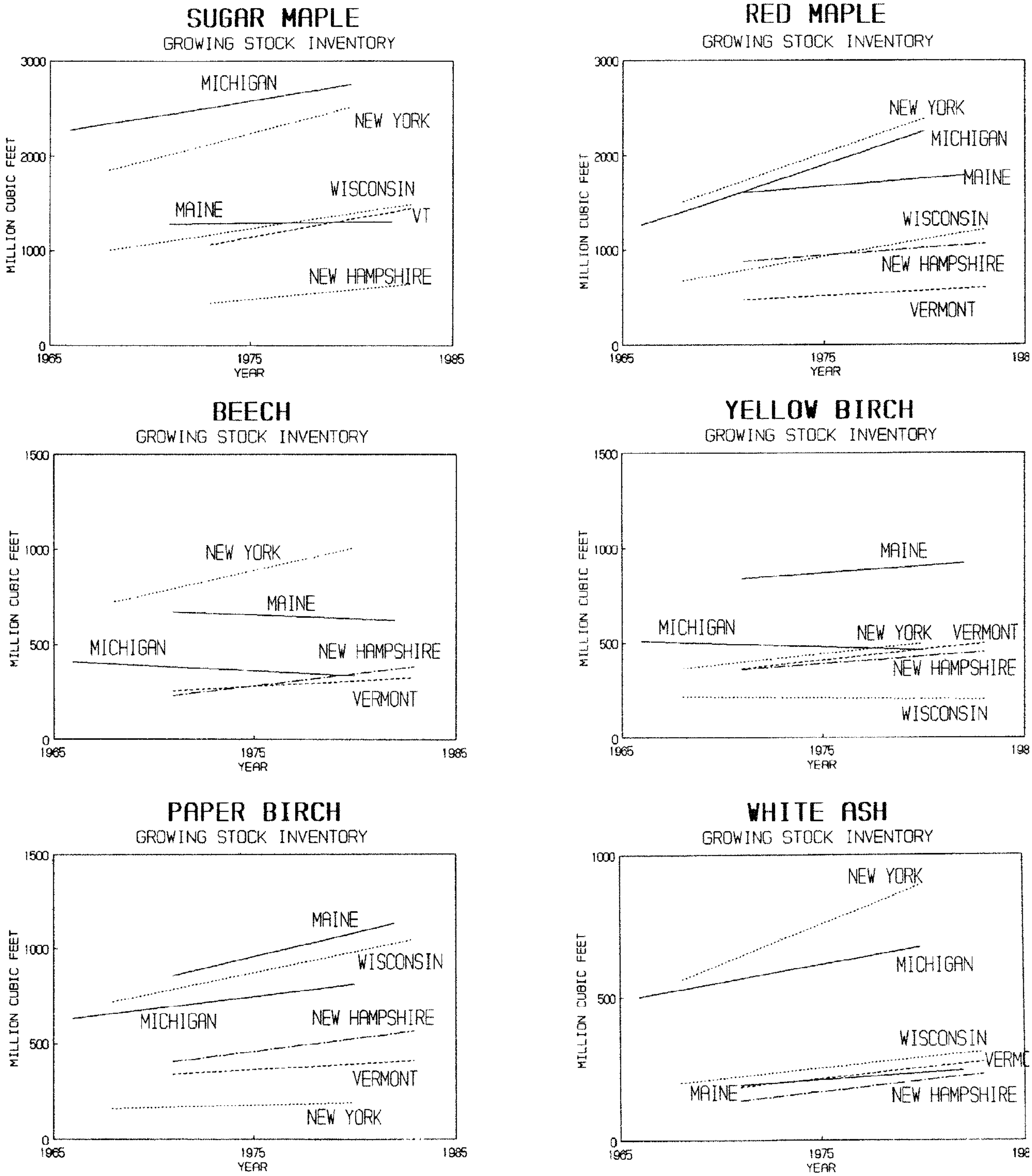
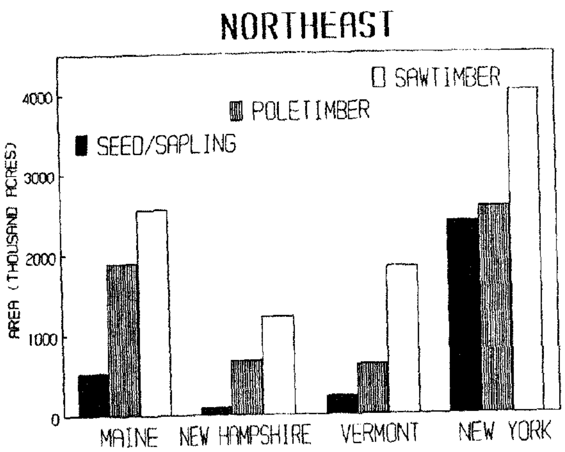


Figure 3. Recent trends in growing stock inventories of the six most abundant northern hardwood species, by state. [Volumes include all forest types; sources in Literature Cited.]



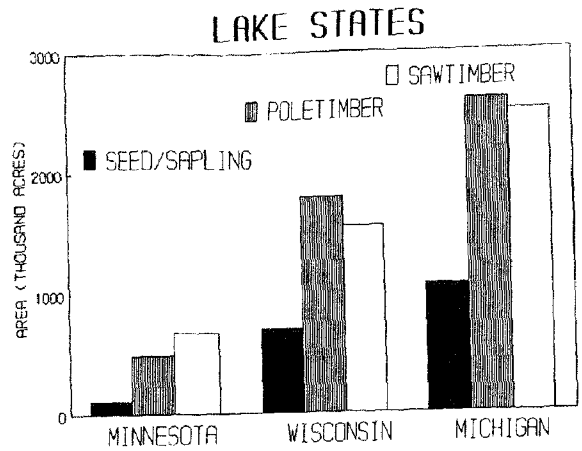
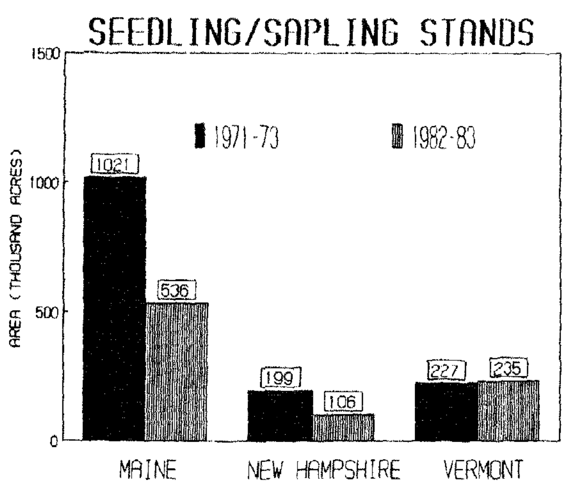


Figure 4. Size-class structure of the northern hardwood type in the Northeast and Lake States, by state.



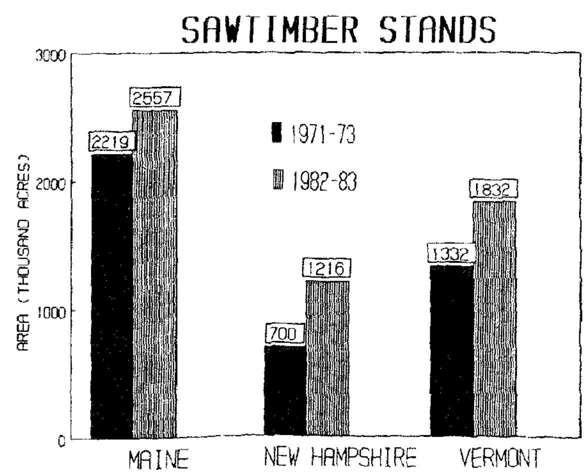


Figure 5. Ten-year change in the area of northern hardwood seedling-sapling and sawtimber stands, northern New England states.

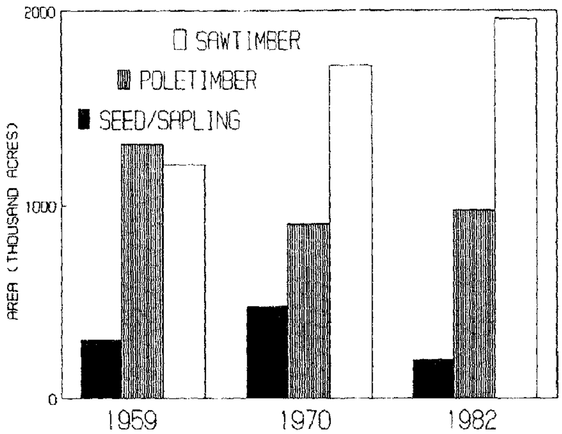


Figure 6. Twenty-three year change in size-class structure of Maine's northern hardwood type.

began ca. 1950 have coincided with the period when ingrowth across size-class thresholds (5.0" for poletimber; 11.0" for hardwood sawtimber) is most evident. When viewed in this developmental perspective, it is not surprising that these surveys have shown dramatic increases in growing stock inventories. In effect, the forest is maturing faster than industrial capacity has developed to utilize it.

Current Status

In order to elucidate certain silviculturally important characteristics of the northern hardwood resources that are not evident in the traditional mensurational assessments, data for the 1980-82 inventory of Maine were obtained from the USDA Forest Service's Forest Inventory and Analysis (FIA) Unit at Broomall, Pennsylvania. All plots that were classified as one of the variants of the "northern hardwood" type (codes 81, 84, 88 and 89) were included. Each "plot" in the FIA sampling design consists of a cluster of five points (one fixed-radius and four prism points) covering approximately one acre. Plots were further classified into one of the three sub-types distinguished in the latest northern hardwood silvicultural guide (Leak et al. 1987) according to the basal area of overstory species.

Species Composition

The sub-types of Leak et al. (1987) account for 85% of the northern hardwood area in Maine (Figure 7) which totals nearly 5 million acres. No sub-type is clearly dominant; the mixed conifer-hardwood (MW) type slightly exceeds the sugar maple-beech-yellow birch (SM-Be-YB) type. One would expect MW to decline in importance as one moved west and south into Vermont and New York, with corresponding increases in the SM-Be-YB type.

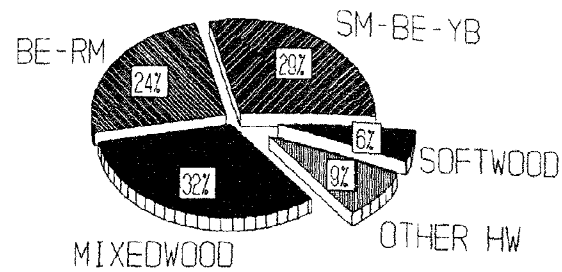


Figure 7. Distribution of Maine's northern hardwood forest by the sub-types of Leak et al (1987).

FIA reports give an accurate description of the average composition of broad types, but do not describe the occurrence and distribution of species. Figure 8 shows the occurrence of the major and minor overstory hardwoods, overstory conifers, and understory saplings, by sub-type in Maine. A species was counted as "present" if a single overstory tree was tallied anywhere in the 5-point cluster plot. Since these data are not a complete tally on the one-acre sampled, they should be interpreted as estimates of the lower end of a confidence interval about the true occurrence. The actual figure, if the entire acre were enumerated, would be somewhat higher, especially in the case of understory saplings which are tallied only on a mil-acre plot at each of the five points (only a 0.5% sample).

Although yellow birch and beech are much less abundant in terms of total growing stock volume (Figure 3), apparently they occur in just as many northern hardwood stands as the more abundant maples (cf. "all sub- types", Figure 8a). In fact, beech and yellow birch outnumber red maple in the SM-Be-YB sub-type, and outnumber sugar maple in the Beech-Red Maple (Be-RM) sub-type, suggesting that the maple species have a greater tendency to occur in associa tion with species outside their genus. Also note that beech is significantly more common in the SM-Be-YB sub-type (70%) compared to the Be-RM sub-type; apparently, the latter is somewhat of a misnomer and should be termed th "Red maple-beech" sub-type to more accurately reflect species distribution in Maine.

Other hardwood species are less common, but often represent important silvicultural opportunities due to their high value. Northern red oak is virtually absent from the SM-Be-YB sub-type: this species is most common in the Be-RM type, as is paper birch (Figure 8b). These specie tend to be associated with a history of more frequent or more severe disturbance, which confirms Leak et al. (198 observation that the Be-RM sub-type tends to have a

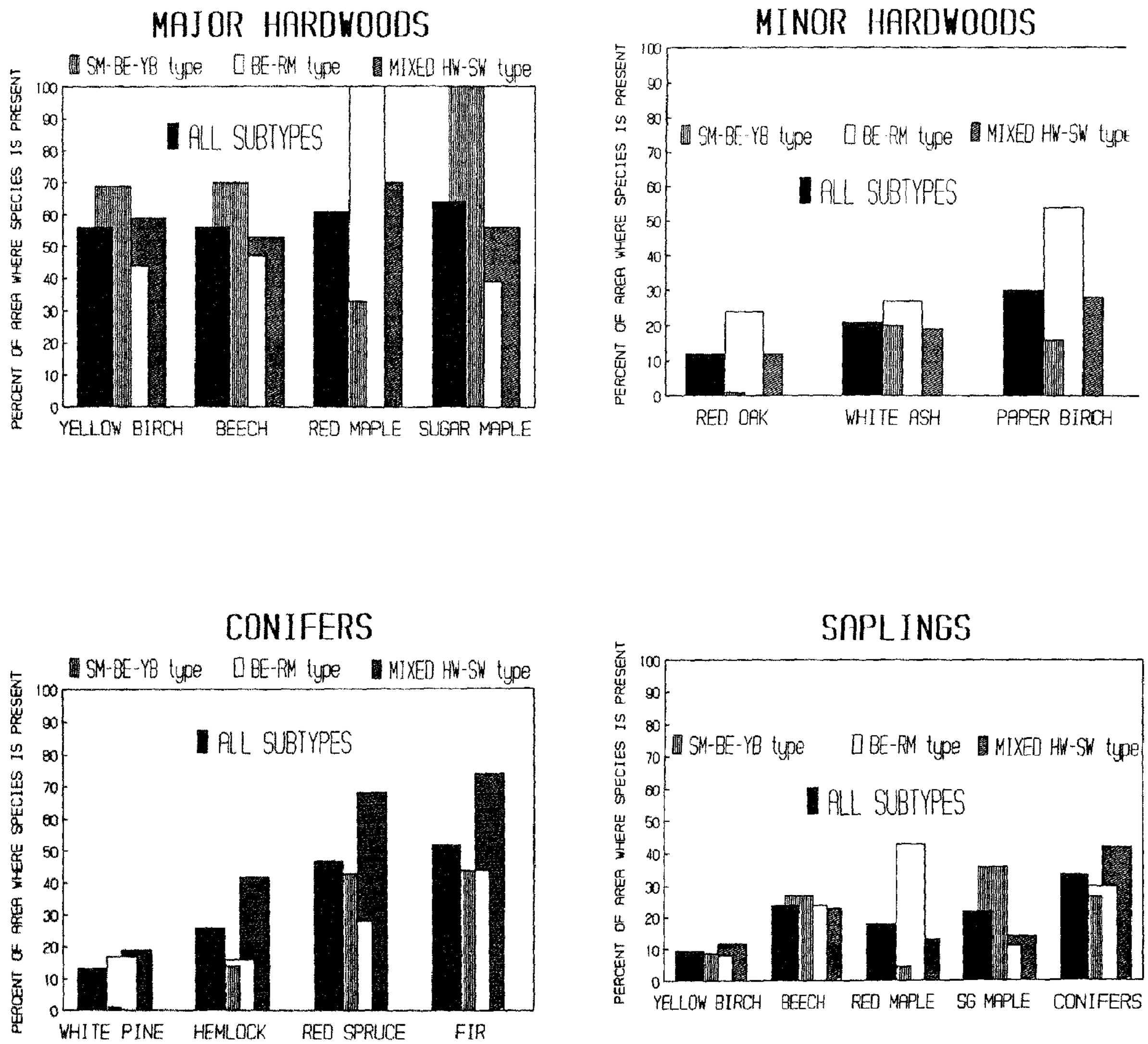


Figure 8. Occurrence of various species by sub-type, Maine, 1982. a. Major hardwood species. b. Minor, high-value hardwoods. c. Conifers. d. Saplings.

greater disturbance history than the others. White ash occurs equally in all sub-types. By definition, conifers are most common in the MW sub-type, but represent an important component throughout the type (Figure 8c). Red spruce is more common in the SM-Be-YB sub-type than in the Be-RM, while balsam fir and eastern hemlock are equally represented in both. Eastern white pine is the least abundant conifer in the northern hardwood type and, like red oak, exists mainly in the Be-RM and MW sub- types.

Data on the occurrence of saplings (1.0 to 4.9 inches dbh) are subject to high sampling error due to the small sample size, yet some interesting trends are apparent. Conifers as a group are more common than any single hardwood species; beech is the most common hardwood, and is equally distributed in all sub-types. The maples exhibit relationships similar to those for the overstory. Yellow birch, which is intermediate in shade tolerance, is less common than its more tolerant associates. The occurrence of a single sapling in this sample would equal 200 stems per acre; thus, if a species is "absent" from this sample, it means that its true density is somewhat under 200 per acre. Viewed in this manner, these data (the area on which a given species was not observed in the 0.005-acre sample) suggest that much of the northern hardwood type does not have the well-developed understory (several hundred stems per acre) of commercial species that characterizes the selection or shelterwood systems of silviculture.

Stocking

Basal areas per acre of overstory growing stock trees and saplings were grouped into classes that correspond approximately with those on the northern hardwood stocking guide in Leak et al. (1987). Considering the dominance of saw- and poletimber size classes, results are surprising: over one third of the stands are stocked below the C level, and another 37% are stocked near the B level (the lower limit of full site occupancy) (Figure 9). Only 29% are sufficiently stocked (over 75 ft^2 per acre) to enable a commercial harvest without understocking the stand. This situation contrasts with data given in Table 13 of Powell and Dickson (1984), which shows a much greater percentage of "overstocked" stands and very little "understocked" area (Figure 9). Powell (personal communication, 1988) verified that this difference is due to a less restrictive definition of stocking used by the Forest Service FIA reports. FIA stocking standards begin with overstory basal area, but give added weight to saplings (and seedlings, if necessary) if the overstory is not fully stocked. The FIA definition is thus an index of whether trees <u>of any size</u> occupy the plot, and differs greatly from the more conventional overstory basal area (used in stocking guides) in stands which have an irregular, storied structure.

When stands are sorted by their harvest history, nearly half of the stands that were partially cut during the 10 years prior to measurement are stocked below the C level (Fig. 10). Heavy partial cutting, leaving residual stands that would be considered understocked by conventional criteria, evidently is a very common practice in this type in Maine. Even with partially cut stands removed, the percentage of harvestable stands increases only to 34%; 27% of the stands with no recent history of harvest are understocked (below the C level).

Silvicultural Treatment Needs vs. Actual Harvest History

During plot measurement, field crews were asked to prescribe the most appropriate silvicultural treatment for the

Figure 9. Distribution of Maine's northern hardwood type by stocking-guide basal-area classes (square feet per acre of growing stock and saplings) compared to stocking levels determined by the USDA Forest Service's Forest Inventory and Analysis (FIA) system (from Powell and Dickson 1984).

stand. According to this assessment, nearly two-thirds warranted no treatment whatsoever (Fig. 11). Harvesting of some type was deemed appropriate on only 31% of the area. This percentage is surprisingly low considering the dominance of sawtimber stands, yet is very consistent with the 29% found to be harvestable using the distribution by stocking classes (Fig. 9). Also surprising is the finding that only 700,000 acres — less than 16% of the pole- and sawtimber area — apparently "need" commercial thinning or improvement cutting.

Field crews also noted any harvesting activity that took place during the past 10 years. Slightly over one-fourth of the area in the three sub- types was subjected to some kind of harvest during the 1970's (Fig. 12). Partial cutting was about four times as common as clearcutting (both terms defined in the context of harvesting, not silviculture). Data reviewed above (*Figure* 10) suggest that at least half of these partial cuttings are heavy enough to regenerate new age classes, although their usual intent is strictly to harvest merchantable timber. At these rates, the effective partial cutting cycle would equal about 50 years (ca. 2% per year, assuming all area eventually is harvested). Clearcuts affected ca. 0.5% per year, equivalent to an even-aged rotation of ca. 200 years.

Age Structure

Stand age structure not only defines the system of silviculture that has been practiced (albeit unintentionally), it also limits future treatment options. As such, age structure is perhaps the most important attribute of the northern hardwood resource relative to the theme of this conference. During the 1980-82 inventory, stands were classified into 20- year age classes (except for the 1-10 class), or were tallied as "two- storied" or "uneven-aged", with no further definition of the age classes present. Using this system, the majority of all stands (between 60 and 72%, depending on sub type) fall into the "uneven-aged" category, with an additional 5-10% in the "two-storied" class (Fig. 13). Most of the remaining, even-aged area occurs as middle-aged stands between 30 and 90. Quite surprisingly, only 28,000 acres (out of 5 million) exist as even- aged stands under age 30, all of which is in the beech-red maple sub-type.

Figure 13 unquestionably supports the contention that the northern hardwood forest is maturing, but is difficult to reconcile with the fact that seedling/sapling stands still account for over 500,000 acres (Figure 4). Much of the seedling/sapling size class must exist as part of irregular stands with "uneven-aged" structures. Simple single-storied even aged stands are clearly the exception rather than the rule, especially in the younger age classes.

To explore the origin of this apparent discrepancy, each age class was further classified according to its harvest history (*Figure* 14). FIA crews distinguished three types of cutting in Maine: clearcutting in blocks; clearcutting in strips; and partial or "selective" cutting. For this analysis, strip clearcuts were excluded; "clearcuts" discussed below thus represent block cuts only. As expected, most (70%) of the partial cuts fall outside the even-aged classes, although 267,000 partially cut acres were tallied as even-aged stands. One would expect most of the stands clearcut during the past 10 years to be even-aged 1-10 year-old stands, yet only 14% actually registered in this class. Nearly 70% of the recent clearcuts were considered to be uneven-aged or two-storied, the same proportion as the partially cut stands. Even more puzzling is the finding that 17% of the recent clearcuts resulted in <u>even-aged</u>, 51-90-year-old stands!

In considering these results, it is important to understand the field procedures used to assess age structure. On each plot, four increment cores were taken (if trees were available). If multiple age classes were present (including saplings which would probably not be cored, but assumed to be younger than any overstory trees), the crew simply tallied the stand as "uneven-aged". Specific age classes were not recorded. Also, rings were counted all the way to the pith, including any suppressed core of narrow rings formed prior to a releasing disturbance when the tree was growing as an advance sapling in the understory of the previous stand. This procedure could distinguish several <u>total</u>-age classes when all trees are effectively the same age when dated from a common release. Given the difficulties in extracting cores and counting rings in the field on dense, diffuse-porous species such as the maples and beech, the natural tendency would be to consider any stand with an irregular structure or mixed- species composition as "uneven-aged", leading to a bias in favor of this category. As Smith (these proceedings) notes, many even-aged mixed hardwood stands can form highly stratified mixtures that can appear multi-aged on the basis of casual inspection.

A Model of Stand Development

While the vagaries inherent in the field procedures leave unresolved the matter of the true distribution of age classes, it is clear from the data reviewed above that Maine's current northern hardwood forest is complex in both composition and structure. Although this forest has been affected little by intentional silvicultural activity, it has been strongly influenced by the activities of man as well as nature. Reversion of abandoned farmland and heavy cutting at infrequent intervals appear to be the dominant activities controlling stand development.

These activities have created forests that are usually far from the silvicultural ideal, whatever their age structure might be. However, the development of this forest in

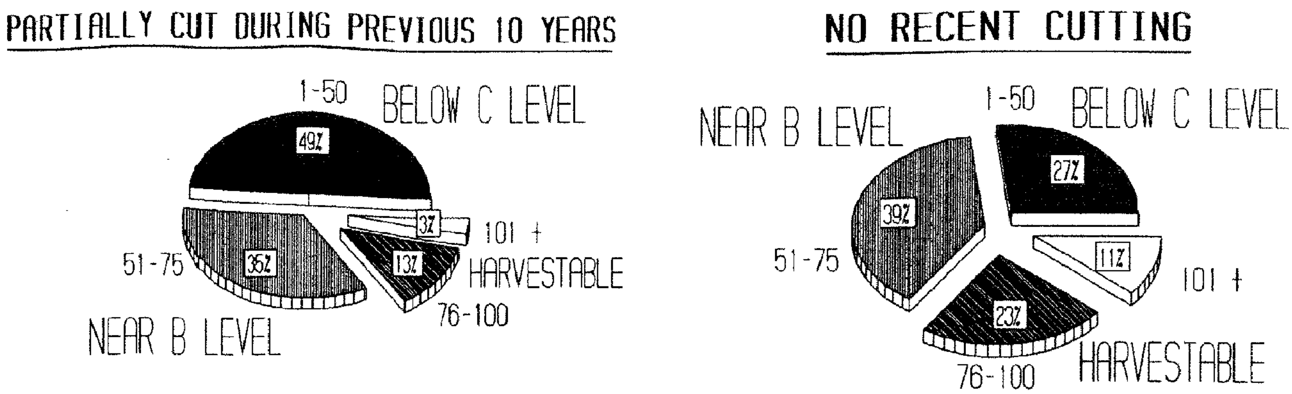


Figure 10. Distribution of Maine's northern hardwood type by stocking-guide basal-area classes, by 10-year harvest history.

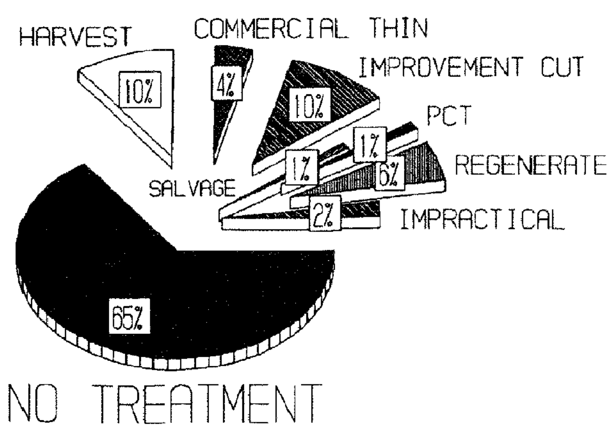


Figure 11. Silvicultural treatment needs of Maine's northern hardwood type, 1982.

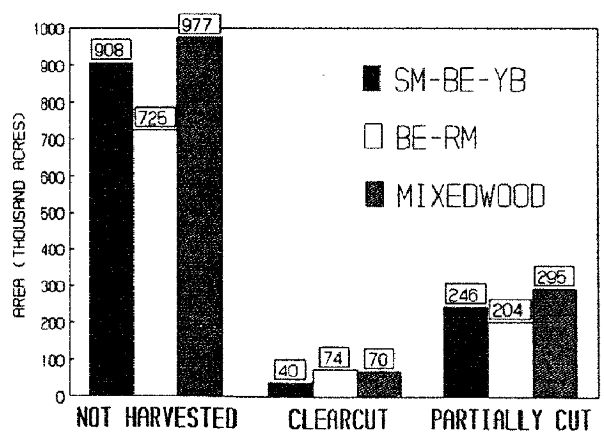


Figure 12. Harvest history (ca. 1970-1980) of Maine's northern hardwood type, by sub-type.

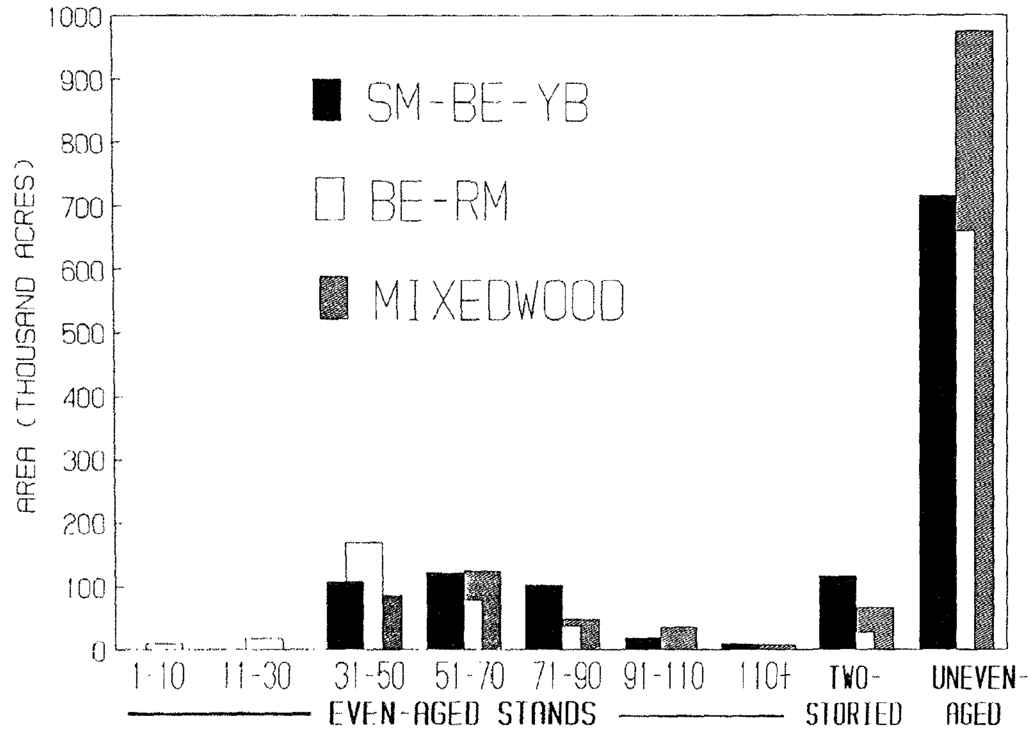


Figure 13. Age structure of Maine's northern hardwood forest by sub-type.

response to this treatment offers silviculturists a point of departure for designing silvicultural systems to improve the northern hardwood growing stock and regeneration. With this in mind, I offer the following hypothesis of stand development in this type.

Given their origin, one would expect northern hardwood stands to contain distinct age classes that coincide with the timing of the disturbances that released them. But, data reviewed above suggest that if even-aged stands exist, they are obscured, perhaps more so than in other forest types which exhibit a more clearly defined even-aged development. However, these irregular stand structures can be explained with an essentially even-aged model if one assumes that the major disturbances do regenerate new age classes but often do not completely eliminate the mature age class(es). As a result, any given acre typically contains two (or perhaps more) distinct age classes: some "hold-over" trees that survive the harvest or natural disturbance, intermixed with a younger age class originating from it.

It is easy to imagine heavy diameter-limit cuttings (a common practice in hardwoods) producing such a result. Consider a stand with two age classes: one in which all trees are merchantable, and one immature class with only some species or individuals having reached merchantable size. Immediately after a heavy partial cutting from above in such a stand, a single, understocked age class would remain. This is a possible origin of the area subjected to partial cutting during the past 10 years that is classified as middle-aged, even-aged stands, and is consistent with the finding that half of all partial cuttings understock the stand below the C level. As the new age class of regeneration develops, the stand once again becomes at least two-aged. When the likelihood that both age classes will form stratified species mixtures is added, it is not surprising that such stands would be classified as "uneven-aged".

This type of extensive management rarely creates either truly even- aged stands or balanced, uneven-aged stands. Indeed, one could argue that these classical silvicultural models do not adequately describe much of what actually goes on in the "real world". The closest silvicultural

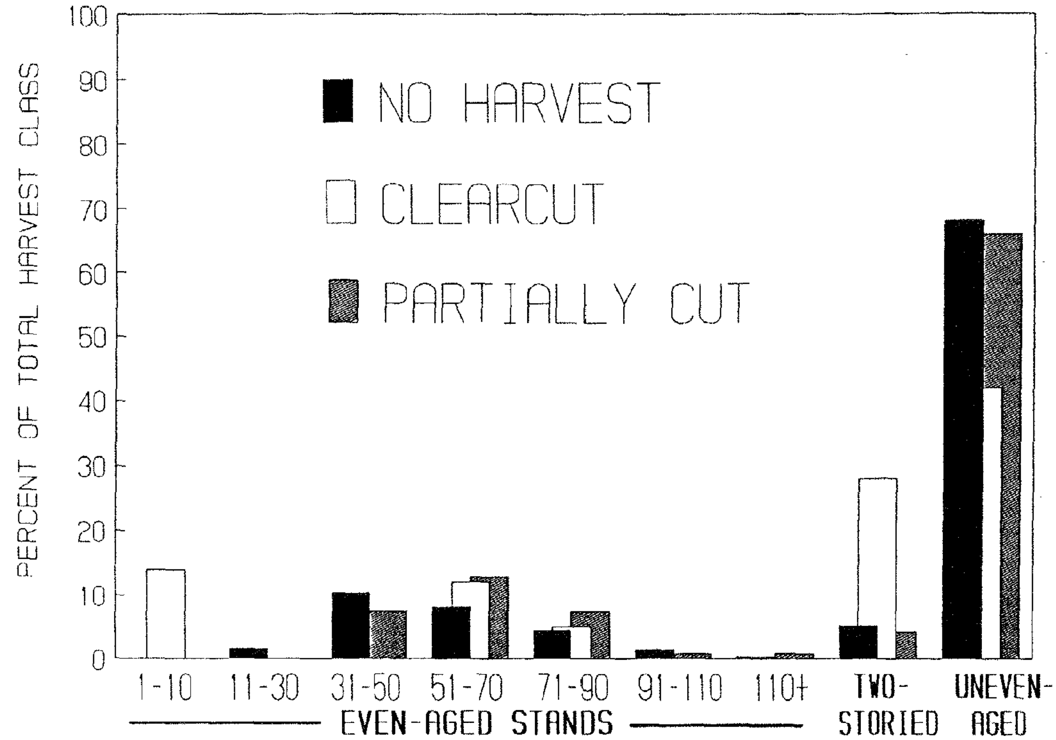


Figure 14. Age structure of Maine's northern hardwood forest by 10-year harvest history.

analogue is probably the irregular shelterwood method, in which the removal cuttings are not completed until well into, or even at the end of, the next rotation. This is essentially an even-aged model, with the relaxed provision that the stand may contain two age classes over at least part of the rotation. The spatial extent of the age classes may be quite extensive, both of which could easily occupy thousands of acres. Marquis (1981) has documented clear evidence of this developmental pattern after heavy chemical-wood cuttings in the cherry-maple type of the Alleghenies, and it is probably common elsewhere, although perhaps less distinct. It is important to note that the group selection model, in which the age classes are small, clearly defined spatially, and mutually exclusive of others, does not mimic these dynamics.

The foregoing is not an argument that future silvicultural practices must somehow be designed to perpetuate a stand development pattern that has resulted from largely economic constraints on forest management, where only the biggest and best trees could be cut. However, two important ecological properties of the northern hardwood species — their dependence on advance reproduction (except birches), and their ability to respond to release after persisting in subdominant canopy strata for long periods — argue in favor of something other than simple even-aged management using clearcutting. An irregular shelterwood system, in which stands contain two age classes during much or all of the rotation, allows silviculturists to take advantage of these properties without the added complexity involved with pursuing truly uneven-aged stand structures with balanced diameter distributions.

Future Silvicultural Implications

The past several decades have witnessed an unprecedented maturation of forests throughout the Northeast (Seymour et al. 1986), including the northern hardwoods. This trend obviously cannot continue indefinitely. Many forest types, including northern hardwoods, have depended heavily on old-field reversion for creating young age classes. In New England, this important trend is largely over; currently, farm fields taken out of production commonly revert to suburban house lots or subdivisions, not forests. Even without the current development pressure, this region is becoming "saturated" with forest land, with less and less farmland to be abandoned. Harvesting activity will thus become the dominant method of regenerating new stands. Because stand composition is largely determined during the regeneration phase, professional attention should focus on controlling these harvest cuttings in a manner that will ensure a high-quality forest for the 21st century.

The maturing forest may also lead to mill expansions designed to take advantage of the widespread abundance of mature timber. Indeed, this is already underway in Maine and other parts of the Northeast, and may spread to other, historically underutilized localities if the public's taste in furniture shifts away from the ring-porous species to the maples and birches. While this is unlikely to lead to wholesale liquidation of millions of acres of maple sawtimber, it will probably create additional harvesting pressure on a resource that does not have a history of silvicultural treatment. Wood-energy markets and biomass harvesting may also lead to more frequent, intensive stand entries. Without compensatory silvicultural treatments with strong emphasis on residual stand quality, this disturbance pattern could easily favor low-value species (Seymour 1986). Foresters will be challenged to resist widespread high-grading and to schedule the harvest of the maturing growing stock in a way that takes advantage of its earning potential and leads to quality regeneration.

In this conference, it is reasonable to examine critically our traditional silvicultural models and ask whether they will be adequate to meet these challenges. Perhaps it is time to pursue a new paradigm that combines the best elements of both even- and uneven-aged management, and preserves foresters' flexibility to respond to the extremely diverse stand conditions that dominate this forest type. I submit that the "two-aged management", irregular shelterwood model postulated above and discussed in more detail by Marquis (1981) and Smith (1988, these proceedings) merits such consideration.

Acknowledgements

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EVEN-AGED MANAGEMENT: WHEN IS IT APPROPRIATE AND WHAT DOES IT REVEAL ABOUT STAND DEVELOPMENT?

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If the choice between even- and uneven-aged management for northern hardwoods is like the same choice for pure stands such as those of ponderosa or loblolly pine, either the wrong question is being asked or the answer should be "none of the above."

Because they are commonly of mixed species composition, northern hardwood stands are complex in structure. As a result, there has always been difficulty in interpreting their development and formulating programs of treatment. The concept of the all-aged stand has commonly been invoked to explain and manage the complexity. It is an interpretation derived from the basic image of the pure, single-canopied, even-aged aggregation, with bell-shaped curve of diameter distribution, as shown in Figure 1, which might be found in a series of loblolly pine plantations including all age-classes.

This concept is very useful for guiding us toward sustained yield in forests composed of complicated kinds of stands. However, the concept of the stratified mixture shows how stands develop over time, how the different species and individual trees interact with each other, and how we can intepret their silvicultural treatment. While there are some mundane things that I will later state about even- and uneven-aged management, the most important point is the even- aged condition makes it easier to see the patterns in which these stands develop as stratified mixtures.

One of the best arguments that can be made for even-aged management of hardwoods is the fact that many of the finest hardwood stands are even-aged. These are the kind that have arisen after heavy removal cuttings or equivalent natural disturbances that have released advance regeneration to grow in varying degrees of mixture with sprouts and truly new seedlings. We find them most commonly where once there was heavy cutting for production of charcoal or other forms of fuelwood, but without short-rotation coppice cutting.

Such even-aged stands of mixed hardwoods are nice to inherit; however, the short-term financial incentives that favor high-grading make them hard to maintain. Regardless of what the age-class structure of hardwood stands is, we are not likely to create or maintain good stands unless we have markets for small, poor trees or the willingness to spend money on killing them. While it is possible to conduct true uneven-aged management, many of the procedures that may appear to create uneven-aged stands do not, and merely hide or postpone some difficult problems.

Cutting that does not create new age-classes is not true, long-term, uneven-aged management. Regulating cutting by J-shaped curves of diameter distribution is not uneven-aged management if no seedlings or saplings are left free to grow.

While it is not really correct to dignify the practice by calling it uneven-aged management, many hardwood stands have been sadly crippled by the high-grading. This very common practice depletes growing stocks of good trees but leaves enough growing space full of smaller or poorer trees that regeneration is generally precluded. Given short memories, the insidious effects of such high-grading often give hardwood forests and their forestry a bad name. High-grading can also accentuate the complexity of hardwood stands and obscure their developmental patterns.

The key to silvicultural practice is knowing how stands will change and grow after treatments. Most of this discourse will concern what even-aged stands tell about the development or dynamics of hardwood stands. The knowledge is useful regardless of what age-class arrangements we may use in particular cases.

Generalities About Even- and Uneven-aged Management

Some things about these two approaches to forest management are independent of stand composition.

Since the age-class structure of forest stands is not easy to change, it is almost necessary to continue with even-aged management if a stand has already become even-aged because of very heavy cutting in the past or some equivalent regenerative disturbance of nature. One can, over a very long period of time, create varying degrees of uneven-agedness by periodic group cuttings. It is also possible, in mixed hardwood stands, to develop stands with trees of two ages. However, such changes require careful attention to timely recruitment of new age classes. Conversely, if a stand already has truly different age classes stocked with good trees, one cannot change over to the even-aged condition without cutting some trees prematurely or carrying some long beyond maturity.

Sometimes management considerations, such as wildlife, aesthetics, soil protection, pest management, or maintenance of permanent seed sources, make it desirable to have stands or strips that always have some large trees. These are clearly situations calling for some kind of uneven-aged management.

A long history of high-grading and the effects of damaging agencies have left hardwood forests full of unbalanced uneven-aged stands overstocked with middle-aged trees and deficient in good regeneration and older age-classes.

This may give ample reason for developing them as uneven-aged stands. They do not necessarily have to be molded into self-contained units of sustained yield. If sustained yield is what is wanted, that is best achieved with collections of stands on large areas. Trying to get it from individual stands through tinkering with J-shaped curves of diameter distribution is a difficult and unpromising stunt.

The J-shaped curve was invented as a means of guiding sustained-yield management of all-aged aggregations of three species of shade-tolerant European trees that differed little in rates of height growth. The truly proper distribution does not exist unless all desired age-classes, including seedlings and saplings shorter than breast height, are indeed represented by equal areas. This kind of balanced distribution is not something one just goes out and finds in the woods. Nature does not provide for regenerative disturbances equal in area and equally spaced in time. Whether it be what we call a stand or a forest, the sustained-yield aggregation must be a deliberate, artificial creation. Most mixed hardwood stands that exhibit semblances of J-shaped curves are the result of differences in the rates of height and diameter growth of the different species rather than the existence of many different age-classes.

It has long been alleged that uneven-aged stands are more productive of wood in large trees (board-foot volume) than even-aged stands. This idea is theoretically correct if the small age-groups of an uneven-aged stand are gradually enlarged through crown expansion by the cutting of adjacent older age groups in successive cuttings. The theoretical advantage is greatest if the groups are small. One can show the phenomenon with sketches (Smith, 1986) but it has not been demonstrated through field observations. The advantage gained is small and may be offset by edge-effects that could produce lop-sided trees.

If one postulates J-shaped diameter distributions that do not provide for enough replacement regeneration, it can be made to seem that the uneven-aged distribution is more productive of board-foot volume than comparable collections of even-aged stands. Usually these involve distributions with q values of less than 1.6. For example, Hasse and Ek (1981) stated that uneven-aged stands were more productive of such large-sized wood than even-aged. However, they based this on stands with low values of q and also indicated that their simulations extended only for 40 years. The one of their simulations that seemed to provide for some semblance of adequate regeneration showed the same board-foot volume production as the even-aged stand. In other words, if one provided for true sustained yield, there was no production advantage in the uneven-aged condition. The most logical conclusion to draw is that, given comparison on a level playing field, one gets the same yield from both kinds of stand structure in the long run.

Even-aged management, as distinct from true uneven-aged management, has certain important operational advantages which make it more attractive economically as well as simpler to apply. Any one operation, whether it be harvesting or stand improvement work, is focused on fewer silvicultural steps. One is more likely to do one thing at a time to a stand than to try to do everything at once each time. Timber harvests on a given unit of land are concentrated in the middle and later part of the rotation and not spread more uniformly over time. Therefore, except for any early thinnings, the total volume per acre removed in each operation is likely to be greater and consist of a narrower range of kinds of products. This means that one can come closer to using equipment specifically adapted to the kinds and sizes of trees being removed or treated. Administration and supervision of operations are cheaper and less complicated.

Where even-aged management increases the amount of wood harvested per acre in a given operation, the cost of roads and of setting up log-loading points will be less. The stands will probably be less congested and this will reduce skidding costs to a modest extent; the lower risk of damage to residual trees may be more important. With even-aged management there is less use of mileage of roads and skid- trails. Since these are the chief source of erosion and stream sedimentation, this has the counter-intuitive effect of making heavy cuttings more compatible with water management than frequent light cuttings. This is especially true if one retains enough advance growth to keep living vegetation in command of the soil growing space.

Relation to Northern Hardwoods

There is one kind of even-aged hardwood management of which there is little in the Northeast. That is the culture of aspen poplar that is common in the Great Lakes Region. Except for its reliance on root-sucker regeneration, this is a kind of silviculture closely akin to growing loblolly pine or Norway spruce by clearcutting and planting. At least when compared with manipulation of mixed hardwood stands, it is conceptually simple and straight-forward. The aspen forests of the Great Lakes Region were originally more the result of silvicultural catastrophe than of plan even though the forestry of the region has been remarkably resourceful about taking advantage of the situation. The prices paid for aspen stumpage in that region seldom seem to make the idea very attractive for transfer to the Northeast. However, there are enough stands of aspen that have resulted from fire or unwisely heavy cutting that we cannot ignore their management whether it be temporary or permanent. It may be noted that aspen does not grow well on former spruce-fir sites or the dry soils where we might logically grow white pine; it does well on good hardwood sites.

Possibilities, more promising for the Northeast, also exist for growing pure stands of paper birch although the species grows well in mixture with other northern hardwoods. Since mixed stands abound in the Northeast, the rest of this discourse concentrates on the complex problems of managing them.

The most crucially important characteristic of the mixed hardwood forest is the fact that virtually all of the important species depend on establishment in some kind of protected micro-environment, typically as advance growth. This makes our silviculture different from that about which most foresters are educated. It is the result of the fact that most of our species are adapted to a humid climate in which fire is not the primary natural agency of forest re-establishment. Most of them are adapted to start as advance growth under old stands and start growing after windstorms or pest attacks have killed the trees above. With the chief exception of the birches and tulip-poplar, the important commercial hardwoods of the Northeast are not adapted to survive as seedlings in direct sunlight. Even yellow, paper, and black birch, regenerate better in side-shade than in the open (Marquis, 1969). The chief fire-following pioneer plants of the Northeast are gray birch, aspen poplar, pin cherry, and various species of Rubus, none of which are of much value.

Most of our knowledge of the indispensible role of advance regeneration in northern hardwood forests comes from the research of the U. S. Forest Service in northern New Hampshire, northwestern Pennsylvania, and the Upper Peninsula of Michigan.

It is also worth noting that hardwood regeneration often depends in varying degrees on vegetative sprouting, especially after heavy cutting. Mixed hardwood stands that consist only of coppice regeneration are seldom desirable; however, scattered sprouts of some species can go on to become some of the best trees of a stand. They grow fast and, if not in excessively dense clusters of stump-sprouts can also be remarkably straight. One species, basswood, regenerates almost entirely from stump-sprouts. There are many situations in which early thinning of sprout-clumps would be a good investment. The bad reputation of sprout regeneration has come from the twisted trees that arise from dense clusters on gnarled "stools" after centuries of short-rotation coppicing for brushwood fuel in the Old World.

Because of heavy reliance on regeneration from pre-established advance or sprout regeneration, it is not surprising that most thought about mixed-hardwood silviculture has involved various forms of either uneven-aged selection management or even-aged shelterwood systems. The only real differences between the two are in the large-scale architecture of age-class structure of what we chose to call stands. It is my contention that species interactions and stand developmental processes are essentially the same whether they take place in a fifth-acre patch of an uneven-aged stand or a hundred-acre even-aged stand that arose after a one-cut shelterwood operation.

The choice of age-class structure does not control the kind of species regenerated. If the regeneration openings are large enough, that is, more than 70 feet wide, and if bare mineral soil is exposed, we could count on at least some regeneration, in the more exposed parts of the openings, of even such intolerants as gray birch.

In a certain sense, it is an advantage of the even-aged condition that, in mixed hardwoods, it has helped reveal what happens in stand development even if we do not chose to have even-aged stands. The same things take place in the even-aged aggregations of which uneven-aged stands must inevitably consist.

Interpretations of Stand Development and Structure

All silvicultural treatments are, or ought to be, based on knowledge of how aggregations of trees will grow and change in structure after the various tree-killing interventions that are used to guide vegetational developments.

Most ideas about stand development are built around the concept of the pure, single-canopied, even-aged stand which is generally found to have a nearly normal, bell-shaped curve of distribution of diameter classes (Figure 1). The reverse J-shaped or negative exponential curve of diameter distribution does not do more than describe a collection of even-aged aggregations, of pure or single-species composition, that constitute a stand or forest that was a self-contained unit of sustained yield. Such a forest or stand would have all age classes up to rotation age represented by equal areas. It is basically an alternative way of regulating the cut of pure stands in which we measure tree diameters rather than stand areas. The closest approximations of stands which fit this concept are found in the interior ponderosa pine type. When we deal with mixtures of species we have something different for which the ideas about silviculture that we brought from turn-of-the-century Europe did not prepare us.

The nature and magnitude of the problem were brought home to me some decades ago by a famous Danish pioneer in forest genetics, Syrach Larsen. I was helping guide him around a plantation of hybrid chestnuts with

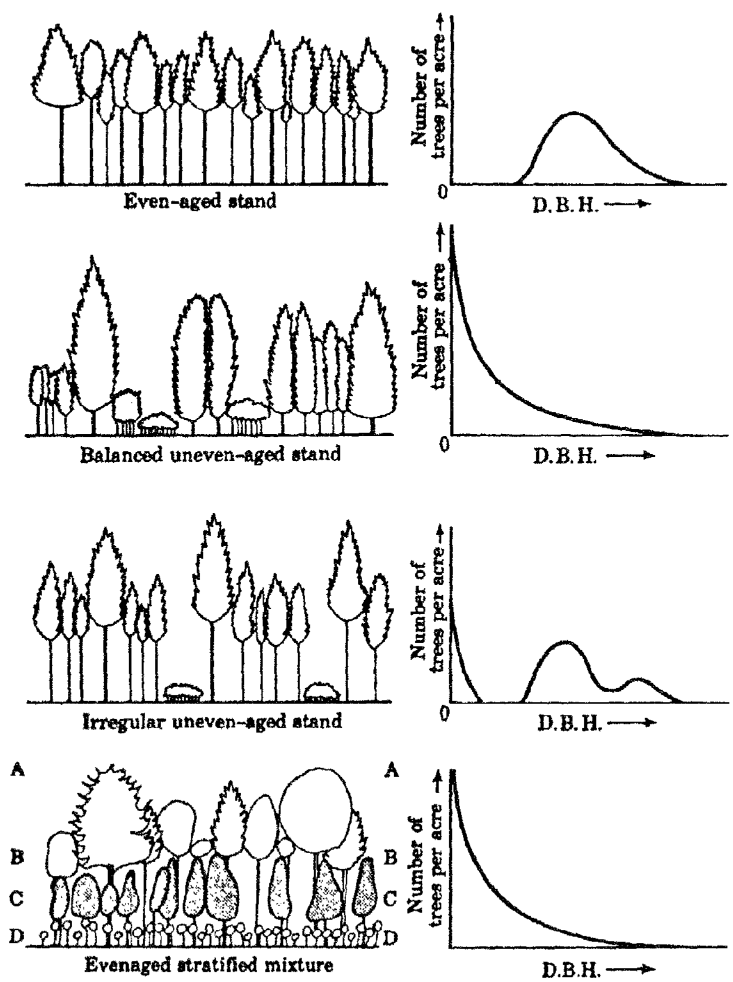

Figure 1. Top sketch shows the pure, even-aged, single-canopied stand around which most ideas of "standard" silviculture are built. The next two depict how this same concept is carried into the kind of uneven-aged structure often used to explain complexity. The bottom sketch shows the concept of the stratified mixture which appears to provide a more accurate interpretation of the development of mixed hardwood stands. (From Smith, 1986)

Arthur Graves, an American pioneer in the same field. At one point, the visitor digressed to inspect an adjacent even-aged Connecicut hardwood stand that had come up after a heavy firewood cutting about 50 years earlier. It had about a dozen species. After a time, he asked me, "How do you ever go about thinning a stand like this?" All I could say was that we just did it by cutting trees here and there. I was rather taken aback that he should be so puzzled. However, what his question revealed was that we were dealing with something alien to "standard silviculture."

At about the same time I had been wrestling with the literature of the tropical rain forest and learned that people used the concept of the stratified mixture to inflict some order on chaos. Somewhat later, in a hemlock-hardwood stand, it occured to me that I did not have to go to the tropics to find such stands because we had them here. Furthermore, we had clear evidence that the structure can exist in the even-aged condition because of our legacy of stands that had arisen after very heavy fuelwood cuttings. The fact that our trees have annual rings enables us to learn things about stand development that are very difficult in tropical moist evergreen forests.

Even-aged Forest as Key to Understanding Stand Development

Not the least of the advantages of the even-aged form of stand is that one is more likely be able to perceive their condition and keep track of their developmental processes.

Whether mixed hardwood stands are managed on the even- or uneven-aged basis, their logical treatment is best understood by knowledge of the ways in which the constituent even-aged aggregations are constructed and develop. In a certain sense there is really no such thing as an uneven-aged stand because those which are called that are actually collections of little even-aged stands each of which is deemed too small to call a "stand." David Marquis (1981a,b) has detected some important exceptions in the form of two-aged stands in northwestern Pennsylvania; these will be considered after dealing with somewhat simpler cases.

Whether we call them stands or aggregations most even-aged mixtures of hardwoods develop as stratified mixtures (D. M. Smith, 1972, 1986; A. P. Smith, 1973; Oliver, 1981). Some species are adapted to grow rapidly in height while some follow along beneath subsisting on the crumbs of light that escape from the trees above (Figure 1). The topmost layer may be fully closed or consist only of scattered emergents; often only one species, such as yellow-poplar, is represented. In the early stages of development, the upper layer may contain short-lived pioneer species such as pin cherry, Rubus, grey birch or aspen, that will uncover some long-lived, initially subordinate stratum when it dies or is removed. If the soil provides a stable moisture supply, there may be successive layers beneath that. Often the lowermost layers consist of half-trees, such as striped maple or hophornbeam, or shrubs.

The uppermost stratum is called the A-stratum or layer and the ones below that are designated B, C, D, and even E successively downward.

The standard crown classes (dominant, codominant, intermediate, and overtopped) were developed for pure, even-aged aggregations of trees and usually create false impressions when used as predictors of future development in stratified mixtures. One can often recognize and use this kind of classification within a given stratum (Oliver, 1978). It is like having one stand on top of another. One can conduct thinnings in two different strata simultaneously.

One of the most important layers of all is not there until the overhead cover is thinned by partial cutting or factors associated with advancing age. This layer is the advance regeneration on which almost all desirable hardwood species, with the general exception of birches, are heavily dependent.

Stratification is a process and not just a way of describing a static arrangement of tree species.

The importance of this view of the structure and development of even-aged mixtures of hardwoods is that it can serve as a guide to silvicultural treatment. It helps reveal that one can release certain kinds of submerged strata (not necessarily all such) and expect the trees that had formerly lagged to develop as a new top stratum that will grow at an accelerated rate. The same action in a pure stand might well involve the freeing of moribund suppressed trees that would probably be more likely to die than to start rapid growth.

Even-aged stratified mixtures typically have some semblance of the J-shaped diameter-distribution curve associated with all-aged stands. This point was detected by Wilson (1953) in even-aged northern hardwoods. The best clue to this phenomenon is the situation in which upper-stratum species such as white ash, birch, or red oak occupy the larger diameter classes with lower-stratum species such as hemlock or beech filling the small diameter classes. Uncritical analysis of diameter distributions often causes stratified mixtures to be mistaken for uneven-aged stands.

A wide variety of options exist for manipulating or modifying even-aged stratified mixtures and some are shown schematically in Figure 2. One can recreate the same kind of mixture by shelterwood cutting or alter species composi-

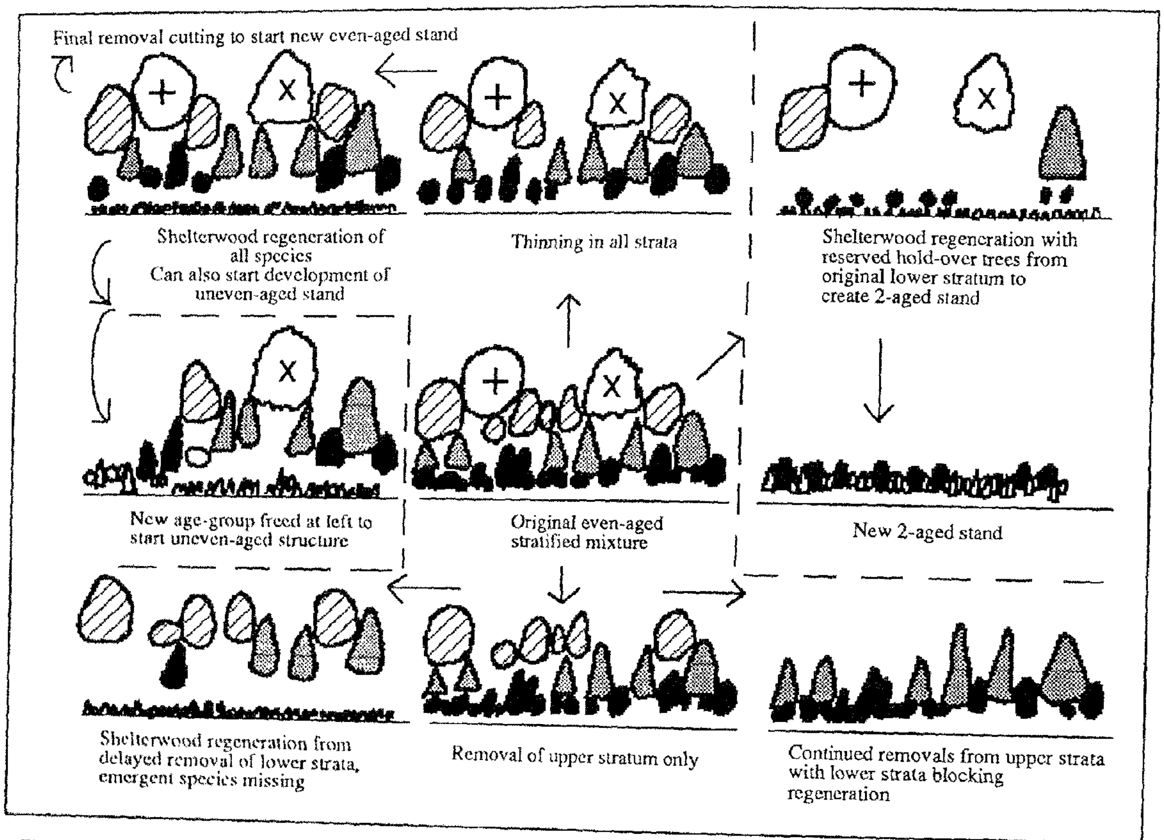

Figure 2. Schematic representation of some variations in the silvicultural treatment of stratified mixtures. For illustrative purposes, all start with an even-aged stand (center); arrows indicate different sequences of cutting leading to different stand structures. The pathway to upper left shows how the original stand might be duplicated or else started toward uneven-aged structure. At the upper right it is shown how hold-over poles, such as those of sugar maple, might be left to form the older component of a two-aged stand. Bottom sketches depict some cutting patterns that start with removal of upper-stratum species.

tion. It is also possible to work toward true uneven-aged condition. Figure 2 is intended only to show what can be done starting with a perfectly even-aged stand. The hardwood stands that we usually find in the forest are likely to be more complicated mixtures of species and age-classes. We generally should make definite decisions about whether to make them more even- or more uneven-aged.

The Upper Stratum and the Emergents

Usually almost everything depends on how the largest and best trees are managed. Given the high premium paid for good hardwood logs and the low values attached to poor, we commonly find that most of the value of a stand resides in the small minority of the trees that are the largest and, almost ipso facto, the best. It may also be heavily concentrated in the butt logs of those trees. Here is a case where we must not let the woods hide the trees from us. Even if most of the gross production of the hardwood forest is suitable only for pulp- or fuel-wood, the economic success of the forest management stands or falls on the size of that fraction of the total production that is of good quality and high utility. As much as possible of the "value added through manufacture" must be made to develop in the growing tree.

If the relatively few uppermost trees are to earn well it is necessary that they get continually increasing amounts of growing space. Paradoxically we have obtained best earnings from those which have, as a result of the dynamic properties of stratified mixtures, been able to claim growing space unchecked. These are the emergents which are typically of species that continue to grow well in height when their neighbors of other species have slowed down or stopped. If they must compete with their own kind, however, they do not become isolated emergents but instead become competing members of a closed stratum of the single species. However, the role of a given species can change depending chiefly on its associates and their regimes of height growth. For example, white ash may be an emergent over maple in Maine but becomes a second-stratum species beneath red oak in Connecticut; red oak in turn becomes subordinate to tulip- poplar in the Delaware Valley.

If the uppermost species form a closed stratum, it is entirely possible for them to become overcrowded regardless of what goes on beneath them. For example, Oliver (1978) found that in Connecticut it was not well to have more than 45 upper-stratum red oaks per acre at the end of the rotation if the goal was to optimize yield of board-foot volume. Overcrowding would almost certainly depress the rate of return revealed by financial maturity analysis.

If we had to thin some of our hardwood stands severely enough to grow fine trees at financially acceptable rates of growth, they might often have to receive the drastic thinning that produces the spacing of apple orchards. In fact, this appears to be true of intensive culture of black walnut. Fortunately, in stratified mixtures we can proceed such that the natural tendency of the leading species to forge ahead may substitute for artificial thinning. The slower-growing lower strata exert training effects without presenting much competition and can also make productive use of their occupancy of the rest of the growing space.

At least in the moist climate of New England, there is some evidence that the lower strata can provide training effects without hampering the growth of overstory red oaks. Kittredge (1986) has shown that, after the red oaks emerge above lower strata of red maple, black birch, and similar species, the growth of oak crop trees is affected by neighboring red oaks, but not by the lower strata. Kelty (1984) found that the above-ground production by overstory hardwoods was not affected by the presence or absence of a significant lower stratum of hemlock. The hemlock production was simply additive. There is also evidence that elimination of the lower strata of hardwood stands increases overstory production in the droughty Ozarks, but not in Massachusetts (Kelty et al., 1987).

What these pieces of evidence suggest is that there are many parts of the eastern hardwood forest where the moisture supply is good enough that one should manage the upper strata almost independently of the lower. The lower strata can be used to provide training effects, extra production, and sometimes potentialities for good growth after release from the overstory.

If the stand density of the lower strata does not affect the growth of the main canopy trees, stocking guides and models such as those of Solomon et al. (1986) for northern hardwoods need to be modified so that the density of the overstory becomes a more critical criterion. If the basal area of the lower stratum does not affect the growth of the upper one, its inclusion in a stocking guide merely diverts attention from what is really important. The prescription guide of Marquis et al. (1984) for Allegheny hardwoods addresses this problem by separating the "CAP" group of upper-stratum species (black cherry, ash, and yellow-poplar) from two categories of lower-stratum species.

The typical upper-stratum species in many hardwood forests often are the very ones that we most esteem. The basic reason is that they have, in the natural course of events, generally attained largest size, best form, and largest proportion of clear wood. It is astonishing that the tendencies of these species to forge to the top has often been manifested after the seemingly devastating heavy removal cuttings for fuelwood that have released advance growth and other desirable forms of regeneration.

Before concluding the consideration of emergents and upper-stratum trees, it should be noted that they are not necessarily always fine trees that can add value rapidly. Sometimes they can be poorly formed crooked or wolfy trees, often hold-overs from older age-classes. These may increase rapidly in volume but continue to command low or negative stumpage prices. Furthermore, they usurp growing space which could be used for something financially productive. All logic calls for either harvesting or killing them unless they serve some role in aesthetics or wildlife management.

Trees of the Lower Strata

Beneath the trees of the strata exposed to direct sunlight are those that must subsist on the leftover light that penetrates to them. There may be more than one layer or stratum of these. The shrub stratum so common in hardwood stands may constitute one. Many parts of the world would envy us for the magnificent spring flora of the lowest stratum that briefly flourishes before the overstory leaves develop. These subordinate layers present both problems and opportunities.

The species involved are necessarily tolerant of shade. They may or may not be adapted to respond to release with accelerated growth. Some may have to do this if they are to produce seeds. Others, often half-tree and half-shrub, can produce seeds in the shade; it may be an over-generalization to suggest that they remain small because, for them, there is no species survival value in reaching for a place in the sun.

Getting lower-stratum trees to develop into good timber trees depends on whether they are phototropic or geotropic. Unfortunately many hardwoods, unlike most conifers, tend to be phototropic. If they grow in the lower strata they often develop crooked stems from growing first toward one patch of sky and later toward another. However, some hardwood species, most notably sugar maple, are comparatively geotropic and can remain straight while their growth is arrested.

Those lower-stratum trees that remain straight and can develop into good stems after release can create a situation in which we can grow at least part of a new stand underneath the old one. This is the kind of situation that Marquis (1981a,b) has pointed out in Allegheny hardwoods. In that case and in a sense, it may take two black-cherry rotations for sugar maples to complete their development. To the extent that what is termed uneven-aged management in many hardwoods stands gives good results and is not high-grading it is because of the effective use of the potentialities of such trees.

The trees of the lower stratum can also act as the trainers of the ones that rise above them. As pointed out previously, any useful production that they contribute may actually be additive to that of the upper strata. They can also provide food and shelter for many kinds of mammals and birds.

However, the lower-stratum trees are usually more of a detriment than an asset in timber management. In terms of financial maturity analysis, the best time to cut many of them is the first day they will pay their way out of the woods. This does not mean, however, that we should fail to take into account the capacity that they may have to initiate rapid growth in value upon some future release. We need to know more about how to distinguish, in the pole stage, between potentially good lower-stratum trees and those best killed or cut for fuelwood. If they are ultimately going to be promoted to the upper stratum it is well to sort them over by thinning during the period of stand development when most attention is focused on the upper strata.

The most important thing about recognizing the characteristics of the lower stata is that it should remind us of the need for getting rid of all or most of it in the regeneration process. The eastern hardwood forest is cluttered with high-graded stands composed mostly of trees that were once in the lower strata. Not uncommonly, foresters who inherit such stands are inclined to blame their poor condition on poor soil or damaging agencies. It is tragic that the better the site the more likely one is to find such stands. We do not wish this problem away by conducting high-grading operations that are alleged to be real selection cuttings and pretending that the lower stratum represents good growing stock.

There are plenty of cases in which the lower strata of a stand do not have trees of good potentialites or ones which cannot feasibly be protected from logging damage. They then constitute an asset of zero or minus value and should be cleared away to make room for regeneration. Fortunately, in the case of hardwoods, some of these may resprout to become good regeneration.

Variations on the Theme of the Shelterwood Approach

We simply cannot get useful regeneration established in such stands unless there are forthright measures to provide new growing space by reducing or eliminating the lower strata. For most good hardwood species, regeneration must be present as advance growth or sprout-sources before rather than after heavy removal cuttings. Shelterwood cutting is basically the way to get the process started, although it can take many forms including some within the framework of uneven-aged stand structure.

In hardwood forests, when we look at what follows the heavy removal cuttings that we often lump under clearcutting, we see vegetation of several different kinds of origin. Released advance growth is usually the most important component. It may include seedlings, seedling-sprouts, saplings and small poles; to the extent that it does it can be viewed as the product of shelterwood cutting. It is increasingly obvious that much of this regeneration also comes from stump-sprouts and other forms of vegetative regeneration associated with coppice cutting. The stumps involved may vary widely in size. Oak regeneration may depend heavily on this source. In fact, the ability of small hardwoods to sprout often makes it possible to be more complacent about logging damage to hardwood regeneration than is the case with non-sprouting species. Finally, after cutting, some birch regeneration does come from germination under relatively open conditions.

There is a temporary stratum of vegetation that is very important after heavy cutting. This is the explosion of pioneer plants, woody and herbaceous, that is associated with hard disturbance. While these plants can act as nurse crops for tree seedlings and provide food and cover for wildlife, their effect on the trees beneath them is mostly detrimental after the first few months. Shelterwood and other partial cutting methods can be used in ways that will allow new trees to get established without opening the door so widely to pioneer vegetation.

Shelterwood cutting does not have to be simple, uniform shelterwood cutting. The very nature of the stratified mixture means that the constituent species develop at different rates. Some species generally become financially mature before others. The more we play on the differences through series of partial cuttings the more irregular the stands become. However, if we start with even-aged stands, this procedure is not really likely to develop truly uneven-aged stands; the range of age simply broadens. German foresters have a name for this kind of silvicultural system. It is "Femelschlag" and it is not easy to translate; the best English term is "irregular shelterwood" and mostly it means getting new regeneration over an extended period.

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UNEVEN-AGE MANAGEMENT: WHEN DO CONDITIONS REQUIRE THIS APPROACH?

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The answer to the question posed in the title of this paper could be that uneven-age management is the only procedure possible where a relatively unbroken tree canopy is required or when all size classes must be present in a relatively small area and a yield of timber products is desired. In a technical sense, these features distinguish uneven-age management from even-age systems.

The first feature (unbroken canopies) is required for aesthetics (USDA For. Serv. 1987) and protection from such items as erosion (Hornbeck et al. 1986). The second feature, size class distribution is required when the management objective is to provide sustained yields at short intervals from the same area. A diversity of size classes also is needed to maintain habitat for large numbers of animal species (Healy 1987). These are the most obvious categorical statements that one can make about the use of uneven-age management of northern hardwoods.

Once it could be said that substantial numbers of less shade-tolerant species could result only from even-age systems, but shelterwood techniques (Kelty 1987) now offer the possibility of producing even-aged stands of tolerant regeneration. Mixed stands of tolerant and intolerant species also result in the Northeast following correctly applied clearcutting (Leak et al. 1986). Group selection allows the introduction of less tolerant species into uneven-aged stands which otherwise would produce only tolerant species under single-tree selection. This illustrates the flexibility of even-age and uneven-age systems with regard to species composition. Flexibility extends to other aspects of management such as stocking, cutting cycles, thinning schedules, and maximum tree sizes and rotations, so that the choice of a system requires an analysis of the factors involved for a specific set of economic and biological circumstances. A useful guide to the quantitative evaluation of variations in all-age management is found in Hansen and Nyland (1987).

Timber Yields and Growth

Evidence is steadily accumulating that sustained yields result from selection cutting when the harvest is controlled by a residual basal area augmented with control in size-class distribution (Crow et al. 1980; Tubbs 1977; Smith et al. 1987; Nyland 1987; Moser et al. 1979; Solomon 1977). Computer simulations extending the time of growth for extended periods add confidence in the general method and in specific techniques (Moser et al. 1979); (Hasse, et al. 1980). However, single-tree selection does not work well with respect to yields when the desirable species are not shade tolerant (Della-Bianchа et al. 1985). Also, the system must be modified by patches or group selection to provide increased yields of less tolerant species. Attempts to increase the proportion of less tolerant species by varying stand density has usually failed (Crow and Metzger 1987).

There are many usable variations in stocking, structure, and cutting cycle. But, in terms of merchantable cubic foot growth (or biomass), most of the variations do not produce substantial differences in total growth (Crow et al. 1981). Sawlog volume growth may be affected by variation in stocking or cutting cycle, however, and one simulation suggests that uneven-age practices in northern hardwoods produce greater sawlog yields than even-age management (Hasse et al. 1980). Converting the stand to a fast-growing intolerant species such as red pine (Frederick and Coffman 1978) results in a greater yield of merchantable volume than with a slow-growing tolerant species.

The quality of yields is more difficult to compare, and experimental evidence for the superiority of a single system or variation is meager. High-quality stands can be produced by selection methods (Tubbs 1977) and the structure of selection forests is thought to be an optimum environment for the development of tolerant tree species for yields of high-quality logs (Bourne 1951, Tubbs 1968, Johnson 1984).

Site

Although site and species composition often are inextricably linked, it is worthwhile to separate their effects on stocking and structural goals. On poorer sites, structures with a large number of smaller trees (q ratios of 1.5 to 1.7), smaller maximum sizes (16 inches d.b.h.) and lower sawlog residual basal areas are recommended (Leak et al. 1987). When fiber or fuel are the primary objectives, structures should have a q of 1.7. Better sites can hold a larger stocking of sawlogs and larger maximum sizes (20 to 24 inches d.b.h.) (Leak et al. 1987; Tubbs 1977). Cutting-cycle lengths are usually longer on poorer sites to account for the development of an economic harvest. The longest cycle recommended is 20 years.

Poorer sites commonly are occupied by less desirable tree species such as beech (Leak 1980; Trimble 1973) and small undesirable trees and shrubs, especially in the eastern portion of the range. On such sites, methods other than individual-tree selection usually are prescribed for timber production.

Species Composition

In the Lake States, 11 variations of the beech, birch, and maple type are recognized for management purposes (Tubbs 1977). In the Northeast, there are three general categories of northern hardwoods. All can be managed using selection techniques with suitable modifications (Leak et al. 1987). Generally, these types in which sugar maple is dominant and/or mixed with white ash and basswood are capable of holding a high stocking of sawlogs per acre and of producing large logs. Similarly, mixed-wood stands containing hemlock, red spruce, or white pine can hold a high total stocking per acre. By contrast, types that include substantial proportions of American beech and red maple generally require lower sawlog residual basal areas for best growth. Cover types that reflect a succession toward more long-lived tolerant species such as red oak-northern hardwoods, aspen, or white birch-northern hardwoods often are managed to provide good environments for the tolerant sugar maple or beech. These types are subject to high mortality rates and frequently are cut to residual basal areas lower than recommended for good growth of the more tolerant species to recover the value of the shorter lived species.

In all site and cover-type combinations, group selection can be combined with single-tree selection to reduce the number of unwanted species and defective or poorly formed stems, and to increase the number of desirable species. Groups range from less than 1/10 acre to about 2 acres, with the smaller groups reproducing more tolerant species and the larger producing a higher proportion of intolerant species.

Cutting in the smaller size classes usually is avoided because of the difficulty in recognizing categories of stem defect and form that require removal. In the smaller size classes of sugar maple or beech, some of the severe variations in form and substantial defect can be overcome in managed stands (Jacobs 1986). Cutting in the pole-size class also is often avoided because of the marginal effect of such cutting on stand growth, and because it is often more profitable to market small sawlogs than pole material. Where markets for poles are weak, there is some advantage to uneven-age management by opening the stand during harvesting in the larger sawlog size classes which may not be possible by even-age management.

Tree age is not an obstacle to uneven-age management in northern hardwoods as it is in other forest types because of the long lifespan of the dominant species and their ability to respond to release at advanced ages (Bourne 1951; Eyre and Zillgitt 1953; Tubbs 1977). But tree size is proportional to rot (Ohman 1968), the effects of beech-bark disease on stand merchantability (Filip 1978), and diameter growth (Crow et al. 1980). However, as management proceeds through several cutting cycles, growth rates by size class increase, presumably partly as the result of a reduction in tree age (Jacobs 1968).

Logging Cost and Returns

Although published studies of logging costs with uneven-age systems are rare, it is fair to say that when costs are high, as in rough terrain or deep snow, the tendency is to remove large volumes per acre and to use long cutting cycles. Also, larger volumes are removed when the product value is low as compared to high. Opportunity cost is a factor to consider when choosing between uneven-age management and liquidating stands that contain a substantial number of small trees capable of improvement in grade and volume.

Federal, state, and local taxes also influence decisions on whether or how to apply uneven-age systems. The availability of equipment and labor also affects the cost of raw material and often is a major influence in the choice of management systems or the development of new ones.

The availability of polewood markets is another factor to consider when choosing a cutting method. Even-age methods lead to relatively large quantities of polewood while uneven-age systems generate mostly products of sawlog size with little polewood yield on better sites in stands with low Q values (Jacobs 1968).

Financial yields depend on size-class distributions and stand stocking (Hansen and Nyland 1987). In the short run, lower stand stocking and small maximum diameters commonly lead to higher internal rates of return. In the long run, low stand densities may adversely affect tree quality and reduce financial yields.

Owner Objectives and Size of Ownership

Studies repeatedly indicate that the objective of most small-tract owners is not timber production. The usual recommendation is uneven-age management on such ownerships (Jacobs 1986), but in reality, high grading, liquidation, or no cutting are common. A widely accepted systematic management procedure for small ownerships is not available, although many schemes have been offered. Jacobs (1986) listed eight obstacles to small tract management ranging from inadequate markets to unfavorable species composition.

Diseases and Insects

Recent reviews (Houston 1986; Allen 1986) discuss the effects of disease and insects on northern hardwoods. Biological killing diseases include the beech bark disease, sapstreak disease of maple, and blights. Other diseases kill or cause loss of merchantability in debilitated trees. The reviewers do not suggest that any of these are the result of a particular management scheme. Blights are sporadic and may result from combinations of insects, disease, and unusual weather conditions or from human-caused effects such as air pollution. They are not linked directly to a management system. Insects damage northern hardwood species, causing growth loss and mortality, but there are no demonstrated relationships with a management system (Allen 1986).

Damage by deer precludes the use of uneven-age systems in some localities (Kelty 1987). For example, where beech is an aggressive species, deer populations may browse the more desirable sugar maple, allowing beech to become dominant under uneven-age management.

Geography and Ecology

In the West, sugar maple is a high-value, aggressive species. Its tolerant competitors are limited in number and sugar maple develops high-quality stems in uneven-aged forests. Regeneration of this species is certain under uneven-age management in northern parts of the Lake States. In the East, uneven-age management can produce a large number of tolerant woody species, many of which are of low value. The probability that an undesirable species will be produced is related to the physiographic and climatic factors mentioned earlier.

The correct choice between uneven-aged and even-age systems depends on the degree of success in meeting management objectives. Part of this success depends on the analysis of the particular situation under consideration. Fortunately, we have acquired much information and flexibility but we still are uncertain about the effect of management systems on such important factors as tree quality so judgment and experience must then be substituted for scientific evidence.

The flexibility of uneven-age systems an the variety of economic, physical, and ecological factors that one can encounter suggest that uneven-age management may be the system of choice in many instances. Examples are: the principal tolerant species is valuable, the site is capable of growing trees large enough to fulfill grade requirements, and the cost of access is acceptable. In such instances, the conflict with economic factors should be minimized. Note that "valuable" may simply mean that the objective for raw material can be effectively met. For example, a user or manufacturer of wood products may consider beech to be of high value if his or her product is best made with that species. Where markets for polewood are poor or when the highest value of polewood is its eventual harvest as sawtimber, uneven age practices may be the best for many owners. Note that under even-age management it is possible to decrease the area of poles by applying the correct practice or to decrease the pole yield by letting nature do the thinning.

When protection or aesthetics require an eternal unbroken canopy along with a timber yield, then uneven-age management is necessary.

Uneven-age management could meet the objectives of many small landowners. But the major conflict apparently is between owner objectives and forestry systems designed to maximize production of high-quality sawlogs over long periods, or to meet other timber objectives. For example, flexibility of uneven-age systems is great enough to provide both fuelwood and wildlife diversity on small acreages (Tubbs et al. 1986), periodic sawlog sales and wildlife diversity or other combinations of objectives (Leak 1986).

Selection cutting often is thought to lead to high grading and the gradual deterioration of stands, but clearcutting often removes trees whose potential value has not been reached. Silviculture can be applied incorrectly in any system, but is recognized most easily in partial cuts in which "good" trees or "bad" trees are cut, or when slash is not managed.

In summary, uneven-age management that includes selection practices can meet many raw material, some wildlife, and most site protection and water-quality goals, as well as aesthetic goals. Uneven-age management will not maximize the number of intolerant species, nor create the best habitat for some wildlife species. It fails the test for aesthetics where species such as white birch are desired. These short-comings can be reduced somewhat by modifying timber production techniques or combining even-age and uneven-age management, or both. It seems that the conflicts that arise often are of an economic nature, or are the result of techniques being misapplied.

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RELATION OF SITE TO SILVICULTURAL ALTERNATIVES

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In developing silvicultural alternatives, site affects (1) choice of species to regenerate or favor in thinning, (2) rotation or stand structure, (3) risks from windthrow, fire, snow-glaze-frost and insects/diseases, (4) impacts on aesthetics, wildlife habitat, and soils, and (5) logging methods. Choice of species generally implies an optimum silvicultural system and rotation. This optimum system is then revised to overcome potential risks or impacts, comply with logging standards, and meet the many social and economic factors that enter into the choice of a silvicultural alternative. Most conflicts can be resolved because of the many silvicultural approaches available in northern hardwoods. The major research needs are better definition of site factors and their relation to silvicultural impacts on site deterioration, tree-quality development, wildlife-habitat components, and insect/disease susceptibility.

Site conditions influence: 1) choice of species; 2) rotation or stand structure; 3) risks from windthrow, fire, snow-glaze-frost, and insects/diseases; 4) silvicultural impacts on aesthetics; wildlife habitat; and soils; and 5) logging methods.

All of these factors affect either the short-or long-term feasibility, costs, or returns of management and thus have an important bearing on the choice of silvicultural alternatives. In this paper I discuss some of the available information on these five topics, suggest how they are integrated in choosing a silvicultural alternative, and point out some of the unresolved questions.

What is Site?

Four general approaches are used in the United States to measure or represent forest site:

1. Direct measures: e.g., site index, periodic height growth, volume production, and log height, etc.

2. Vegetative methods: cover types, indicator plants (Pfister et al. 1977, Barnes et al. 1982).

3. Physical/chemical methods: soil series, soil-site equations based on physical/chemical measures, topographic methods.

4. Biophysical methods: essentially a combination of items 2 and 3 where land units are defined by several related factors such as land form, soils, and vegetative cover (e.g., Fay and Leak 1982).

Each of these approaches tends to emphasize one or more important aspects of that obscure concept we call "site." The choice of approach depends on the objective (land-use planning, project planning, timber response, multiple-use response, etc.) and the feasibility of defining and mapping the site features. For this paper I have combined all approaches into a single, broad definition: site is any combination of climatic or edaphic factors that influences the (1) reproduction, growth, survival, or competitive position of a species, (2) environmental response, or (3) operability.

Site conditions and vegetation response vary greatly from region to region because of differences in climate, bedrock mineralogy, competing species, and disturbance factors, so there are few specific rules that apply from one area to another.

Choice of Species

Perhaps the most obvious site-related alternative is choice of tree species to favor in regeneration or thinning operations. Usually, the question is: on this given site (whether good or poor), what are the best species to favor for the production of wood products, wildlife habitat, or other needs? Species are influenced by site in three ways: regeneration and establishment success, growth rate, and quality.

Regeneration

Sampling undisturbed stands over a range of sites in the White Mountains of New Hampshire shows that species composition varies greatly with site—defined in this instance by different types of soil material or glacial deposit (Fig. 1, Leak 1978a). White ash is found mostly on sites enriched with organic matter or moving water. Sugar maple also is found here, as well as on fine-till soils. Red maple is common where sugar maple is not abundant. Softwoods occur on shallow, wet, or dry sites. Species such as paper birch, yellow birch, and aspen are not site specific in keeping with their pioneer nature.

The understories of the stands represented in Figure 1 tend to be consistent with the overstories, i.e., they tend to be dominated by the tolerant to somewht tolerant species found in the overstories (Table 1, Leak and Solomon 1975). However, we can easily move the composition toward less tolerant species by heavy cutting. The stand in Table 1 is primarily on washed tills derived from granite, which would support beech and red maple rather than sugar maple, ash, or abundant softwoods. Species composition on these same types of soil materials, but derived from different bedrock or located in a different climatic zone, would support somewhat different species mixtures (Leak 1978b).

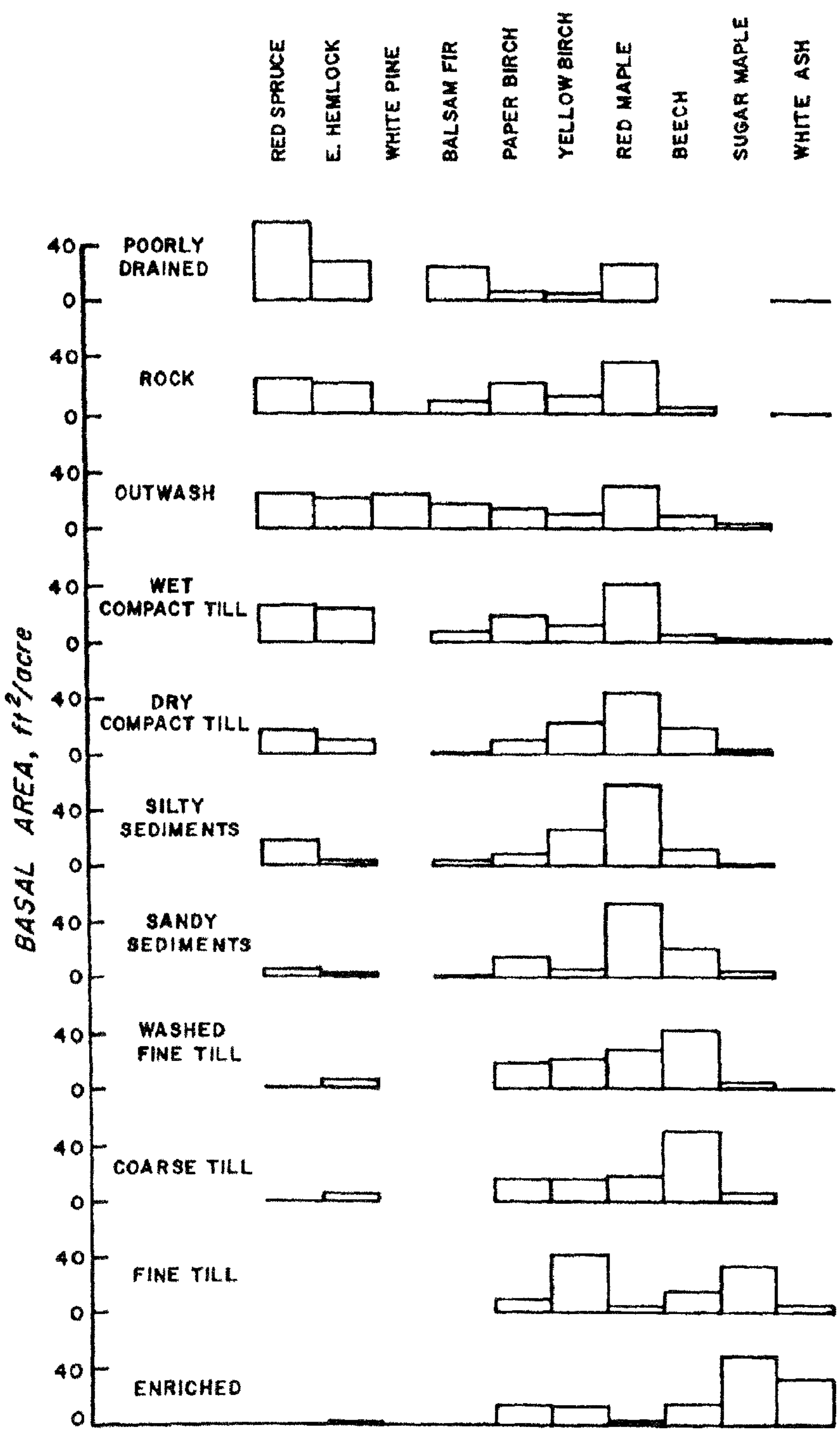

Figure 1. Basal area, in ft²/acre, by species and soil material (habitats) for evenaged stands 50 to 100 years old in the White Mountains of New Hampshire.

Table 1. Species composition of overstory (percent of basal area) and understory (percent of stem numbers 2 to 25 mm basal diameter) 9 years after light cutting to 100 square feet/basal area in a stand growing on washed tills (Leak and Solomon 1975).

Species	Overstory	Understory
	——— percent ———	
Beech	21.8	30.5
Yellow Birch	9.2	2.6
Sugar maple	5.2	2.8
Red maple	34.5	19.1
Paper birch	18.5	1.2
White ash	1.1	2.9
Red spruce	0.4	0.0
Eastern hemlock	8.2	0.3
Others	1.2	40.6

Understories under intolerant overstories (aspen, paper birch, etc.) are, of course, a different species mix than the overstory. These understories tend to reflect site conditions, e.g., softwood understories occur on shallow, wet, or dry sites and northern hardwood understories on well-drained, fine-textured tills. In oak-pine types, however, there sometimes are distinct differences between overstories and understories because the species sometimes tend to alternate; pine over oak and then oak over pine. Site has some influence (Table 2) because oak-pine types tend to occur within certain climatic zones and often on well- to excessively well-drained soil materials, though stand dynamics are equally important. Some believe that wildlife interactions are involved in oak-pine alternation (Alexander 1980, Leak 1987).

Table 2. Percent of milacres dominated by oak or white pine regeneration ($\leq$ 2.9 inches dbh) related to soil material under pine and oak-hardwood stands partially cut 4 to 6 years earlier.

Cover	Soil material	Percent milacres dominated by: Oak	Pine
Pine[a]	Outwash	65	0
	Sandy sediment	19	0
	Silty sediment	32	4
	Wet compact till	14	4
	Mean	32	2
Oak-Hardwood[a]	Shallow to bedrock	8	8
	Coarse sandy till	2	18
	Fine sandy till	35	15
	Fine sandy till	12	0
	Fine till over pan	12	0
	Mean	14	8

[a]Four pine stands averaging 93 ft^2 basal area/acre with 90 ft^2 in pine, and five oak-hardwood stands averaging 79 ft^2 basal area/acre and 14 ft^2 in pine.

The reason why site tends to influence species occurrence is not known. All we know is that sites (defined by type of soil material) differ in nutrient relations (Gillespie and Smith 1985, Stehn 1983), available water, temperature regime, aeration, forest-floor depths (Leak 1976), and herbaceous/shrubby competition (Table 3). Certainly, through site preparation, weed control, and/or artificial seeding we can influence natural trends in regeneration; but the costs will rise in proportion to the work involved. We also need to note the influence of site on growth and quality before we undertake large regeneration expenses.

Table 3. Numbers of understory stems/acre (0.5 foot tall to 2.9 inches d.b.h.) and percent ground cover under five oak-hardwood stand 4 to 6 years after cutting.

Soil Material	Basal area/acre	Number of understory stems	Percent ground cover
	ft. 2		
Coarse sandy till	77	2600	8
Shallow bedrock	77	5000	58
Fine sandy till	54	7100	50
Fine sandy till	98	11626	52
Fine till over pan	88	14187	61

Growth

Site index varies with type of soil material (Table 4). However, the relationship is flat for certain species and variable for others, partly because site index is difficult to sample and measure in northern hardwoods. Sugar maple, ash, and paper birch show some logical relationships. But species such as red maple seem almost oblivious of where their roots are anchored.

More obscure but potentially important is the effect of site on diameter growth. Preliminary work with dominant, free-to-grow sample trees indicated that diameter growth declines steeply with increased d.b.h. on mediocre sites (e.g., sandy tills) but remains near constant on fine tills (Leak 1983). Mean annual diameter growth in poletimber stands on good sites (enriched, fine till) was found to be about one-third greater than on mediocre sites (Leak 1979). Higher and more prolonged rates of diameter growth typical of good sites influence board-foot and quality production more than cubic-foot or biomass yields (Leak 1982).

Table 4. Mean site index (50 years), in feet (Leak 1978a).

Habitat	Paper birch	Yellow birch	Red maple	Beech	Sugar maple	White ash
Poorly drained	—	40	—	—	—	48
Rock	56	48	60	—	—	—
Outwash	—	60	63	—	—	—
Wet compact till	54	57	52	—	—	70
Dry compact till	70	56	60	57	—	—
Silty sediments	62	62	64	—	—	—
Sandy sediments	68	61	52	—	60	—
Washed fine till	66	—	—	57	—	—
Coarse till	66	55	—	65	50	—
Fine till	77	68	—	—	68	76
Enriched	74	63	—	—	72	81

Quality

The primary, known influences of site on quality production are, as described, on species composition and growth trends—the propensity to maintain diameter growth in the large size classes. Certain high-value species such as ash, sugar maple, and oak are easily regenerated and grown only on a limited range of sites. In addition, there is some evidence that epicormic branching of oak is more severe on mediocre sites than on good ones (Smith 1966), and Shigo (1984) suggested that the occurrence of defects in associated clusters of trees might be related to site conditions.

Rotation or Structure

Rotation refers to the stand age at which the final harvest takes place under even-age management. Stand structure is the diameter distribution maintained following a selection or group-selection harvest. Both are influenced by site.

Rotation age is defined in at least two ways: the time required to grow a certain average-size tree (the technical rotation) or the age at which mean annual increment culminates. A recent simulation study indicated that the time required for a northern hardwood stand to reach a quadratic mean d.b.h. of 14 inches under an intensive thinning schedule ranged from 124 years on site index 50 to 77 years on site 70 (Solomon and Leak 1986). Age of culmination of mean annual board-foot increment ranged from 105 years on site 50 to 77 years on site 70. Rotations for culmination of biomass production are much less—40 to 50 years. Rotation age is important for several reasons. The shorter the rotation, the higher the proportion of the forest that is regenerated at each entry under usual approaches to even-age forest regulation, and the higher the proportion of forest in young age classes. Short rotations also mean a shorter period of investment for costs required to establish or culture a given stand. Finally, short rotations mean a shorter period of time available to recover losses of organic matter or nutrients during the cutting operation. In general, rotations of 60 years or more have been suggested as adequate for these recovery processes (Bormann et al. 1977), but the available information is incomplete.

On good sites, where large vigorous trees can be grown, the indications are that diameter distributions can be maintained through uneven-age management that have large maximum tree sizes, high proportions of sawtimber, and low values of q (the quotient between number of trees in successive 2-inch d.b.h. classes). The opposite is true on poor sites where the diameter distribution is characterized by small maximum tree sizes, low proportions of sawtimber, and high q values (steep J-shaped curves) (Leak et al. 1987). The cutting cycle probably is somewhat shorter on good sites due to the higher values and growth rates involved. The main influence of these structural differences relates to economics: potential differences in products, rates of value growth, and value of the residual growing stock.

Risk

Four types of risk deserve mention: windthrow, fire, snow-glaze-frost, and insects/disease, though most of what we know is observational rather than experimental.

Windthrow is perhaps the most serious and widespread site-related risk. Stands on shallow, moist soils (e.g., wet compact till) are extremely prone to windthrow. Some managers suggest that any partial cutting is unwise on such sites; others believe that cutting up to one-quarter to one-third of the basal area is feasible, especially if the reserve trees are chosen for windfirmness. Next in susceptibility to windthrow are moist (silty/clayey) sediments, and then shallow, well-drained sites (dry compact till and shallow bedrock). Hardwoods are more resistant to windthrow and breakage than softwoods during the leaf-off period, but not during the growing seasons.

Fire is seldom serious on most northern hardwood sites. Areas with outwash or shallow bedrock are most susceptible. These generally support softwood, mixedwood, or poor oak stands, but may contain early-to mid-successional northern hardwood associates. By the destruction of organic matter, fire appears to cause substantial deterioration to outwash and shallow-bedrock sites. For example, the pitch pine-bear oak stands in New Hampshire appear to be white pine-northern red oak sites that were burned repeatedly.

Heavy, wet snows may crush seedling/sapling hardwood stands, especially in small openings. But the damage is seldom as severe as it appears (Blum 1966), and is not easily related to site characteristics. Glaze damage appears to be related to elevation and perhaps other topographic factors, but the incidence of glaze damage in New England has not been well documented. Frost damage is fairly common and recurs on clearcuts at the base of slopes; occasional frosts in late spring can damage larger trees in the lower slope positions. Beech is especially susceptable, sugar maple and ash less so (Rast and Brisbin 1987).

Insect/disease damage in relation to site is another subject we know little about. Species composition influences susceptibility in certain cases. Sites that support oak in mixture with either hardwoods or softwoods are susceptible to gypsy moth. White ash and red maple, both site-related species, are resistant to saddled prominent. Certain root rots such as Armillaria are restricted by elevation (Rizzo 1986). There are opportunities for much additional research on the relationships between site and insect/disease incidence and damage.

Impacts

Site conditions influence at least three types of silvicultural impact: aesthetics, wildlife, and soils.

In New England, aesthetic impacts are of major importance. Perhaps the primary reason for practicing uneven-age management is to minimize aesthetic disruption. Site relates to aesthetics in two ways. First, some sites are most suited to the intolerant species best regenerated by clearcutting. On such sites, aesthetics may limit the size, location, or configuration of clearcuttings. Second, certain site conditions are related to topography and elevation, factors which also influence visibility.

Some of the tree, shrub, and herbaceous species that provide critical wildlife-habitat conditions are site dependent. For example, encouragement of oak mast or softwood deer yards is most feasible only on certain sites. Abundance and size of wildlife cavity trees is related to site. The beech-red maple stands that occur on washed tills develop large numbers of smaller cavity trees at a fairly early age. The large den trees required by certain mammals are best developed on good sites (fine tills and enriched sites) (Yamasaki and Tubbs 1986, Tubbs et al. 1987). Species richness and density of the herbaceous layer also varies among areas differing in bedrock mineralogy or nutrient status (Siccama et al. 1970).

Clearcutting produces a decline in forest-floor organic matter over about a 15-year period followed by a gradual return to normal over the next 50 to 60 years (Covington 1981, Federer 1984, Synder and Harter 1987). In addition, nutrient leaching is accelerated but returns to preharvest levels in about 10 years (Hornbeck et al. 1987). The extent to which losses and recovery rates are affected by site is not known. There is a general belief that these impacts could be greatest on dry, sandy soils where much of the exchange capacity is dependent on organic matter, or on shallow soils where rooting is restricted by bedrock, water, or shallow pans (White 1986).

Harvesting

Site conditions—slope, drainage, texture—have important influences on logging equipment, methods, seasons, roads, and costs, and on the potential for damage to tree boles and roots. In turn, harvesting methods and equipment provide a means for overcoming some of the risks and impacts mentioned previously.

Where clearcutting is the logical choice to favor desired species, the same objective can be accomplished with less aesthetic impact through large-group selection methods, low-density shelterwoods, or strip cutting. These methods have much less impact on nutrient loss from the forest floor. Cable systems also are becoming available to minimize site disturbances and road-building activities, especially on steep or wet areas.

Integration

A variety of silvicultural techniques are available for regenerating northern hardwood species. Intolerant species (e.g., paper birch) can be regenerated successfully by clearcutting, wide-strip cutting (> 1 chain), or large-group selection (> 2/3 acre). Intermediate species can be favored by low-density shelterwoods (30 to 50 percent/crown cover), narrrow strips (< 1 chain), or small-group selection (< 2/3 acre). Tolerant species regenerate well under single-tree selection or dense shelterwoods (80 percent crown cover), and remain as a component under most other cutting methods. As a result, most species can be regenerated under even-age or uneven-age techniques. Potential silvicultural conflicts related to aesthetics, wildlife, nutrient drawdown, and so forth generally can be resolved by modifying the silvicultural approach.

The process of integrating silvicultural alternatives with site conditions in a given stand can be approached by answering four questions:

1. In view of timber/wildlife objectives and site potential, what species or species mixes should be regenerated (or favored in thinning)?

2. What is the first choice for harvesting method, equipment, and site preparation?

3. What are the known risks and impacts?

4. What modifications are needed in harvesting/logging methods?

For example, consider a mature hardwood stand in mid-New Hampshire on a coarse sandy till. Species composition would be abundant beech, some red maple, perhaps a few oak on southerly aspects, some paper and yellow birches, and a few hemlock. The best timber species is paper birch, though some might opt for intensive site preparation and shelterwood cutting to maintain the oak.

Clearcutting, leaving a well-disturbed site, is the natural option—good for many species of wildlife also.

The only risks and impacts are: adverse aesthetic impact from clearcutting, losing the oak with its wildlife and timber values, organic-matter losses, and nutrient leaching on this dry site. To meet these concerns, the likeliest prescription might be to use small patch clearcuts or group selection with openings about two-thirds to 1 acre in size. Some of these would be placed near oak seed sources. Light partial cutting should be done between groups to harvest mature or risky timber and to maintain vigor and crown expansion in the oak. The stand would have to be somewhat accessible because group-selection cuttings that remove one-quarter to one-third of the timber (mostly beech and red maple) will not finance heavy access costs.

Unresolved Questions

At least four major questions remain unresolved. First, a great deal of additional research is needed on site classification so that the important factors influencing regeneration, growth, quality, and competitive position can be defined more sharply.

Second, silvicultural impacts on site quality (deterioration) remain unclear. Following prolonged agricultural use, we do see a change in forest type or species mix (Bormann 1982), which implies temporary site deterioration. However, forest productivity often is not affected, and may even be increased, because agriculturally related species (pines, other softwoods, oak) may be more productive and valuable than the natural type. Fragile sites (e.g., outwash, shallow bedrock) do appear susceptible to real losses in productivity following fires, agricultural use, etc.

Third, the relation of site to tree quality and insect/disease susceptibility is not clear.

Fourth, wildlife-habitat responses to site and silvicultural treatment are not well documented. In particular, little work has been done in northern hardwoods on herbaceous and shrubby layers, or on cavity-tree development.

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PROTECTING SITE PRODUCTIVITY: AN ECOLOGICAL PERSPECTIVE ON NORTHERN HARDWOOD SILVICULTURE

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From an ecological perspective, site productivity reflects the ability of the whole forest ecosystem to promote the growth of merchantable northern hardwoods. The current understanding of how harvesting affects each of five ecosystem properties—soil characteristics, stand characteristics, quality of the forest environment, hydrology, and nutrient cycles—is discussed. Care and planning in the application of silvicultural systems are essential to minimize site disturbance and thereby protect the native productivity of northern hardwood sites.

Introduction

In this symposium, site productivity refers to the ability of a given area to grow merchantable northern hardwoods. Typically it is measured as timber or biomass yield at a specified age. But tree growth depends on complex interactions among vegetation, soils, biotic, and climatic factors over the 80 to125 years required for a northern hardwood forest to mature. From this broader ecological perspective, site productivity reflects the ability of the whole forest ecosystem to promote merchantable tree growth. It is measured as soil characteristics, stand characteristics, quality of the forest environment, hydrological function, and nutrient conservation. Harvesting is assessed in terms of the extent to which it interrupts or diminishes these ecosystem properties.

In this paper we describe key properties and functions of the northern hardwood forest ecosystem, and discuss the current understanding of how harvesting affects the ecosystem. The discussion considers what can be done to minimize the detrimental effects of harvesting and thereby protect the native productivity of sites. Care and planning in the application of silvicultural systems are essential to this objective. Because only a part of the stand is harvested at a time, uneven-age management systems tend to be associated with less overall disturbance of the site. However, the more extensive impacts often associated with even-age management can be mitigated by following the recommendations presented.

The Northern Hardwood Forest Ecosystem

The northern hardwood forest, eastern forest cover type #25 (Eyre 1980), is characterized by three commercial species—sugar maple (Acer saccharum Marsh.), beech (Fagus grandifolia Ehrh.), and yellow birch (Betula alleghaniensis Britt.). Pin cherry (Prunus pensylvanica L.), paper birch (Betula papyrifera Marsh.), and aspen (Populus tremuloides Michx.) may be found in young, even-age stands. Red maple (Acer rubrum L.), black cherry (Prunus serotina Ehrh.), white ash (Fraxinus americana L.), red spruce (Picea rubens Sarg.), hemlock (Tsuga canadensis (L.) Carr.), basswood (Tilia americana L.), northern red oak (Quercus rubra L.), and eastern white pine (Pinus strobus L.), also might be present.

This northern hardwood type is found from the Maritime Provinces of Canada through northern New England, New York, and Pennsylvania to small areas in the southern Appalachians. It also occurs in Minnesota, Wisconsin and eastern upper Michigan, Ohio, and Indiana. Sugar maple is the most common species over this range, occurring on all but the extremes of soil drainage. The importance of beech diminishes in the western part of the range and yellow birch in the southern part. Beech tends to dominate on drier sites and yellow birch on wetter sites (Eyre 1980). Pin cherry is important in young stands in the Northeast and aspen is prevalent in burned areas in the Lake States.

Since the settlement of coastal New England more than 300 years ago, most of the northeastern area presently in northern hardwoods has been logged repeatedly or has reverted to forest from cropland or pasture. Ownership includes state and national forest lands, industrial forest holdings in northern New England, and predominantly small parcels, less than 40 ha (100 acres) that are privately held. Clearcutting and shelterwood cuts are the most common types of silvicultural harvest in the Northeast, though individual-tree selection and group selection are practiced widely.

In the northern Lake States, the northern hardwood forests generally have been logged two or three times, dating back to the late 1800's. Today, most stands are in the pole- to small-sawtimber stage. This resource is predominantly in the private sector, and numerous large parcels are managed for sawtimber products. Both uneven-age and even-age management are common, with selection and shelterwood the preferred methods of regeneration.

Climate, soils, and topography are variable across the range of northern hardwoods (Tubbs et al. 1983, Wenger 1984). Climate in the Lake States is continental, with cold winters and short, warm summers. Precipitation averages 500 to 800 mm (20 to 30 inches) per year. By contrast, the climate of the Northeast is tempered by proximity to the Atlantic Ocean and by several mountain ranges. Temperature fluctuations are less extreme and average annual precipitation is 800 to 1000 mm (30 to 40) inches.

Topography across the range of northern hardwoods tends to be rolling, but grades into steep and mountainous regions in the Northeast. In the Lake States, the groundwater table is frequently within the rooting zone forming large, poorly drained areas, whereas steeper terrain facilitates better drainage in the Northeast. Soils in the Lake States originated from glacial outwash sands, sandy to loamy tills, and lacustrine clays, and are classified primarily as Alfisols (Udalfs and Boralfs) and Spodosols (Orthods). Soils in New England, also of glacial origin, are usually Spodosols (Wenger 1984).

In general, soils found in mature northern hardwood forests have an upper organic layer or forest floor of new and partially decomposed leaves, twigs and other plant materials, and humus. This layer supplies nutrients to extensive fine-root systems, contributes to the water-holding capacity of the soil (Martin 1988), protects the mineral soil from extensive erosion (Patric 1976), and contains a bank of buried seeds important to regeneration (Bormann and Likens 1979, Frank and Safford 1970, Marks 1974). It is also the site of extensive activity by fungi, bacteria, and other microorganisms that promote the breakdown of organic matter and cycling of nutrients (Hendrickson et al. 1985, Jurgensen et al. 1979, Smeltzer et al. 1986). The deeper, mineral horizons provide substrate, nutrients, and water for the bulk of tree-root systems. They are characterized by lower concentrations of organic matter per unit area (overall they contain more organic matter because of the greater total mass) with larger proportions of available, partially weathered, and unweathered minerals (Bormann and Likens 1979).

Site Disturbances Associated with Harvesting

The northern hardwood forest ecosystem has been described in terms of its mature, relatively undisturbed state. Using this condition as a reference, harvesting can be evaluated by the extent to which it diminishes ecosystem function or degrades the site. The discussion that follows summarizes research on disturbances of the soil, stand, forest environment, hydrology, and nutrient cycles that may be caused by harvesting.

Soil Disturbance

Soil disturbance associated with harvesting of northern hardwoods generally refers to mechanical mixing or removal of the forest floor, soil compaction, and the creation of ruts. Severe disturbance can diminish the ability of the soil to support optimum tree growth or regeneration. Inversion and disruption of soil layers alters water flow, nutrient availability, and aeration. Erosion displaces soil from hillsides and deposits it down slope, often in streambeds.

Scarification is the mixing or sweeping of the organic and mineral layers caused by dragging branches or stems across the soil surface. Light scarification improves the seedbed for species such as yellow and paper birch and the conifers (Barrett et al. 1962, Marquis 1965a). Extensive scarification inverts and mixes the soil, exposing deep mineral layers which are susceptible to erosion, especially on steep slopes.

Heavy equipment moving over the surface of the soil causes compaction or collapse of soil structure, especially on shallow, wet, or fine-textured soils (Patric 1976). Bulk density is decreased and pore space is reduced, thereby reducing aeration and infiltration, leaching, and storage of water (Campbell et al. 1973, Hatchell et al. 1970, Moehring and Rawls 1970). Existing plant roots may be broken, and further root penetration and growth may be inhibited. Soil compaction has been shown to reduce long-term site productivity, particularly for Douglas fir (Went and Thomas 1981) and ponderosa pine (Froelich 1979). Compaction also can reduce the regeneration potential of a young stand following harvesting (Froelich and McNabb 1984, Hatchell et al. 1970, Raghaven et al. 1981, Youngberg 1959). However, these impacts have not been documented for northern hardwoods.

The creation of ruts or deep depressions by tires or tracks involves mixing, compaction, and displacement of some soil into an adjacent mound (Martin 1988). Ruts on flat terrain may fill with water while those on steeper slopes are susceptible to erosion (Patric 1976). Several decades may be required before the ruts fill in with soil (Hatchell et al. 1970). Establishment of seedlings in rutted areas may be slow and sparse (Martin 1988) and residual trees may show reduced growth (Moehring and Rawls 1970).

Disturbance of soils on a site is strongly influenced by the number of pieces and type of equipment used, the layout and construction of roads and skid trails, and the sizes and types of products removed.

Equipment Used: Where chain saws are used to fell and buck trees one at a time, only the logs (cable logging) or logging equipment (tractors, skidders, feller-forwarders) move over the site. The use of feller-bunchers together with skidders adds activity of another piece of equipment, with increased likelihood of greater disturbance (Martin 1988).

Some generalizations have been made with respect to type, weight, size, and capability of various types of harvesting equipment. Because of their greater maneuverability and clearance, articulated rubber-tired skidders can cover more rocky, steep, and diverse terrain than crawler tractors (Campbell et al. 1973). For the same reasons, rubber-tired skidders have the potential for inflicting more extensive damage.

Heavy, large feller-forwarders loaded with several cords of wood tend to compact the soil, forming deep ruts and associated mounds (Martin 1988). Smaller equipment with lighter loads can have less of a concentrated impact, but tend to affect a wider area. Cable logging, in which only the logs themselves move over the soil, can significantly reduce disturbance of the mineral soil compared with tractor logging, though disturbance of the litter may be about the same (Hatchell et al. 1970, Wooldridge 1960).

Roads and Skid Trails: Roads and primary skid trails subject to repeated passes by harvesting equipment are the major sources of erosion in forests (Patric 1980). Overall soil disturbance is highly correlated with the proportion of the site developed into roads (Kochenderfer and Wendel 1980). Therefore, construction and layout of roads and skid trails have a major influence on site productivity. Even on steep mountain slopes, careful construction followed by rapid revegetation can minimize the erosional impact (Reinhart and Eschner 1962).

Compacted soils on roads and skid trails can create problems for future establishment and growth of trees. Hatchell et al. (1970) reported that nine trips resulted in compaction of some sites to a porosity below 10 percent, a level often cited as critical for aeration needs of many agricultural crops. Repeated traffic over wet soils greatly increases susceptibility to compaction and erosion (Hatchell et al. 1970, Hornbeck et al. 1984, Martin 1988, Patric 1976).

Size and Type of Products Removed: In general, the larger the products removed from the forest, the greater the disturbance of soil over a broad area. For example, skidding of whole-trees tends to scarify a wide area whereas skidding of sawlogs forms deeper impressions in a concentrated area (Martin 1988). Shortwood systems, where the logs are removed from the woods on a forwarder, result in little to no scarification, but may cause compaction if the same skid trails are used repeatedly. Increased weight on a forwarder does not necessarily result in proportionally increased compaction (Trettin and Padley 1985).

On sites logged for chips, dead trees may be removed, minimizing buffering action of materials otherwise left on the soil surface. Logging residues reinforce the litter cover and protect the underlying soil from additional compaction and erosion (Patric 1980). Over the long term, this mulch retains moisture and builds up the organic matter content of the soil (Heiburg 1939).

Stand Disturbance

Stand disturbance refers to the degree of change in species composition, quality, and quantity (expressed as basal area, density, or biomass) of commercial trees associated with harvesting. More intensive harvests are generally associated with greater changes in stand characteristics. Depending on the overall silvicultural objectives, selective removal of trees may or may not significantly change the species composition while providing more space and resources for the residual stand. Small gaps may be occupied by seedlings of the same species as the overstory. In the Northeast, larger gaps favor the establishment of yellow birch seedlings, and strip clearcuts are prescribed where yellow birch is the desired species (Barrett et al. 1962, Hornbeck et al. 1987, Marquis 1965b).

Block clearcutting dramatically alters the stand characterisitcs. Basal area and biomass of the forest are reduced nearly to zero. A century or more may be required for another northern hardwood forest to mature. During this time, basal area increases, density of stems decreases (Smith 1986b, Tubbs et al. 1983), and several definite shifts in species dominance take place.

Immediately after clearcutting, the site may be occupied primarily by seedlings, grasses and herbs, especially raspberry (Barrett et al. 1962, Hornbeck et al. 1987, Marks 1974). In the Northeast, sprouts and seedlings begin to dominate by 3 to 5 years after cutting. Noncommercial species like pin cherry conserve nutrients on the site (Hornbeck et al. 1987, Likens et al. 1978, Marks 1974), a benefit which may outweigh competition with desired commercial species (Safford and Filip 1974). By 30 years, the pin cherry has died out (Marks 1974) and the sugar maple-beech-yellow birch complex that dominates the mature northern hardwood growing stock in the Northeast is established. Around 60 years, some yellow birch in the understory may die out, though individuals may remain in the overstory for over 100 years. The resultant maple-beech forest may continue to replace itself for decades thereafter, or assoicated conifers may dominate eventually (Leak 1987).

In the Lake States, however, the raspberry, brush, and grass stage lasts much longer unless the stand is well stocked with adequate advance regeneration prior to cutting (Tubbs 1977). Fifty years following clearcutting, the forest is typically dominated by sugar maple, with lesser amounts of yellow birch, basswood, red maple, and eastern hemlock (Albert and Barnes 1987). Areas that have been burned following cutting often have an aspen component which is generally replaced by the more tolerant northern hardwoods after 50 to 60 years.

Disturbance of the Forest Environment

Removal of some or all of the trees alters the physical characteristics—temperature, light, and moisture—of the forest environment. The mature hardwood forest is characterized by tall, large-diameter trees with large crowns overlapping to form a more or less continuous overstory canopy. From budbreak to leaffall the forest floor is shaded from direct sunlight. In addition, leaf surfaces are transpiring, drawing moisture from the soil, and raising the humidity within the forest.

Changes in the physical characteristics of the environment are more or less proportional to the intensity of the harvest. Small reductions in stand density tend to open up gaps in the canopy, increasing light penetration to localized portions of the understory or herbaceous layer. If the gap is small, it may be filled by extension of branches from neighboring trees. Seedlings present in the gaps are released and rapidly take up the space and light.

Intensive harvests change the physical environment over much of the site. In the absence of shade, sunlight strikes the soil surface directly and the temperature of both the air and the soil are raised. Barrett et al. (1962) made a direct comparison of uncut, partially cut, and clearcut plots in a northern hardwood forest. They found that reduction of stand density below 60 square feet of basal area resulted in a substantial increase in both the number of days in which high temperatures were measured and in the extremes of temperature fluctuation. Bormann and Likens (1979) attributed increased decomposition of the forest floor to increased activity of microorganisms because of higher average temperatures at the soil surface.

Tree removal also effectively eliminates both evapotranspirative loss of moisture from leaf surfaces and root uptake of moisture from the soil. The result is consistently higher levels of soil moisture (Barrett et al. 1962, Likens et al. 1978). If revegetation of the site is rapid, these effects are short-lived. By the following growing season, stump sprouts, seedlings, grasses, and herbs may be established and be transpiring moisture. By the second growing season after cutting, revegetation begins to shade the forest floor, and during the next 8 years a new canopy closes, reestablishing conditions similar to those in the mature forest (Covington and Aber 1980, Hornbeck et al. 1987, Marks 1974).

Hydrological Disturbance

Hydrological disturbance is the extent to which harvesting alters the movement of water on a given site. Hydrology of a site not only influences availability of moisture for tree growth but also affects soil nutrients, soil erosion potential, and streamwater quality and quantity. Overall, a combination of factors including climate, slope, aspect, and vegetative cover of the site, and depth, infiltration, and water-holding capacity of the soil affects the hydrology of a site (Douglass 1967, Hornbeck et al. 1984). About 500 to 1000 mm (20 to 40 inches) of precipitation, more or less evenly distributed throughout the year occurs in regions that support northern hardwood forests (Hornbeck et al. 1984). During the growing season a percentage of the rain infiltrates the soil where it is taken up by plant roots. Some precipitation may be lost to the ecosystem through deep seepage, though virtually watertight bedrock has enabled detailed hydrologic studies of small watersheds in New Hampshire (Likens et al. 1977). Most precipitation infiltrates the soil and is either stored or flows downward and laterally to a seep or stream. If the soil is frozen or saturated, or has low porosity or wettability, rain may flow overland into streams soon after striking the vegetation or soil (Hornbeck et al. 1984). Snow is stored on the soil surface until a period of thaw when it may infiltrate or run off (Hornbeck and Pierce 1969).

Soil disturbance due to harvesting tends to decrease the infiltration and water-holding capacity of the soil, thereby increasing overland flow (Craul 1976). Without vegetation or litter to intercept precipitation, the mineral soil takes the direct impact of rainfall. Especially on steep slopes, increased volume and velocity of runoff erodes the soil faster and carries a greater sediment load (Patric 1976).

Most critical in terms of cutting disturbance are areas around streambeds. These areas generally are characterized by poorly drained, fragile soils which may be the site of extensive biological activity. In addition, they support vegetation that protects streamwater quality by taking up nutrients before they are lost from the site in streamflow, by providing root systems that reduce stream channel erosion, and by shading the stream (Hornbeck et al. 1984). Cutting riparian vegetation increases light, temperature, and sediment load in the stream, promoting growth of some algae and altering the densities of stream biota (Noel et al. 1986). Because of the greater volume of flow during storms, organic debris dams may be washed out or shifted, altering patterns of flow and habitat for aquatic organisms (Likens et al. 1978).

In general, a reduction in forest cover increases water yield and stormflow (Hibbert 1967, Hornbeck and Ursic 1979) depending on factors such as the percentage of the watershed cut, topography, soil characteristics and disturbance during logging, and proximity of cut area to stream (Hibbert 1967, Hornbeck and Ursic 1979, Hornbeck et al. 1984, Likens et al. 1978). Due to decreased evapotranspiration, the increase in water yield is greatest during the first growing season after cutting. If harvesting does not significantly degrade the site (Likens et al. 1978), revegetation is rapid, and volume of streamflow returns to previous levels by 5 to10 years (Hornbeck et al. 1984). Uptake of moisture is influenced by density of trees and height and rooting depth as the forest develops. Hardwood species differences do not seem to influence water yield (Douglass 1967).

Nutrient Cycle Disturbance
Disturbance of nutrient cycles refers to the changes brought about by harvesting in the storage or availability of the mineral nutrients required for plant growth. Nutrients are stored in the northern hardwood forest ecosystem in living and dead vegetation, forest floor, soil and soil solution, and fauna (Bormann and Likens 1979). Inputs may include wet and dry deposition, weathering of soil particles, the major source of calcium, magnesium, potassium, and phosphorus, or biological fixation, which is a small source of nitrogen in northern hardwood forests (Bormann and Likens, 1979). Outputs are measured as losses in streamflow or volatilization (Binkley and Richter 1987, Likens et al. 1977). Nutrient budgets indicate the rate of accumulation or depletion for a given site, phase of forest development, or disturbance.

Harvesting generally causes two types of nutrient loss from the northern hardwood forest ecosystem. First, nutrients are part of the forest products directly removed from the site. Leaves and twigs tend to have the highest concentrations of nutrients, especially nitrogen, so that harvesting of crowns with stems represents a larger nutrient loss than stem-only removals (Hornbeck and Kropelin 1982). Harvest of certain species like oaks, which accumulate large amounts of calcium (Johnson et al. 1982), also may influence overall nutrient status, especially where few residues are left or returned to the site. Second, disturbance at the time of cutting may alter the biological processes that normally sequester nutrients. Additional nutrients are released by increased decomposition and microbial activity at the soil surface (Harvey et al. 1978, Jurgensen et al. 1979, Mroz et al. 1985), but may not be taken up by the roots of recently cut stems or small seedlings. Thus, they are susceptible to leaching and loss in streamflow (Johnson 1986). In northern hardwood forests in the White Mountains of New Hampshire, nitrogen is particularly susceptible to loss in this way (Hornbeck et al. 1987, Likens et al. 1978, Martin and Pierce 1980, Mroz et al. 1985).

Harvesting affects some sites more than others. Fertile sites with a history of net accumulation of nutrients stored in the soil as well as in the vegetation may recover rapidly after substantial removals. By contrast, infertile sites, e.g. those with shallow to bedrock or alluvial soils, wetlands, or those with known nutrient deficiencies, may require fertilization or may not be suitable for any type of harvest (White and Harvey 1979, White 1986). Sites in between these extremes may be able to sustain limited disturbance and removals. Little is known about the rate at which nutrients are made available to regrowth or about the amounts required by commercial species at various stages of recovery. The budget approach has been used for generally predicting rotation length based on estimated rates of replacement of nutrients through precipitation, weathering, or fertilization (Aber et al. 1982, Freedman 1981, Patric and Smith 1975, Smith 1986a).

Discussion
An understanding of how harvesting affects the forest ecosystem provides a framework for evaluating northern hardwood silviculture. The following discussion assumes that a major objective of forest management is to protect site productivity by minimizing disturbance associated with harvesting. Using the criteria for site disturbance just described, uneven-age management is compared with even-age management. It is important to note that extremes of any type of disturbance may be the consequence of the application of the silvicultural system rather than the system itself.

Soil Disturbance
Uneven-age management generally causes less mechanical disturbance of the soil than even-age management. Clearcutting often involves two or more pieces of equipment or larger, heavier equipment that may be potentially more damaging to a greater percentage of the site. Seymour (1986) states that large feller-bunchers, feller-forwarders, and long-reach booms are best suited to site preparation or overstory removal where the objective is the release of small advance growth. Small, maneuverable feller-bunchers are preferred for commercial thinnings, and chain saw and skidder combinations are most effective for improving irregular stands as stems of all diameters and species are removed.

Although roads and skid trails may be planned systematically over the site in either type of harvest, deep rutting on wet soils is more likely during clearcutting than partial cutting (Martin 1988). Craul (1976) found that infiltration was reduced by less than 10 percent in soils within partial cuts in New York, and by less than 20 percent in strip and block clearcuts. Removal of whole trees minimizes protection of the soil by residues. Less organic matter is available for building up the soil structure and moisture-holding capacity and supporting soil biota (Jurgensen et al. 1979).

Stand Disturbance
Uneven-age management generally causes less disturbance of a stand than even-age management. Uneven-age management involves manipulation of already established species to meet certain silvicultural objectives (Leak et al. 1987). Subsequent harvests may be planned for 15 to 20 years (Tubbs et al. 1983), over which period the environment is expected to remain reasonably constant. By contrast, even-age management is associated with much greater uncertainty. Major changes in the environment initiate a series of shifts in species dominance over

several decades. The relationships between precut forests, young revegetation, and the desired commercial forest are not obvious or well understood. Logging systems and practices are constantly changing, but the effects of various types of mechanical disturbance, intensity of harvest, and removal of nutrients on species composition require long-term study.

Disturbance of the Forest Environment

Uneven-age management is likely to change the physical environment of the forest less than even-age management. Stem density determines the degree of canopy closure, canopy height, and evapotranspiration, which influence temperature, light, and moisture conditions. Partial cutting increases the heterogeneity of the environment, with small, localized changes in temperature, moisture, and light, but only a portion of the overall site is affected. Clearcutting creates a more extreme but relatively uniform environment over the entire site. These conditions, in turn, affect the composition and development of the subsequent stand (Barrett et al. 1962, Hornbeck et al. 1987, Marquis 1965b).

Hydrological Disturbance

Because the increase in water yield is generally proportional to the percentage of the forest cut, uneven-age management has less impact on the hydrology of a site than even-age management. A conventional clearcut in New Hampshire increased water yield by 7 percent over 10 years; a progressive stripcut increased water yield by 4 percent and a commercial thinning did not increase water yield (Hornbeck et al. 1987, Martin 1986). Most of these increases occurred during growing seasons due to decreased uptake and evaporation of water by the vegetation.

Increases in erosion, sediment load, and nutrient loss, often associated with greater water yield from clearcuts, can reduce productivity of the site (Hornbeck et al. 1984, Likens et al. 1978, Martin and Pierce 1980, Patric 1976).

Stream channels and adjacent poorly-drained sites are sensitive to cutting disturbances. Both water quality and quantity are affected. Noel et al. (1986) reported a shift in dominance to green algae in streams draining clearcut areas over diatoms in streams draining uncut areas. Macroinvertebrate densities were 2 to 4 times greater, and periphyton densities were 6 times higher in cutover areas. These changes apparently were caused by the increase in light, temperature, and particle size of sediment in the stream draining the clearcut watershed. Such impacts are reduced by maintaining forest cover (e.g. buffer strips) around the stream channel.

Nutrient Cycle Disturbance

In general, uneven-age management has a less severe impact on nutrient cycles of northern hardwood forest ecosystems than even-age management. Direct removals of nutrients in a single thinning are considerably smaller than removals from single intensive harvests. Because of the greater concentration of nutrients in tree crowns, whole-tree removal tends to have a greater impact than stem-only removal (Freedman 1981, Hornbeck 1986, Smith 1986a). Hornbeck and Kropelin (1982) found that harvesting with leaves increased removals of N by 19 percent, Ca by 12 percent, and K by 15 percent over removals without leaves. Whole-tree clearcuts with removal of 96 percent of the aboveground living and dead biomass, 30 percent of the estimated available Ca, and 85 percent of the estimated K can have a major impact on total nutrient reserves of the site (Hornbeck and Kropelin 1982). Although uneven-age management may result in greater nutrient removal over the course of a rotation (Smith 1986a), the magnitude of any one removal is a smaller percentage of total site capital. Overall, nutrient reserves are more likely to remain above levels required for tree growth.

Elevated nutrient concentrations in streamwater parallel the extent to which the site is cleared, stand density is reduced, and the soil is disturbed. Uneven-age practices that minimize these types of site disturbance also minimize nutrient losses. Martin and Pierce (1980) found that mean nitrate levels of streamwater rose from 2 mg L^{-1} to 25 mg L^{-1}, and calcium levels rose from 2 mg L^{-1} to 6 mg L^{-1} in the second year after clearcutting. Losses from streams draining partially clearcut watersheds and progressive strip cuts were substantially smaller. Clearcutting only the lower 40 percent of the watershed studied by Hornbeck and Kropelin (1982) resulted in an increase of 3 mg L^{-1} nitrate and 1 mg L^{-1} of calcium. Leaching losses tend to be greatest during the first 3 years after cutting and return to precutting levels by 5 to 10 years (Hornbeck et al. 1987). As an example of an extreme case involving experimental delay of regrowth after cutting, leaching losses over a 10-year period represented 28 percent of total nitrogen and 88 percent of the estimated available calcium (Likens et al. 1978). However, Patric and Smith (1975) emphasized that nutrient loss in streamwater after most conventional cuts followed by rapid regrowth is minimal.

Product removal and leaching combined accounted for less than 3 percent of the total capital of the nutrients studied by Hornbeck et al. (1987). However, they estimated that 26 to 596 percent of the available nutrient capital was lost. Aber et al. (1982) suggested that such intensive harvests on a short-rotation basis can reduce fiber yield substantially.

Conclusions and Recommendations

Site productivity is closely related to the extent of disturbance of the soil, stand, forest environment, hydrology, and nutrient cycles associated with common harvesting practices. Applications of silvicultural systems aimed at minimizing short-term disruption and long-term degradation of the site are preferable. Based on available ecological information, it appears that uneven-age management of northern hardwoods has met these concerns more often than even-age management. However, even-age management is often the best choice from a practical or economic outlook. Several recommendations for protecting site productivity can be made.

Minimize soil disturbance by:

* Harvesting when soils are dry or frozen. This might involve planning of harvests so that poorly drained areas or wet sites can be logged in late summer or fall or during cold periods. Ideally, logging could be suspended when the site is too wet (Martin 1988).

* Planning the type of equipment to be used based on characteristics of the site. Smaller, lighter, tracked vehicles could reduce compaction and mixing of soils on wet sites. Reducing the weight carried by feller-forwarders could reduce overall soil compaction (Hornbeck et al. 1984, Martin 1988).

* Planning skid roads along contours as much as possible. Avoid roads that run straight uphill (Martin 1988). Minimize the area in main skid roads and landings, that is subject to repeated passes of equipment (Kochenderfer and Wendel 1980, Patric 1980).

Minimize stand disturbance by:

* Clearcutting only those sites that are well stocked with advance regeneration.

* Planning harvests to favor the desired species. For example, light scarification and strip cutting are known to favor yellow birch (Hornbeck et al. 1987, Marquis 1965b).

Minimize disturbance of the forest environment by:

* Cutting in strips or small patches rather than large block clearcuts. Some shade would be maintained over a portion of the site to mitigate the extremes of sunlight and temperature fluctuation, thereby favoring the establishment of commercial species (Barrett et al. 1962, Hornbeck et al. 1987).

Minimize hydrological disturbance by:

* Planning roads away from wet soils and streams to reduce runoff and erosion, and to protect streamwater quality, and by limiting or avoiding stream crossings (Hornbeck and Ursic 1979, Martin 1988).

* Maintaining buffer strips close to streams (Hornbeck and Ursic 1979).

* Cutting only parts or strips of watersheds at one time (Martin and Pierce 1980).

Minimize nutrient cycle disturbance by:

* Allowing hardwoods to remain on-site for a period after cutting in the summer until the leaves fall off. Hornbeck and Kropelin (1982) demonstrated that removal of leaves increased nutrient removal by 4 to 19 percent, depending on the specific nutrient, over harvesting without leaves.

* Leaving other residues—limbs, crowns, and dead trees—well distributed on site as much as possible.

* Protecting on-site nutrient reserves by reducing soil disturbance, using the practices outlined above.

* Planning longer rotations or fertilization after intensive harvests to allow replenishment of nutrients (Aber et al. 1982, Smith 1986a).

In general, forest management plans should be based on a knowledge of the ecology of the soils and the landscape as well as the ecology of the vegetation. Sensitive or fragile areas, such as wetlands and nutrient-poor sites should be identified in advance and avoided where possible. Harvesting plans should be flexible enough to accommodate suspension of logging on wet soils during unfavorable seasons or weather. Finally, careful operation of equipment can be effective in mitigating the disturbance associated with harvesting on any site (Craul 1976, Patric 1980).

Several key issues with respect to the effects of harvesting on long-term productivity of northern hardwood sites need to be addressed in the coming years. First, a reliable way to identify "sensitive" sites would enable foresters to plan harvests or management programs. White (1986) has made a beginning in this regard by cautioning against intensive harvesting on coarse-textured outwash sands, soils with high percentages of coarse fragments, shallow soils, soils with phosphorus, potassium, or magnesium deficiences, and areas with high seasonal water tables. Aber et al. (1982) and Smith (1986a) used computer simulations to try out different regimes based on specific assumptions about site productivity, harvest intensity, and replenishment rates.

Second, relationships between intensity of harvest, sources and rates of nutrient replenishment, and rotation length need to be established more precisely. Required nutrient levels, key nutrients for certain species, and the ability of certain sites to supply them need to be identified.

Until such information is available, forest management must be conservative, aimed at promoting merchantable tree growth by minimizing disturbance of the ecosystem and protecting overall productivity of the site.

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THE HEALTH OF NORTHERN HARDWOOD FORESTS IN RELATION TO TIMBER MANAGEMENT PRACTICES

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The most significant pest problems of northern hardwood forests are those which cause a direct degrade in timber quality, or result in the occupation of productive sites with defective trees. Preventive measures are most often cited as the key to successful disease management. Although sound in principle, most recommended preventive measures are general in nature, and provide little specific guidance for practicing forest managers. A few specific sanitiation recommendations exist which aid in management of these diseases in affected stands.

Most diseases of northern hardwoods may be found in unmanaged stands as well as in stands managed by either even-age or uneven-age silvicultural systems. With few exceptions, decisions regarding forest management strategy will be dictated by factors other than disease considerations. This will remain the case until more specific disease management guidelines are developed. Even-age systems require greater attention to preventive measures, while uneven-age systems use both preventive and sanitation techniques. New and more specific disease management guidelines must come from additional research on the biology of early stand development, and on the development of harvesting equipment and systems which result in less damage to residual trees and to the site itself.

Introduction

Northern hardwood forests are not threatened by many chronic forest pathogens that cause widespread, direct tree mortality. This is due largely to the great diversity in tree species, and the different local timber uses and harvesting practices which maintain that diversity created, in part, by a complex mosaic of ownerships.

Generally, thrifty northern hardwood stands can be regenerated successfully on a wide variety of sites, and following a wide array of management practices under all silvicultural systems (Leak et al. 1987). The abundance of this and other related forest types, often even after repeated highgrading and mismanagement, testifies to the general resiliency of this forest.

The most important disease-related impacts occurring within these forests are related to timber quality characteristics (Baskerville 1977, Miller et al. 1978). In a recent review of hardwood inventory statistics, Wallace (1987) indicated that 49% of the sawtimber in Vermont is rough or rotten (cull); 33% of the growing stock in New Hampshire is classed as cull; 75% of the sawtimber in Minnesota, and 65% in New York is in Grade #3 or poorer logs; and 66% of the resource in Maine is in Grade #3 or poorer (Powell and Dickson 1984). Volume loss as a result of wood decay, and value loss resulting from stains and discolorations continue to be the major forest disease problems (Shigo and Larsen 1969, Shortle 1987). Several canker diseases also directly affect bole quality. Diebacks and declines of varying intensity have occurred in the past, and those associated with short-term climatic trends or triggered by primary biotic agents will likely recur. "New" declines may be described as more becomes known about the interrelationships of air pollutants, acidic precipitation, and the northeastern forests (Smith 1981, Linzon 1986, Klein and Perkins 1987, Mitchell 1987).

To bring these diseases into the perspective of forest management, background information is provided on the biology and damage characteristics of the most important problems, followed by a brief review of the "disease pyramid"—those factors which regulate disease occurrence and severity. How silvicultural systems will influence the disease pyramid is then discussed, along with the pathological implications of several key forest management techniques currently practiced.

Principal Forest Health Problems

I. Root Diseases

Armillaria Root Rot: The single most important root disease problem in northern hardwoods is Armillaria root rot. Biology of this disease in eastern hardwood forests was recently reviewed by Wargo and Shaw (1985). It is believed to act as a secondary pathogen. Tree roots become colonized and tree mortality results only to individuals that are sufficiently stressed by some other factor. Stress factors that commonly occur in hardwood forests include defoliation by insects such as the saddled prominent, gypsy moth, and forest tent caterpillar, or severe or abnormal weather conditions (Houston 1967, 1981, Kessler 1965). Damage to residual trees following partial cutting also commonly occurs (Ostrofsky et al. 1986).

Damage caused by Armillaria spp. varies with the tree species and the stress factor involved. For example, Shigo (1969) described a condition known as "collar crack" in paper and yellow birch which develops when Armillaria spp. infects roots. Trees with collar crack were commonly found in stands which had been partially cut. Collar crack is a serious problem, especially for paper birch, because development of discolored wood progresses at a very rapid rate compared with other northern hardwoods (Shigo and Sharon 1968). Subsequently, stem decay fungi can rapidly invade the injured bole and result in rapid tree decline. Wargo (1982) found that in beech damaged by the beech bark disease, only those portions of the roots and root crown area directly aligned with bark necrosis on the bole were infected by Armillaria spp. Although it weakened infected trees, the fungus did not cause direct mortality.

Prevailing Management Recommendations: Infection by Armillaria spp. depends on tree condition, therefore keeping trees vigorous by preventing stress is most commonly recommended (Manion 1981). Spraying to control defoliators, removal of low vigor trees, and thinning the stand to improve growing conditions for residual trees is recommended for stands already affected by one or more stress agents (Houston 1981).

Sapstreak Disease of Maple: Another disease which appears to be increasing in importance is a vascular staining disease of sugar maple called sapstreak (Hepting 1944, Kessler 1978). Root and butt injuries are the primary avenues through which trees become infected (Houston 1985). Sapstreak disease is caused by the pathogen Ceratocystis coerulescens, and has been responsible for substantial mortality in sugarbushes of New York (Beil and Kessler 1979) and Vermont (Houston and Fisher 1964). The organism is a wound pathogen, and is capable of rapid growth within infected individual stems. Both large and small sugar maple which are affected to the point that the crowns exhibit symptoms do not recover, and will usually die within 3 or 4 years (Kessler 1978). The fungus is a common saprophyte in northern hardwood forests, and it rapidly colonizes the freshly cut ends of logs of most northeastern hardwood species (Shigo 1962).

Prevailing Management Recommendations: Control of this disease by preventing or reducing injuries to the roots and root crown area is the most effective management strategy. Prompt removal of infected trees during timber stand improvement operations is also recommended (Kessler 1978).

II. Stem Cankers

Nectria Canker: Several stem cankers on northern hardwoods cause serious degrade in the quality of individual stems, but only occasionally affect a large number of individuals in a stand. Of these, the target canker caused by Nectria galligena is the best known. Although most eastern hardwood species may become infected, yellow and paper birch are the most susceptible northern hardwoods. N. galligena usually is considered a problem on trees that are growing "off-site", overtopped, or of otherwise poor vigor (Lortie 1969). Certain geographical areas near large lakes are especially high hazard zones for this disease (Anderson and Mosher 1979).

Because infection by N. galligena is usually associated with branches less than 0.5 inch-diameter (Grant and Spaulding 1939), most bole infections develop before trees reach large sapling or pole size. Although older stem infections do not result in significant growth loss, serious losses in timber quality do occur (Manion 1981). Furthermore, because infected trees may survive for long periods, valuable stand space is occupied by low-quality individuals.

Prevailing Management Recommendations: Eradication of Nectria-infected trees in pole-sized stands of oak did not control the disease (Roth and Hepting 1954). However, removal of infected trees during timber stand improvement operations remains the primary management prescription. Regenerating heavily damaged stands to less susceptible species is also recommended (Anderson and Mosher 1978). Logging during the winter months, when successful infection of tree wounds is least likely, has also been recommended (Lortie 1969).

Eutypella Canker: Eutypella canker is a disease similar to Nectria canker in its effect on tree quality, but it is important only on sugar and red maples. This causal fungus, Eutypella parasitica, is also a wound pathogen and requires exposed xylem as an infection court. Cankers appear most commonly on suppressed trees, and infected trees often occur in clusters within the stand (Kliejunas and Kuntz 1974, Shigo 1984).

Prevailing Management Recommendations: Kliejunas and Kuntz (1974) suggest that efforts to eradicate Eutypella canker during timber stand improvement operations should be more successful than those to eradicate Nectria canker. This is based on their findings that the distance spores of E. parasitica are dispersed is more restricted, and the fungus produces fewer spores.

Diaporthe Canker: Yellow birch are susceptible to a shoot blight and stem canker caused by Diaporthe alleghaniensis, and may be killed by the disease until they reach the size of small saplings. This appears to be one of the few serious diseases of reproduction stands, especially in the north-central states (Kessler 1976). The disease has also been reported from New England (Hepting 1971). The impact of this disease on future stand development has not been assessed.

Prevailing Management Recommendations: Although no direct control is known, Kessler (1976) suggests that trees growing offsite, or growing under severe competition are most susceptible.

Beech Bark Disease: Beech bark disease is perhaps the only disease of enough importance in northern hardwoods to demand primary action rather than be managed within the context of the overall silvicultural objective. In Maine, more than 44% of the American beech is classed as cull, primarily due to the beech bark disease (Powell and Dickson 1984). In New York, it was recently considered the second most important of all forest diseases in terms of volume lost (Levesque and Miller-Weeks 1987).

This canker disease results from the interaction of several organisms; the primary players are a scale insect (Cryptococcus fagisuga) and several species of fungi in the genus Nectria (usually N. coccinea var. faginata in northern New England). A comprehensive review of the problem is provided by Houston and Wainhouse (1982).

The disease is a particularly formidable forest management problem for several reasons. First, it causes direct mortality, often killing the largest trees in the stand. High mortality usually occurs during the "killing front" stage of the disease (Shigo 1972). Twery and Patterson (1984) have shown that beech mortality in central New England is highest in stands dominated by hemlock. The disease also reduces tree growth and timber quality. But the most serious loss is that of site productivity, especially in the "aftermath" zone (Shigo 1972, Houston 1975). This is a direct result of the shade tolerance and the sprouting capacity of American beech, and its ability to withstand a high level of stem infections and continue to survive (Ostrofsky and McCormack 1986).

Prevailing Management Recommendations: Several management recommendations have been proposed, each dependent on local stand conditions and stage of disease development. In the "advancing" (only scale insect present) and killing front (scale and fungus present) stages, timely salvage of large beech is recommended. This usually can be accomplished by some form of partial cutting compatible with uneven-age management objectives (Filip 1978). In aftermath forest stands dominated by advance beech reproduction, shelterwood harvesting regimes in conjunction with herbicide treatments have been proposed (Kelty and Nyland 1981, Ostrofsky and McCormack 1986). Clearcutting and stand conversion to conifers may be another alternative for some sites. The recent discovery that at least some beech in almost every stand are resistant to infestation by the scale insect provides managers with another tool to combat this disease (Houston 1982, Houston and Houston 1987). Specific techniques to manipulate resistant beech in forest stands are currently under investigation.

III. Internal Discolorations and Decays

Grouped as a class, the organisms causing discoloration and decay are the most significant pathogens of northern hardwoods, primarily because of their effect on wood quality and timber value. The process of discoloration and decay has been the focus of an intensive research effort by the USDA Forest Service for nearly 30 years, and many reviews of the subject are available (Shigo 1967, 1979, Shigo and Marx 1977, Shortle 1979).

Wounds, defined as injuries to the vascular cambium and/or cork cambium, are required to inititate the process of discoloration and decay in living trees. Decay can be just as serious in small trees as in larger trees if excessive wounding occurs. Conversely, most northern hardwoods have the potential to develop into large, high quality trees if excessive wounding does not occur. Although the process is similar regardless of the cause of wounding, it is useful to examine the role of natural wounds separately from those caused by human activities.

Natural Defects: Throughout their life, trees are wounded by a number of agents, including animals, insects, and severe weather. Except in small woodlots and other intensively managed areas, damage by most of these agents is beyond direct control.

The most important natural wounds, however, result when branches are lost through the natural shedding process. Rapid death and shedding of moribund branches, followed by rapid branch stub closure minimizes development of discolored wood. Presently, control of stand density is the primary way in which the manager can influence the branch-shedding process.

Logging Wounds: Wounds which occur to residual trees during a partial harvest or other intermediate timber stand practice are critically important to growing quality timber. Although often viewed as non-preventable, the overall level of wounding can be reduced through careful evaluation of stand characteristics prior to the harvesting activity (Ostrofsky 1988). Such stand damage is directly within the control of the forest manager, and therefore represents a key area where substantial losses in quality can be prevented.

Prevailing Management Recommendations: Control of stand density is the primary way in which natural branch shedding can be manipulated, although specific recommendations for different species mixes and sites are lacking. Pruning would appear to be an alternative, but is currently practiced only in intensively managed, small woodlots. Preventing wounds during logging operations, and maintaining good tree vigor should minimize losses to discolorations and decays.

IV. Declines

Maple Decline: Several declines of sugar maple have been described, but those occurring in forest stands are usually the result of severe and/or repeated defoliation by insects (Houston 1981, Allen 1987). As a result, trees become less vigorous, and dieback begins. When the defoliation pressure continues, tree physiology is altered and the tree becomes susceptible to infection by secondary pathogens. Armillaria root rot is commonly found associated with declining trees, and although trees growing on poor sites, or which already are weakened are often the first to decline, large otherwise healthy trees are also at risk.

Stress factors other than defoliation can also be involved in maple decline. For example, drought and forest disturbances such as logging or sugarbush activities can result in tree stress (Mitchell 1987). In addition, more than one stress factor may be operating simultaneously.

Current reports from New York and Vermont indicate that decline symptoms in sugar maple are widespread and may be increasing in severity. The decline does not appear to be associated with defoliation stress in all areas of New York, but may be the result of insect activity in most areas in Vermont (Levesque and Miller-Weeks 1987).

Prevailing Management Recommendations: Successful management of sugar maple decline depends on accurate identification of the stress-causing agents. If defoliation by insects is the principal stress, direct control of the insect populations may be most appropriate. Difficulty arises when unknown or multiple stress agents are involved. In these cases, the usual preventive measures are recommended for stands suspected of being at risk: preventing excessive logging wounds, matching the species composition to the most suitable sites, and maintenance of tree vigor by thinning. However, it must be recognized that thinning just prior to, during, or immediately after a stress event can exacerbate damage resulting from Armillaria root rot.

Birch Decline: Paper and yellow birches have undergone several periods of decline, the most well-known occurred during the late 1940's to the mid1950's (Nash et al. 1951). Recent declines in Maine have been attributed to defoliation by the birch casebearer and by leafminers. Declines in New York and Vermont appear to be associated with long periods of dry weather (Levesque and Miller-Weeks 1987). As with other declines, one or more stress factors result in the gradual dieback of the crowns, and the increased susceptibility to secondary insects and pathogens.

Prevailing Management Recommendations: As with all tree declines, identification of the principal stress factors is necessary before appropriate action can be recommended. Preventive measures are the same as those stated for sugar maple decline.

Factors Regulating Disease Development

Pathologists generally recognize four factors which regulate disease development and severity. These factors include characteristics of the pathogen, host, and environment, and the factor of time. Although all four components operate together to determine the actual course of the disease, usually one factor predominates in its influence on disease development. All factors have been used to manipulate the impact of certain forest diseases; some are more easily manipulated in the context of forest management than others.

As forest managers, our ability to regulate environmental aspects of the site such as available light and moisture, and proper site selection, followed by host manipulation (species composition, vigor) appears to be our most powerful tool. An adjustment in time can also play an important role, and is usually accomplished by shortening rotations to avoid losses resulting from decay.

Forest managers have little opportunity to directly control these pathogens, especially over the short term of one or two rotations. However, certain avenues of biotechnological research may soon provide the opportunity to experiment with this approach as well. Changes in the characteristics of the pests as a result of the forest management practiced will occur over a longer period of time.

Discussion—Where Does Forest Management Fit In?

All diseases described above can be found in stands managed either by uneven-age or even-age silvicultural systems. Both strategies are likely to require several stand entries during the rotation. Which intermediate practices are used, and how they are applied will also significantly impact disease occurrence and timber loss. Regulation of disease is determined not so much by the management strategy used, but how the system is applied.

The Size-Quality Relationship: Most forest sites have the potential to produce higher quality timber than is presently grown. The quality characteristics of a stand are largely determined by tree size and age (Fig. 1). Traditional size specifications for veneer quality timber is evidence of this.

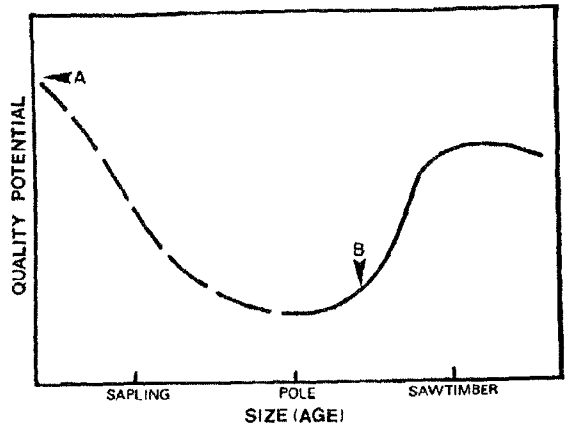

Figure 1. Conceptual view of the size-quality relationship for northern hardwoods. Trees start with a given genetic potential (A) at the time of seed germination. As they develop, quality potential is eroded by environmental factors—insects, diseases, branch shedding rates, etc. (broken line). Wood quality increases when defect accumulation by the corewood ceases (solid line). The current minimum operational tree size (B) is indicated.

Indeed, a principal reason for the overabundance of poor quality wood is the tendency in forest management to decrease the rotation age. This has resulted in a decrease in the average diameter of the wood grown. Simply put, a greater percentage of the volume of a small tree is occupied by a central core of knots and discolored wood than occurs in a large tree. By the late sapling to early pole stage, this defective core is usually fixed by a barrier zone (Shigo and Marx 1977). The main bole is then free of branches and will remain clear, unless previously infected by canker organisms or injured during subsequent logging operations. Now, wood quality gradually increases as tree size increases until maturity, and loss from internal decay becomes insignificant.

Using this size-quality concept, it becomes clear that there are two courses of action which will lead to improved overall quality. The first is to lengthen the rotation, and grow larger trees. The second is to manage in a way that will reduce or eliminate the defect and disease problems early in the development of the stand. The choice of silvicultural prescription should be based, at least in part, on which of these two strategies is considered acceptable for current ownership objectives. Under some stand conditions, a silvicultural option may be available which will aid both strategies.

Silvicultural Consequences: In managed stands of the Northeast, uneven-age systems have been successfully used to grow trees under long rotations for sawlogs and veener. Such systems (either single-tree or group selection) permit the removal of unsound individuals for firewood, pulp, or fuel biomass at regular intervals, and the development of high quality individuals by providing the extra time (if required) to increase in size. Forest practice under these systems will rely heavily on sanitation measures to manage most diseases (Filip 1978, Kliejunas and Kuntz 1974).

The obvious difficulty with uneven-age management is that frequent and repeated stand entries can result in serious damage to the residual trees. If the promising, high quality trees become injured, the management objective is defeated. Prevention of injuries is critical, and management practices such as timber marking, road layout, season of activity, and choice of logging equipment determines degree of success. Another potential problem with uneven-age management is the difficulty in determining vigor and growth potential of advance reproduction. Small trees are often old trees, and although they may survive, they are likely to be less vigorous and more vulnerable to damaging agents than younger reproduction of the same size (Houston 1987).

Shelterwood systems present advantages and disadvantages for disease management similar to those of uneven-age management systems. Removal of defective trees may be accomplished so that they do not contribute seed to the regenerating stand. Ideally, high quality trees should be left in the overstory to contribute high quality seed. These overstory residuals may be damaged during the initial seed cut, with concomitant loss in stem quality.

Clearcutting provides the opportunity to "start anew" with the forest, and with the problems associated with timber quality. Under this system, preventive techniques for disease management offer the most advantage. Assuming a desirable species mix in adequate quantity, the task becomes one of early stand manipulation. Identification of high-potential individuals, and density control to maintain tree vigor and to insure rapid, early natural shedding of branches is required. As with the other systems, the intermediate practices will affect disease development. For example, excessive wounding of residual trees during thinning is just as much a potential problem in even-age stands as in uneven-age stands.

Research Needs

Examination of the prevailing management recommendations for the diseases outlined above underscore the need for additional research. Although most pathologists agree that preventive measures are critical to managing diseases in the forest, few specific recommendations are available. This is especially the case for young (seedling through sapling) stands. The natural role of diseases in early forest stand development is poorly understood. There is a lack of information on the natural thinning role which diseases play in very young stands. Information on the rate of branch development, aging, and senescence would facilitate our understanding of the natural process of branch shedding, and could lead to new density requirement guidelines to minimize the size of defective tree cores. Sonderman and Brisbin (1978), and Sonderman (1985, 1986) have provided insight into this process in older sapling and pole stands of central hardwood species. This exemplary work needs to be expanded to northern hardwoods, and to younger stands.

A better understanding of how young trees respond to infection by various pathogens is needed. For example, conflicting reports exist as to whether or not the various canker diseases affect primarily "weakened" trees (Kliejunas and Kuntz 1974, Lortie 1969) or healthy trees, as well (Manion 1981). The work of Anderson and Mosher (1979) also suggests that Nectria canker is not simply a disease of low-vigor trees. Are the trees more susceptible to begin with, or are they "of low vigor" because they are cankered? Additional studies of microenvironmental conditions in young stands could help to answer these and similar questions.

Disease detection methods for young stands need to be developed or improved. It is very difficult to identify many of the common problems on smaller trees, yet earlier detection is critical if problems are to be avoided, especially when shorter rotations (and smaller trees) are desirable.

Maintenance of tree vigor is recommended as a preventive measure for nearly all diseases. A better understanding of what "tree vigor" is, and ways to measure it should be a high research priority. In addition, it is still unclear, on the forest management level, just how to go about maintaining or improving tree vigor. For example, although the use of fertilizers is often recommended for improving vigor of street trees, fertilization under forest conditions may result in adverse, disease-related side effects (Safford and Czapowskyj 1986). Certain thinning regimes, long believed to improve tree vigor, have had similar consequences (Wall 1983, 1986).

Along with the ecological aspects, operational aspects require more attention. In every silvicultural system, the potential to injure desirable crop trees is present. The recommendations are always "don't wound trees". How? There is a continuing need to develop harvesting equipment and systems that are less damaging but operationally productive. Forest biologists must become more enlightened about forest engineering, and vice-versa. This need has long been recognized in Scandinavia (Knutell 1987), but related research in the northern hardwood region lags behind.

Continued research is also needed on sanitiation methods. However, this approach tends to be better understood than are approaches to prevent diseases.

Conclusions

It is most important to manage forest diseases by stage of forest development. Young, even-age stands will require the application of disease-prevention stategies, knowledge of which is admittedly limited at this time. Management of diseases in older even-age stands will rely more heavily on sanitation procedures, and on salvaging low quality, but useable individuals. As even-age stands approach maturity, options for managing diseases to improve timber quality become limited.

Uneven-age management requires use of both preventive and sanitation techniques on a continuing basis, which probably makes the overall forest management job more difficult to administer. However, the possibility of more frequent entries may be a decided advantage in the timely application of certain control practices.

Certain diseases, such as beech bark disease and the declines, are more disruptive, and require special ameliorative techniques to regain site productivity, or establish species better suited to the site. Because these diseases interrupt the planned progression of a "normal" silviculture strategy, recommendations should be developed on a case by case basis, with advice from specialists familier with the particular problem.

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ENTOMOLOGICAL CONSEQUENCES OF EVEN- AND UNEVEN-AGED MANAGEMENT IN NORTHERN HARDWOOD FORESTS

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There have been no controlled studies to document the entomological consequences of even- and uneven-aged management in northern hardwood forests. Empirical evidence indicates that either silvicultural approach can have positive or negative effects on populations of insect pests depending on the degree to which the treatment alters insect life systems and influences the character of the residual stand. Encouraging a mixture of tree species or age classes and minimizing damage to the residual stand will reduce the probability of outbreaks (stand susceptibility) or likelihood of significant damage (vulnerability).

Both short- and long-term studies are necessary to elucidate interactions bertween silvicultural methods and insect pests. Foresters must be familiar with the potential insect problems associated with the major forest types. The ability to prevent insect-caused damage is, in part, determined by the forester's skill in recognizing susceptible forest conditions and early evidence of potential outbreaks.

I commend the organizers of this symposium for designing a program that takes a holistic view of northern hardwood silviculture. As a forest entomologist interested specifically in northern hardwood insects, I have tried over the years to communicate results of my research and make pest management recommendations to forest managers. All too often, however, I find myself in a room talking solely with other forest entomologists or pathologists!

In one respect this is understandable, because of the nature of most forest pest problems. Rarely are we dealing with one type of organism in any situation. Rather, the end result in terms of tree growth loss, degrade or mortality can be attributed to a sequence of events that includes a complex of insects and microorganisms. On the other hand, by talking only to ourselves it is often easy to overlook the primary purpose of our work; that is, to serve forest management.

Our parochialism is a result, in part, of the burgeoning knowledge and intense specialization that characterizes every field of modern science. In my view, it also reflects the manner in which students are exposed to subjects in many forestry schools. Forest protection courses are often taught by people with a background in agriculture, who may be excellent teachers and active in research, but by the very nature of their training they are unable to relate subject matter to the forest situation. This, coupled with the fact that protection courses are usually elective and not required, preconditions practicing foresters, in turn, to treat these aspects of forest management as "elective".

This attitude is changing, in large measure because of the acceptance and relevance of integrated forest pest management. This forest protection concept is predicated on an understanding of forest pest life systems, forest stand dynamics and how these two phenomena interact (Waters and Stark 1980). Integrated pest management in southern pine forests is a good example of the need, benefits and interdisciplinary nature of such an endeavor (Thatcher et al. 1980). This program could not have been accomplished by forest entomologists or forest pathologists alone, but clearly it required the collective expertise of scientists and practitioners from a range of forestry disciplines.

Today I would like to share with you some thoughts on how I believe silvicultural alternatives that are commonly prescribed for northern hardwood stands can affect forest insect pests. Much of what I will say is based on intuition and common sense, tempered, I hope, with some sound ecological reasoning! I can provide no examples based on controlled long- or short-term studies that address the entomological consequences of even- and uneven-aged management in this forest type.

I want to impress upon you that any silvicultural treatment you employ to influence stand structure, species composition or tree growth can influence stand susceptibility to insect pests and vulnerability to damage. The effect can be either negative or positive.

The Silvicultural Systems

Many factors determine the silvicultural approach most appropriate for a specific northern hardwood stand. Management objectives, silvical characteristics of the tree species, site conditions and economic realities influence choice of a prescription. Stands with a multiple age structure and comprised of shade-tolerant species (e.g., sugar maple, beech) generally are suited for uneven-aged silviculture, and even-aged silviculture is particularly effective in creating and maintaining an important component of shade-intolerant or intermediate species (e.g., paper birch, white ash, black cherry, yellow birch) (Gibbs 1978, Nyland 1987). In other words, the even-aged approach creates conditions favorable to the faster growing, higher value, light-demanding species, and uneven-age systems will inevitably result in domination by the slower growing, lower value species that tolerate lower levels of light for survival and growth (Smith and DeBald 1976). There are, however, many exceptions to these generalizations. The character of the stand that ultimately results from application of either silvicultural system depends on the available seed source, degree of site disturbance, status and condition of regeneration at the time of cutting or, in the case of uneven-aged management, degree and frequency of future intervention (Nyland 1988a).

For the purposes of my discussion, I assume that under the right circumstances (from economic and ecological points of view) both even- and uneven-aged approaches are viable options for northern hardwood stands (Leak et al. 1969). The important implications from an entomological perspective are the characteristics of the residual stand in terms of species composition, diversity and arrangement of age classes, and the degree of stress or injury inflicted on the site or the residual trees.

Most of the insect problems that we experience in northern hardwood stands are probably not a result of implementing different silvicultural prescriptions. To some degree, these outbreaks reflect a history of disinterest in northern hardwood management or abuse in the form of exploitation. The latter has occurred under the guise of "management" practices such as selective cutting, diameter- limit cutting and high grading (Nyland 1986). The end result is manifested today in stands containing innumerable low quality, low vigor and probably genetically inferior trees. These conditions favor insects that flourish in weakened or stressed hosts (secondary insects such as roundheaded borers and ambrosia beetles). Defoliators, sucking insects and many insects that feed on seeds or seedlings, on the other hand, are examples of pests that readily attack healthy, vigorous trees (primary insects). Outbreaks of the latter, though most certainly influenced by quantity and quality of available food, are often more directly affected by abiotic or other biological factors.

Silvicultural Practices and Pest Management

Control of forest insect pests and/or mitigation of their damage by silvicultural means has been advocated by forest entomologists for many years. During earlier days of professional forestry in North America, the advantages and long-term value of cultural practices were espoused by forest entomologists in both Canada (e.g., Balch 1934) and the United States (e.g., Craighead 1925, Graham 1929). In later years, when we indulged in the uncritical application of inexpensive and very effective chemical insecticides, Graham (1951, 1959) and others presaged the consequences of total reliance on these tools and pleaded for us to instigate preventive action through silvicultural methods. To one degree or another, contemporary forest entomology texts (Knight and Heikkenen 1980, Coulson and Witter 1984, Berryman 1986); several progressive management systems for major insect pests such as southern pine beetle (Nebeker et al. 1985, Belanger and Malac 1980), spruce budworm (Blum and MacLean 1984, Montgomery et al. 1982), mountain pine beetle (McGregor and Cole 1985), western spruce budworm (Carlson et al. 1985) and gypsy moth (Gottshalk et al. 1988); and many educational curricula (e.g., McLean 1987) stress this aspect of forest management.

Certainly most of us who deal with, or are affected by, forest pests would rather prevent outbreaks by applying sound ecologically based methods, or at least be able to suppress outbreaks with biological tools, rather than attack problems with materials that might be environmentally costly. This is often easier said than done. In the first place, it is unrealistic to think that all forest pest problems have an ecological solution. It is difficult for us to influence many of the biological and physical variables that determine the dynamics of an insect's life system. By the same token, for economic or social reasons, it is often not feasible to base pest management on the ecological side of the management equation (Waters 1971).

The theory of forest pest management through silvicultural means is far ahead of practice, but more often than not modern pest management strategies attempt to include silvicultural procedures that are tailored to pest habits (Knight 1976, Nebeker et al. 1986, Wainhouse 1987). This approach can be appealing to the forest manager and, at the same time, take advantage of our understanding of herbivory and the diverse aspects of insect/plant relations (Schowalter et al. 1986). Numerous studies indicate that silvicultural practices can affect, either positively or negatively, the three basic kinds of forest insect populations: stable-low density, cyclic and eruptive (Berryman and Baltensweiler 1981).

Silvicultural Practices - Can They Affect Insect-caused Damage in Northern Hardwoods?

As I implied earlier, we have few data and no controlled studies on which to base silvicultural recommendations for insect pest management in northern hardwood forests. Most recommendations are predicated on empirical evidence from this and other forest types, or reasoned through common sense founded on our understanding of insect ecology or insect-plant relations.

Past entomological studies have provided information about the life histories, effects, and history of outbreaks for the economically important hardwood insects. Papers presented at two recent symposia reviewed the most important insects and diseases that are associated with major northern hardwoods (Allen 1987, Houston 1986). The principal dieback and decline diseases prevalent in northern hardwood types have also been recounted (Houston 1981a, b). In addition to descriptive and historical information on specific pests, an awareness of the complex interactions that occur between forest management activities and pest damage clearly pervades this literature. The interrelation between insects, diseases and forest conditions is a common thread that surfaces whenever we critically examine these forests in terms of susceptibility to most outbreaks or vulnerability to damage.

The degree to which insect populations are influenced by silvicultural systems, as would commonly be used as elements of even- or uneven-aged management, depends on links that occur between pest ecology and characteristics of the residual stand. For example, the following can influence population trends and the potential for damage:

Features of Insect Ecology

- feeding behavior - degree of host specificity, penchant for certain host age classes.
- relative importance of biological and physical factors on insect population dynamics - food quality/quantity, fecundity, pathogens, parasites, predators; temperature, moisture, air movement.
- insect-host vigor relations - outbreaks associated with vigorous or stressed trees (i.e.,primary or secondary insects)?
- location of forest stand within geographical distribution of insect - found at the margin of the insect's distribution, or more centrally located?
- spatial relationship of infested stand to other forest types - intermixed with other forest types to lend species diversity and abundance of competitors and natural enemies, or part of an extensive monoculture?
- origin of insect - native or introduced.

Characteristics of Residual Stand

- tree species diversity.
- age class diversity.
- stand density, and uniformity of spacing.
- physical damage resulting from logging practices.
- degree of physiological stress to trees following silvicultural treatment.
- compatibility of tree(s) with site conditions.
- genetic characteristics of trees.

Association of Stand Conditions and Insect-Caused Damage in Northern Hardwoods - Some Examples

Circumstances Involving Primary Insect Pests

Beech bark disease in the northeastern United States and maple blight in Wisconsin are two examples that have been used frequently to illustrate relationships between forest management practices and forest susceptibility to a pest. These two cases have some common elements, but are quite different in an ecological sense. The exotic, host-specific beech scale was inadvertently introduced from Europe into an environment characterized by suitable climate, abundant food, and the absence of effective natural enemies. The food supply resulted from past high-grading that fostered a dominance of beech in many northern hardwood stands (Houston 1975). Maple blight, a type of maple decline, is an indigenous problem. It was engendered by a sugar maple monoculture created as a consequence of selective cutting that removed the shade-intolerant hardwoods during the 1920's, followed by a second wave of cutting that removed drought-stressed hemlock shortly thereafter (Graham 1965). Creation of this sugar maple monoculture presumably induced population increases for a complex of sugar maple defoliators (Giese and Benjamin 1964) during the 1950's. Subsequent defoliation, combined with adverse weather and a root rot, resulted in extensive sugar maple mortality (Houston and Kuntz 1964).

Past cutting practices were undoubtedly important to the chain of events that resulted in both beech decline and maple blight. However, we should not loose sight of the fact that other events favorable to the organisms involved played a role as well. Often, these differ markedly between indigenous pests and those that have been recently introduced. For example, the beech scale is not native to North America. Like other insects that are exotic to an area, a suitable climate, abundant food and an absence of co- evolved natural enemies made for conditions that allowed its population to erupt (DeBach 1964, Berryman 1986). The exotic nature of the scale was a key element that precipitated the beech bark disease problem over such an extensive area in northeastern North America.

The indigenous defoliators that set the stage for maple blight, on the other hand, occur throughout the range of sugar maple, yet their populations rarely attain outbreak levels. Quantity of food (prevalence of sugar maple) was only one of several factors involved in the development of maple blight. A coincidental occurrence of other favorable habitat elements was necessary to permit unusually high populations of two species of leafrollers, the consequences of whose feeding habits, in turn, provided oviposition sites for maple webworm, the principal defoliator.

The point I want to emphasize is the complexity of factors that affected the build-up of beech bark disease and maple blight. We should not attribute the origin of either problem solely to the presence of susceptible stands. Insects of this kind (i.e., primary pests) have many habitat requirements that must be met simultaneously in order for outbreaks to be initiated and sustained (Strong et al. 1984). Hence, the population dynamics of these insects may be more strongly influenced by a combination of favorable factors like regional climatic conditions, local weather and the success or failure of associated predator and parasitoid life systems.

While these two examples illustrate insects that may cause rather widespread damage across large regions, other pests may have more localized importance. Among these are a variety of insects that cause forking or other stem deformities in sugar maple (Allen 1987). Observations in

Michigan's Upper Peninsula (Simmons and Knight 1973) indicate that incidence of this damage may be exacerbated by forest management activities. Populations of several of these pests are typically highest in relatively open stands following heavy cutting. Available evidence suggests that proper control over residual stand density would help to minimize the potential for these insects to inflict important damage within a stand.

Similarly, under certain forest conditions black cherry is very susceptible to insects that damage the terminal shoot. On the Allegheny and Monongahela National Forests, as many as 43% of the trees in some areas can be damaged in this manner (Rexrode 1978). These pests were a problem especially in plantations.

Sugar maple mortality and crown dieback following severe defoliation by saddled prominent also illustrate problems that appear related to stand management. In Vermont, damage was most extensive in stands that were predominantly sugar maple (85% or more of the stems) and relatively even-aged (Teillon et al. 1981). Historical evidence indicates that outbreaks often begin in high elevation stands that are predominantly beech (Martinat and Allen 1988). Beech appears important to outbreak development and resulting damage that occurs in lower elevation sugar maple stands. I believe that favorable weather and the release of sparse populations from the regulatory effects of egg parasites may also play a role. Weather factors are implicated, because populations of several other defoliators usually increase simultaneously with saddled prominent (Allen 1987).

Circumstances Involving Secondary Insect Pests

A good example of a northern hardwood pest that thrives in stands of stressed or low vigor trees is sugar maple borer. Even though I consider this the most serious insect pest of sugar maple, it is probably also the one that will be most responsive to control through silvicultural practice (Newton and Allen 1982). Stressed sugar maple (e.g., low vigor, off-site or dieback-afflicted) in pole-sized stands with low tree species diversity are very susceptible to attack by this beetle (Allen 1987). The extensive borer damage that we see in many stands today reflects, in large measure, a legacy of high-grading or total absence of deliberate "management." Historically, landowners have typically extracted timber whenever opportunity permitted, with little or no concern for the vigor, quality or character of the residual or future stand (Nyland 1988a).

Bronze birch borer is one of the most important insects attacking paper birch (Conklin 1969). It is commonly recognized as a problem of both forest and ornamental trees growing under stress (Loerch and Cameron 1984). Borer activity is the principal reason that birch does not recover from dieback (Barter 1957). Susceptibility to outbreaks of this pest can be minimized and damage mitigated if we maintain stands of healthy and vigorous trees. Experience suggests that weakened and mature birch should be removed from a stand, marking should be designed to minimize overexposure of residual birches, and logging operations must be done carefully to prevent physical injury to the remaining trees (Balch and Prebble 1940, Redmond 1957). Also, valuable stands should be protected from numerous defoliators that can predispose birch to borer attack and eventual decline (Allen 1987).

Discussion

In the absence of definitive studies that address the consequences of practicing even- and uneven-aged management of northern hardwood stands in relation to insect pests, one must rely heavily on empirical evidence. Similarly, research has not yet demonstrated clearly defined silvicultural tactics that can be used to prevent or minimize losses from specific pests. Therefore, I can only discuss the application of silvicultural practices in relation to what we know about the nature of primary and secondary insect pests that are commonly associated with this and other forest types.

In my judgement, either silvicultural system, even though applied correctly in a forest management sense, can lead to an insect problem if we alter key aspects of an insect's life system, and ignore evidence from the entomological history of structurally similar stands.

Experience with several forest pests indicates that the commonly used silvicultural methods may either create outbreaks by altering the forest environment to favor insect population build up (adaptive instability) or they may help to mitigate normally occurring instability (developmental instability) by increasing the resilience of the forest ecosystem (Berryman 1986). In this context, I would like to discuss the ecological implications of even- and uneven-aged management in relation to northern hardwood forest establishment (site selection), forest character (species and age class diversity) and forest growth (vigor, harvesting damage) (sensu Coulson and Witter 1984).

Let me say at the outset that I appreciate the economic and practical constraints under which a forest manager must operate. Given that we have much to learn about the interactions between insect ecology and northern hardwood forest conditions, at this juncture I would only ask that in your forest management you remember two things: 1) there are opportunities to minimize or prevent pest problems while you implement silvicultural methods to optimize forest management goals (the two endeavors are not mutually exclusive); and 2) any silvicultural tactic employed to enhance your forest management objectives may also create conditions that, alone or in concert with other events, favor an insect pest.

Site Selection

Foresters are well aware that most tree species grow best within a well defined range of site conditions. Both shade-tolerant and intolerant northern hardwoods will survive under a variety of environmental situations (Fowells 1965), but each species reaches its best development under a unique combination of climate, soil and topography (Auchmoody 1987). Matching the tree species and site conditions for both planting and natural regeneration is as important in northern hardwood management as with other forest types where we must reduce management costs and meet a variety of resource needs (Tubbs 1987). Site characteristics are important because they affect productivity and quality development (Erdmann 1986), but they can also influence susceptibility to forest pests and vulnerability to damage (Stoszek 1986). In particular, populations of secondary insects are especially likely to increase in stands dominated by low vigor trees that result from a mismatch between site conditions and tree species requirements.

Fortunately, northern hardwoods are relatively free of the devastating, eruptive populations of bark beetles and other inner bark borers that are associated with many coniferous and other broadleaved forests. Observations suggest that the ubiquitous sugar maple borer, however, is one example of a northern hardwood pest whose normally stable, low-density populations can increase to economically important levels when maple exists on poor sites. These "outbreaks" do not kill the trees, but significantly degrade maple sawlogs (Newton and Allen 1982). Also, limited evidence indicates that sugar maple (Teillon et al. 1983, Simons et al. 1983) and black cherry (Schultz and Allen 1977) growing on poor sites may be more vulnerable to growth loss and mortality following defoliation.

Stand Composition

At one time or another, probably all of us have heard the expression "diversity leads to stability." This dictum has been part of several forest pest management recommendations in North America since the early 1900's (e.g., Graham 1926), and has formed the basis of early arguments against the practice of monoculture (Graham 1951, 1958, 1959). Single species, even-aged forestry is still viewed as a precursor to several forest insect and disease problems (Gibson and Jones 1977, Dahlsten and Rowney 1983, Nebeker et al. 1986). On the other hand, some (e.g., Crossely et al. 1973, Burdon 1982) claim that the available evidence does not support the idea that single species even- aged stands are more at risk than mixed stands.

The probability that an outbreak will occur in a given situation depends on many factors besides the plant community diversity. Such things as trophic interactions (Crossley et al. 1973), degree of polyphagy (Redfearn and Pimm 1988), susceptibility to predation and parasitism (Lawton and Strong 1981) and many other characteristics of the pest, host and forest community (Gibson and Jones 1977, Stanton 1983, Haukioja 1986) determine susceptibility. Nonetheless, empirical evidence indicates that, for a variety of reasons (Way 1977), lack of diversity can set the stage for many pest problems (Kulman 1970, Pimentel 1977).

In northern hardwood types, forest tent caterpillar, saddled prominent, and host specific insects such as sugar maple borer, maple leafcutter, and pitted ambrosia beetle are certainly favored among stands dominated by sugar maple. Plantations of pure black cherry appear more susceptible to insects that damage terminal buds (Rexrode 1978), and natural black cherry in monocultures sustains more defoliation by cherry scalloped shell moth (Schultz and Allen 1977) than does cherry in mixed stands. As mentioned earlier, beech bark disease and maple blight are associated with stands predominated by their hosts.

Age Class Distribution

From an ecological perspective, the mixture of age classes that should result under deliberate uneven-aged management creates another form of diversity that may influence survival of many insect pests. Most primary insects can feed on trees in a range of size (age) classes, but secondary pests are more fastidious. Populations of both types of herbivores, however, tend to peak initially within stands at particular stages of host development (Schowalter et al. 1986). Two well documented examples of this are the different complexes of insects (and diseases) associated with the six developmental stages of southern pine (Thatcher et al. 1986), and those common to three size classes of aspen (Graham et al. 1963).

Even when market or site conditions dictate that foresters manage for a single species, the age class diversity inherent to uneven-aged management may help to make stands either less susceptible to outbreaks of certain pests, or less vulnerable to damage. Also, there appears to be a critical threshold for stand size below which outbreaks of eruptive pests (that is, those for which populations are maintained at low levels for long periods and then abruptly reach outbreak levels over extensive areas) are not lkely to initiate (Berryman and Baltensweiler 1981). Hence, with even-aged management we may be able to reduce the danger from these kinds of pests by controlling the size and distribution of the area regenerated. This would create an interspersion of different stand conditions and introduce a degree of diversity across the forest.

Tree Vigor

That tree vigor can influence many facets of insect herbivore biology is well documented (e.g., Ahmad 1983, Denno and McClure 1983, Mattson and Scriber 1987). For secondary insects, tree physiological condition is the principle element that affects host selection and insect reproduction and survival. Changes in tree vigor may also influence primary insects, albeit in more subtle ways, by altering such things as chemical defenses and host nutritional quality.

Appropriate silviculture should be a basic tenet of all pest management strategies. In most northern hardwood stands, secondary insects do not pose the same threat that they do in some other forest types. Nonetheless, maintenance of tree vigor by minimizing harvesting damage within the residual stand, matching tree species to site conditions, protecting trees from damage by primary insects and properly allocating growing space in relation to age class development will help to reduce susceptibility to some insect pests and vulnerability to damage. Certainly, available evidence indicates that this is the case with sugar maple borer (Newton and Allen 1982) and an ambrosia beetle in sugar maple (MacLean and Giese 1967), the peach bark beetle in black cherry (Schultz and Allen 1975, Kulman 1964), and bronze birch borer infestations in white birch (Barter 1957).

In even-aged silvicultural systems, thinning to appropriate levels of residual stand basal area is necessary to optimize growing space for individual trees. Such a treatment, or series of treatments, may have a positive effect on biochemical and physical characteristics that determine tree susceptibility to secondary insects (Matson et al. 1987, Nebeker 1985). However, certain methods of thinning may also place a temporary stress on a stand that can, if they follow or occur along with a major disturbance such as defoliation, tip the balance in terms of a stand's vulnerability to damage. Assessment of stand condition and awareness of disturbance history before implementing thinning prescriptions will help prevent the creation of pest problems under certain site and stand conditions (Nebeker et al. 1985).

Recent experience with a forest tent caterpillar outbreak in Vermont is a case in point. Sugar maple in stands that were thinned just prior to or during the outbreak experienced heavy mortality. It is believed that this excessive mortality resulted, in part, because an unusually high insect population was concentrated on fewer trees (thinning lowered the basal area), and that the method of thinning left trees with small crowns (the thinning removed many large crowned trees) (Teillon et al. 1983). Also, the stress of this approach to thinning combined with the stress of heavy defoliation prevented stand recovery. The interaction between methods and intensity of thinning and insect defoliation has been observed for yellow birch as well (LaBonte 1978). The obvious lesson here is to consider stress history before implementing timber stand improvement, precommercial thinning or harvesting activities.

A concern that forest entomologists and pathologists have whenever a selection system is employed in uneven-age management, is the frequency with which a stand must be entered to accomplish silvicultural goals. Stem or crown damage may involve a significant proportion of the residual stand after several cutting cycles (Nyland 1987). This is of special concern to pathologists, because these injuries can result in extensive decay or grade loss (Shigo 1966, Houston 1986). Even though it is impossible to eliminate this damage entirely, it can be minimized by directional felling to avoid injury, designing well-organized skid trails that accommodate terrain and machinery, selecting appropriate equipment, logging at a time of the year when site and tree conditions are favorable and educating logging contractors (Nyland 1988b).

Challenges

First Challenge

In order to better understand the interactions between silvicultural practice and the dynamics of northern hardwood insect populations, we need to carefully monitor stands in which different silvicultural treatments are practiced. Periodic assessment of tree condition and insect abundance, beginning when silvicultural treatments are first imposed and carried through several treatment cycles, is the best way to determine the impact, or net effect of insect activity.

Understanding net impact is a critical ingredient of sound economic evaluations which, in turn, play a key role in pest management and silvicultural decision making. This information is necessary to assure that pest control dollars are used efficiently (Johnson 1972). Careful evaluation of long- <u>and</u> short-term tree and stand responses to insect-caused damage in northern hardwood variants and different silvicultural regimes is required. In addition, in order to adequately assess the affects of an infestation we must know something about stand management and natural disturbance history, and tree and stand condition prior to an outbreak. This requires the united efforts of forest entomologists, pathologists and managers to establish and periodically examine long-term permanent plots. This combined expertise is needed also to interpret acquired data and help to derive silvicultural recommendations that can both serve forest management needs and help to minimize pest damage.

Second Challenge

To effectively manage northern hardwood stands, the forester should be familiar with and understand the major insect pests of northern hardwoods. Forest managers must learn to recognize early evidence of outbreaks of the primary pests, and early signs of damage or susceptible conditions associated with secondary pests. That means we must pressure for including pest management in the core curriculum of our forestry schools, and pay greater attention to forest pest management in our continuing education efforts. For only if we become better acquainted with both the problems and the opportunities can we develop effective programs to reduce the risk of damage and loss in the stands we seek to manage.

Recognition of threatening populations of primary pests is necessary to properly time preventative measures or, at least, to avoid implementation of silvicultural treatments when other stresses are imminent. Early recognition of secondary pest damage or susceptible trees will help to identify stems that should be removed in tending an age class or different stages of development. In short, only as we learn to take a more holistic approach to forest management will we likely make important strides to reduce the dangers of devastating insect outbreaks and, in doing so, help to optimize resource values.

Conclusions

Both even- and uneven-aged silvicultural systems can either ameliorate or enhance the susceptibility of northern hardwood stands to insect outbreaks and vulnerability to damage. The entomological consequences of any forest management activity depend on many factors and, similarly, many factors in addition to quantity or quality of food and microclimate influence an insect's life system. Though we lack evidence from controlled studies, experience indicates that maintenance of vigorous stands and, where practical, creation of a diversity of species and age classes within the forest will help considerably to prevent certain insect problems or, at least, to minimize long- and short-term losses if an outbreak occurs.

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TECHNOLOGICAL ALTERNATIVES— WHAT'S AVAILABLE TO ACCOMPLISH SILVICULTURAL OBJECTIVES?

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If the hardwood forests of the northeastern United States are to expand their contribution to the regional economy, harvesting will have to be greatly accelerated. A wide assortment of harvesting machinery and techniques is currently available. Increased levels of harvesting will require working under a wider range of conditions, and on more difficult sites. Planning and control of harvesting operations will have to be improved, and new technologies developed that will allow economical and environmentally acceptable logging on a wider range of sites. The key to developing the harvesting systems of tomorrow lies in recognizing that harvest is part of the overall forest management system.

Introduction

Harvesting forest products is a key element in managing forest land. Besides being the means by which raw material is supplied to our vast forest products industry, harvesting is also used to achieve many other forest management goals, such as wildlife habitat management, landscape management, and watershed management. Accomplishing this wide range of forest management goals necessitates that those involved in making forest management decisions have a working knowledge of harvesting equipment and systems. This knowledge of machinery and techniques and their potential applications and limitations will enable forest managers to better communicate with harvesting contractors and achieve the desired forest management goals.

Harvesting Systems

Harvesting is commonly classified in two basic ways (Mattson 1985): According to the silvicultural system that has been selected to best meet the timber management goal, or according to the way in which wood is moved from the stump to a landing. The three types of harvests commonly identified in the former way are clearcuts, thinnings, and selection cuts.

Clearcuts entail removing all the trees on the harvested tract; removing "all" trees, however, may mean different things to different people. The forest manager may interpret it to mean removing all trees down to a 2-inch-diameter stem; the logger may interpret it to mean all trees down to a 5-inch-diameter stem, which he feels is the smallest tree that he can economically harvest. Clearcuts are typically applied as regeneration cuts where full sunlight on the forest floor is required, as with aspen, to establish the new tree crop, or, an area may be clearcut to replace the original stand with a different species, as when a poor-quality hardwood stand is converted to conifers.

Two variations of clearcuts, the seed tree and shelterwood methods, are commonly used in even-aged management systems. Both systems consist of a clearcut made in two passes several years apart. The first cut removes part of the original stand to develop the proper conditions required to establish natural regeneration on the forest floor. When the regeneration is established, the second cut removes the remainder of the original stand. The result is a new even-aged stand.

Thinnings are intermediate cuts made in young, even-aged stands to remove poor-quality trees and to release the better trees for accelerated growth. Thinnings are typically done in second-growth, pole-size stands of northern hardwoods. The forest manager must avoid excessive damage to the residual stand and site, or the long-term goal of the thinning may be negated by reduced tree quality and lowered site productivity. The problem is compounded by the fact that trees removed in thinnings are typically low in value, so the harvesting contractor needs high production rates to achieve economic viability. This magnifies the potential for excessive damage and increases the need for coordination and cooperation between the forest manager and the contractor.

Selection cuts are partial harvests typically applied to uneven-aged stands in which the trees to be harvested are either selected individually or in small groups. This method is commonly applied to sawtimber stands of northern hardwoods. Harvested trees range widely in size and quality, from large, high-quality veneer and sawlog trees to smaller, lower quality trees suitable only for pulpwood or firewood. Because the volumes to be removed are often low, the forest manager may need to accommodate the contractor either by delaying cutting, increasing the harvest volume, or accepting reductions in stumpage value commensurate with the additional logging costs.

The second method of classifying harvesting—the form in which the wood is moved from stump to landing—encompasses three major types of harvesting systems: the shortwood, tree-length, and full-tree systems. Shortwood systems convert trees into roundwood products at the stump, and logs or pulpwood are transported to the roadside. This system does not have the potential for whole-tree utilization, and the logging slash is normally left distributed through the stand randomly or in windrows if directional felling techniques are used. Shortwood harvesting can be applied in clearcuts, thinnings, and selection cuts. It is usually a labor-intensive operation with chain saw felling and preparation of the roundwood products and mechanical transportation of the roundwood to roadside.

Totally mechanized shortwood systems are being used in softwoods, but are not found in hardwood harvesting operations.

Tree-length harvesting systems fell, delimb, and top the trees at the stump; transport the tree-lengths to the landing; and typically either buck the tree-lengths into conventional roundwood products at the landing or haul the tree-length stems intact to the eventual use point. Tree-length systems can be quite mechanized; the only manual work may be delimbing and topping the trees that have been mechanically felled. However, tree-length harvesting in hardwoods is normally labor-intensive, with chain saw felling, limbing, and topping. Tree-length harvesting is the most commonly used system in hardwood sawtimber stands where large, high-quality logs are being harvested and available mechanical equipment (i.e., feller/bunchers) cannot fell the trees without doing excessive damage to the valuable butt log. A drawback when using tree-length logging in selection cuts is that the long length of the material being skidded can cause excessive damage to the residual stand unless precautions are taken.

Full-tree harvesting systems transport the entire felled tree to the landing for processing. Typical applications include whole-tree chipping systems and systems built around processors that delimb and slash the trees into roundwood at the landing. In hardwoods, whole-tree chipping is the only full-tree harvesting system being used because there are no mechanical processors that can effectively delimb hardwoods. The full-tree systems are the only ones that result in complete utilization of the available biomass. These systems are generally completely mechanized and are very capital-intensive.

There are, of course, other ways to classify harvesting methods and systems. The degree of mechanization is frequently referred to, and this will be discussed later in sections dealing with economics and constraints on harvesting systems. Another classification criteria, ground-based versus aerial or cable systems, will be used more frequently in the future if the current trend toward aerial and cable systems continues.

Regardless of the type of harvest system being employed, four basic functions need to be carried out: Felling the tree, transporting the wood to the landing, processing the tree into the desired products, and hauling the products to market. The order in which the in-woods transport and processing functions are performed can be quite flexible. Storage or inventory is commonly included to help ensure an efficient harvesting operation.

Harvesting Equipment

A wide assortment of harvesting machinery is available to the logging industry. Here I will briefly discuss the types of machinery being used to carry out the four basic harvesting functions and comment on their general applicability.

Any discussion of logging machinery should begin with the chain saw. In the hands of a skilled operator, the modern chain saw is a very efficient tool for felling, delimbing, and bucking. Particularly in hardwoods, the chain saw is still an essential harvesting tool, because of the lack of suitable mechanized equipment (Sarles 1985). The need for well-trained, motivated forest workers will continue in the foreseeable future. Because a shortage of skilled workers would create a major obstacle for the timber industry, both forest managers and timber harvesters should be doing everything possible to ensure the availability of well-trained forest workers.

The greatest variety of harvesting equipment available today exists for the felling function. Typically, these machines are designed to sever the tree from the stump and carry the tree upright until it can be placed into a "bunch" of felled trees—hence, the name feller/bunchers (Figure 1). Feller/bunchers commonly use shears to sever the tree. Shears are durable and efficient, but limited in the size of tree they can cut, particularly in hardwoods, and all cause splitting in the butt of the tree. Shearhead feller/bunchers, therefore, are used almost exclusively in pulpwood harvesting. Sawhead feller/bunchers, which use a saw to do the severing (Figure 2), are now being developed. These machines have the capability of severing sawlog-size trees without doing excessive damage to the valuable butt log. A problem that arises in applying feller/bunchers to sawtimber harvesting is that the weight of the trees being handled is so great that the machine has to be massive just to support the tree. Large machines have difficulty maneuvering in a stand being selectively harvested without doing excessive damage to the residual trees. Large machines are also more expensive, requiring a higher production rate to be economical.

Machinery available today for in-woods ground transportation falls into two basic categories—skidders and forwarders. Skidders at least partially drag the load on the ground; forwarders carry the load completely off the ground, usually on the back of the machine.

Two types of skidders are in widespread use—cable and grapple skidders. Both are typically rubber-tired, four-wheel-drive, articulated-frame machines. The difference is in how the load is secured. Cable skidders use a winch with wire rope to pull the trees or logs to the machine and to elevate the butt ends for transport (Figure 3). A number of "chokers" are used to secure the individual pieces to the winch line. Primary advantages of cable skidders are that

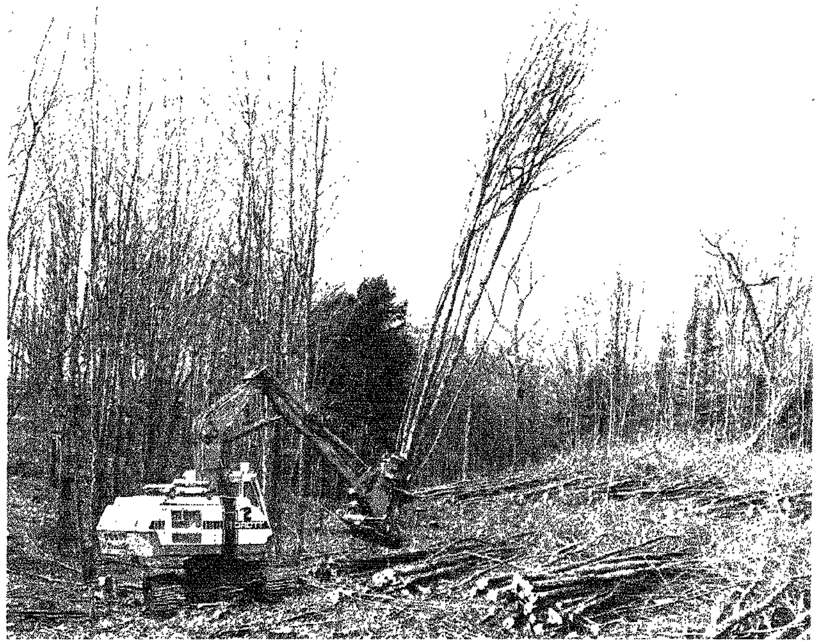

Figure 1. Typical excavator-based feller/buncher with accumulating shear head.

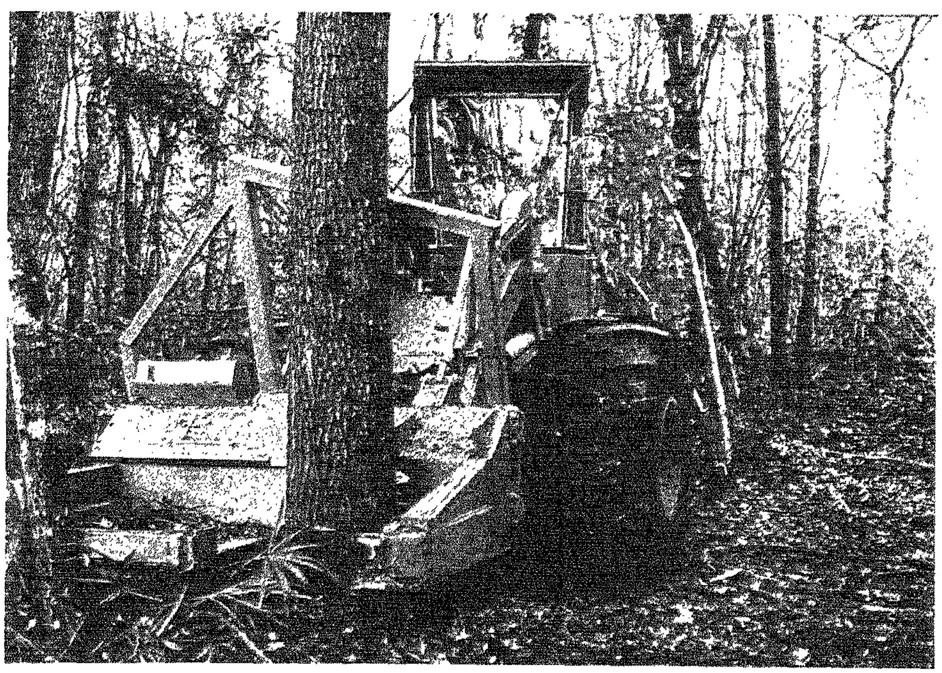

Figure 2. Newly developed sawhead feller/buncher.

a number of scattered pieces can easily be winched together to build a full load, and they can get through difficult terrain by dropping the load, moving the skidder ahead, and then winching the load back in, all without releasing the trees or logs. Cable skidders are most commonly used in selection cutting operations where individual trees are being cut and tree-length harvesting is being employed.

Grapple skidders use a set of hydraulically operated arms to secure the load to the skidder and to elevate the butts for transport (Figure 4). They are used almost exclusively with feller/bunchers that prepare optimum-sized loads for the skidder. Their primary application is in highly mechanized tree-length and full-tree harvesting systems where high production rates are a necessity.

Forwarders are typically rubber-tired, four-wheel drive, articulated machines with a load space built into the back, and with a hydraulic knuckle-boom loader to load the wood onto the vehicle (Figure 5). They are used exclusively in shortwood operations and generally in pulpwood harvesting. They can be used successfully in clearcutting, thinning, or selective cutting situations.

There has been increasing interest in recent years in the application of cable logging systems in the eastern United States. Cable logging is well developed from years of use in the mountainous West, but it has not historically been applied in the East due primarily to economics. Typical cable logging systems are high-cost units requiring valuable timber to be operated economically. However, the development of smaller, lower cost units in recent years has opened the door to potential application in the East, particularly in the rugged Appalachian region. Several small cable logging systems are currently available, and as more experience is gained with these systems, they will continue to see broader application (LeDoux 1985).

Mechanical in-woods processing equipment commonly used with hardwoods consists of whole-tree chippers and mechanical slashers. This limited use of processing equipment is due to the lack of delimbers mentioned above. Slashers are typically used in pulpwood operations where tree-length material is delivered to the landing or roadside for conversion to standard pulpwood lengths. Whole-tree chippers are very productive machines. They are always used in highly mechanized, high-output operations and are capable of impressive levels of man-day production. Whole-tree chipping is most commonly applied in clearcutting where the primary product is pulp or energy wood.

Transportation of primary forest products from the woods to the mill is done mostly by truck. Where it is available and economical, rail and barging are used to a limited extent. Roundwood is typically hauled by three- or four-axle trucks, with self-contained loaders, and often pulling a "pup" trailer. Typical capacities are 10 to 12 cords of pulpwood or sawlogs. Tree lengths are hauled by tractor-trailer combinations with specially built pole trailers, and whole-tree chips are generally transported in specially designed chip vans. For economic efficiency, haul trucks of all types have grown quite large in recent years, which has definite implications for the forest manager. Today's haul trucks require a higher class of roads than the smaller trucks of yesteryear, and these better-class roads affect the planning and layout of timber sale areas.

Harvesting Economics

Economics is, of course, the bottom line of any business. Harvesting systems have grown to the point where investments of hundreds of thousands of dollars are required to put an operation in the woods. This has reinforced the point that logging is a business and needs to be conducted in a profitable manner. Simply stated, the profit of a logging enterprise is production multiplied by the difference between the value of the wood produced and the cost of producing it.

$$\text{Profit} = \text{Production (Value - Cost)}$$

This equation can be used to illustrate several key points about today's logging industry. The first is that minimum operating cost is not the total economic picture (Thompson 1988). It is an important consideration, but only one of three variables in the profit equation. Second, the level of production is very important. Because increased production can lower the unit cost of producing wood, it can positively affect the profit equation in two of the three related variables. If we assume that the unit value of wood produced will remain constant at differing levels of production, then overall profit can be significantly affected by increases in production. This is an important underlying factor in the trend toward more highly mechanized, high-production harvesting systems.

Recent studies have shown that costs of logging equipment have risen much faster than the prices received by loggers (Cubbage et al. 1988). At the same time, the rate of increase in logging costs has been significantly lower. This indicates that loggers have increased productivity or are receiving lower profit margins, or both. This trend reinforces the importance of production level in the profit relationship.

Generalized relationships for harvesting costs are difficult to develop because many variables affect the cost of any given harvesting operation. Many case studies have been reported in the literature, but their results are generally not

Figure 3. Typical rubber-tired cable skidder.

Figure 4. Typical rubber-tired grapple skidder.

widely applicable to other operations. Recently however, several attempts have been made to look at the range of results reported for various case studies (Figure 6), and at least some general conclusions can be drawn from these analyses (Sarles and Luppold 1986, Winsauer and Mattson 1987). Paramount among them is that the most cost-effective harvesting systems currently available are the more highly mechanized, capital-intensive systems. The difficulty is that these systems are also the most sensitive to a wide range of variables that can affect the viability of the operation.

Highly mechanized systems are affected more strongly by variables such as tree size, terrain, soil moisture, snow depth, type of cut, and skidding or yarding distance than less capital-intensive systems. The high production potential of these systems is traded off against the much more restricted set of conditions in which they can work to their potential. Their more limited applicability requires that the forest manager and logger work together to ensure that the harvest is economically viable for the logger and that it meets the objectives of the landowner.

Obtaining sufficient capital to invest in harvesting equipment is a major economic challenge faced by loggers. The high financial risk associated with logging limits the amount of capital that banks are willing to loan for the purchase of logging equipment, and increases the interest rates charged for this money. The high cost of capital magnifies the need for high levels of production to generate cash flow, and compounds the other constraints inherent in highly mechanized harvesting operations. Capital-intensive harvesting systems necessitate the need for year-round operation. Because of high fixed costs, these systems cannot remain economically viable with extended periods of down time. This affects forest managers as well since they will be asked to provide year-round harvesting opportunities by loggers wishing to work through all weather conditions and seasons.

Year-round harvesting also increases the need for all-weather roads. Road access to harvest areas is a major cost and will increase as higher quality roads are required. Because the cost of moving highly mechanized systems is high, forest managers will be pressured to provide larger harvesting areas to minimize the frequency of moving. Large harvesting systems and large haul trucks also require large landing areas to work efficiently. Setting aside large

Figure 5. Typical shortwood forwarder.

landings can significantly affect the amount of land in production if many small tracts have to be harvested.

Impacts of Harvesting

The literature abounds with papers concerning the impacts of harvesting machinery on soil and nutrient reserves, on the residual stand (in partial cuts), and on water yield and quality. Several other papers in this conference will address these concerns in greater detail, so I am going to discuss them only from the standpoint of their impact on selection and utilization of harvesting equipment and systems. Many of these concerns are also background issues affecting recommendations that will be discussed later in this paper.

The impact of harvesting equipment on the soil is a serious concern, because the best hardwood stands typically grow on heavier soils that are highly susceptible to severe damage by the passage of heavy equipment. Martin (1988) summarized the existing knowledge of soil disturbance and offered management recommendations for controlling damage to these sites. His key points include avoiding conditions that will lead to severe rutting on the site through careful design of transportation patterns, and curtailing activity during extremely wet conditions that will lead to rutting. Proper planning to minimize soil compaction and disturbance of the organic layer is another key recommendation.

The effects on nutrient reserves of harvesting systems that utilize almost all of the aboveground biomass in a forest stand, such as whole-tree chipping, has been the focus of intense study in recent years (Harvey et al. 1981). Although these concerns do not directly influence the selection of a harvesting system for a given stand, they are certainly of critical importance to the overall management of the stand. The value of the increased recovery of biomass from the site must be balanced against the possible loss of future growing potential.

Subsequent silvicultural operations must also be considered in the selection of harvesting systems. In a case where the site is going to be converted to another species, and slash removal, site preparation, and planting are required, the use of a whole-tree harvesting system may significantly improve efficiency. The point is that the total management situation must be considered, both in terms of economics and potential impacts on the site.

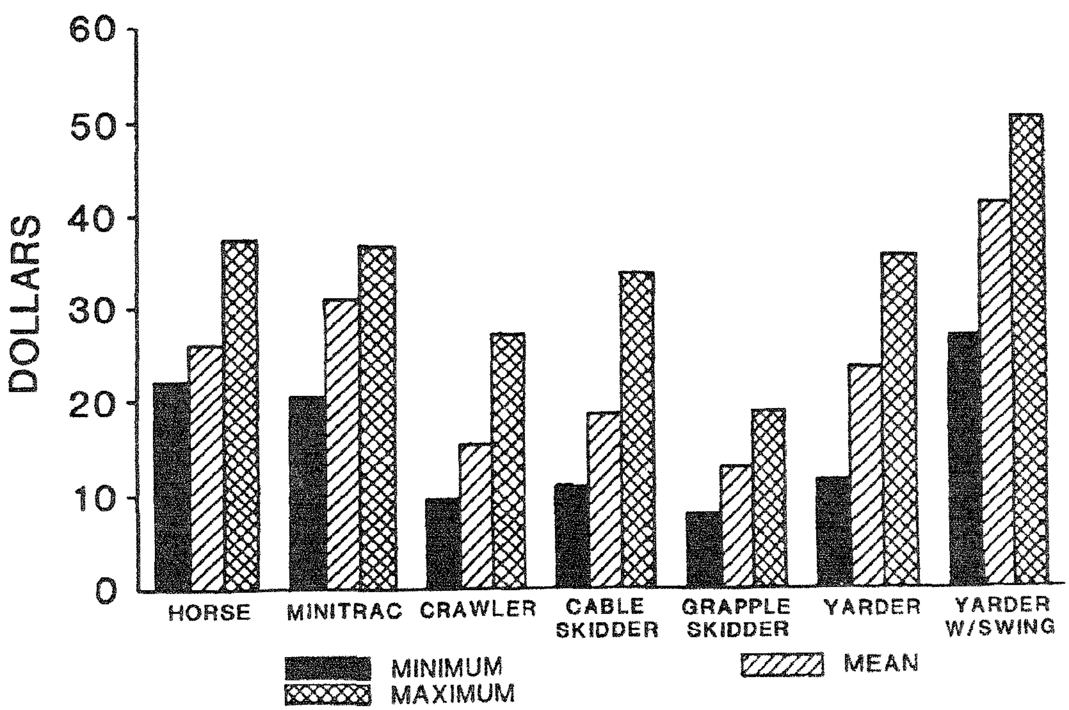

Figure 6. Production cost per cord for various typically used logging systems (taken from Sarles and Luppold 1986).

Damage to the residual stand is a major concern in any harvesting situation where partial cutting is being applied. Particularly in hardwoods, one of the objectives of cutting should be to improve the growth and quality of the residual stand. This is certainly true for both even- and uneven-aged management systems. Because of the danger posed by improper harvesting, damage to the residual stand has been studied extensively in hardwoods, and evaluations of stand damage are part of almost every report on hardwood harvesting systems (Nyland and Gabriel 1972, Biltonen et al. 1976, Hannah et al. 1981, Kelley 1983, Lamson et al. 1985, Bruhn 1986). All studies indicate some residual stand damage, and it is unlikely that we will ever devise a system that totally eliminates damage to residual trees. The question is, what level of damage is acceptable within the management objectives for a particular stand? Past studies have identified several key points that can be used as general guidelines until better information is available. First, full-tree skidding is unacceptable in a partially cut hardwood stand, because the broad branching characteristics of hardwoods make it impossible to remove them without causing excessive damage. It is also very difficult to skid tree-length material without doing significant damage. Thus, tree-length skidding should be done only with proper planning, and with very good equipment operators. Usually the only way to keep damage low is to restrict ground skidding to log lengths bucked at the stump, or to a shortwood system using forwarders. In both cases, results will depend heavily on the operators. Residual stand damage is one of those areas where the human factor cannot be ignored. Unless operators are properly motivated and conscientious, damage cannot be avoided regardless of planning, supervision, or training.

Utilization

Most conventional harvesting systems recover only a small portion of the available biomass. For example, Mattson and Carpenter (1976) found that 41 percent of the aboveground weight of sawtimber-size trees and 49 percent of pole-size trees were left in the forest after a conventional selective harvest of a northern hardwood sawtimber stand. Christopherson and Barnett (1985) reported on efforts to recover the tops and limbs; their work indicated technical feasibility, but marginal economic feasibility.

An increasing hardwood resource, concern about the drain on nutrient reserves that attends intensive utilization, increased costs of harvesting equipment and fuel, and greater awareness of the ecological value of forest litter dictate that we must carefully evaluate our desire to increase the level of utilization in all harvesting operations. Under certain circumstances, it may be prudent to limit the level of utilization of the trees that we are harvesting.

Future Needs

Harvesting Systems

The great range of conditions that support northern hardwood forests requires harvesting systems that can operate efficiently and economically over a wide variety of soil, terrain, weather, and stand conditions. This is especially true for partial cutting operations, where any mismatch between the harvesting system and the stand conditions will increase the potential for adverse site and stand impacts.

The single most important need at present is probably for improved thinning systems. The combination of a partial cut and low product values often results in a difficult harvesting opportunity. Thinning is also a major need on the millions of acres of hardwood forests held by private, nonindustrial owners in the Northeast (Smith and Spencer 1985). These owners, who often rate timber production as one of the lesser values of owning timberland, are especially sensitive to the negative impacts of improper harvesting.

Harvesting Equipment

Any discussion of harvesting systems for northern hardwoods brings out the need for development of several new machines. Hardwoods often grow with a definite lean, and can only be manually felled in a limited arc. This creates the potential for damage to residual crop trees. The ability to sever and directionally-fell large hardwoods would both increase the efficiency of harvesting by aligning the felled trees in the best orientation for skidding, and also reduce residual stand damage. A suitable machine would probably be a directional feller as opposed to a feller/buncher, for the previously mentioned reason that a machine with the capability to pick up a large hardwood from the stump and move it to a bunch would probably be too large for efficient operation in a partially cut stand. A directional feller could be based on a smaller carrier, aiding maneuverability and also keeping the cost down.

Another machine need is for a mechanical delimber capable of handling at least pole-size hardwoods. Production of an acceptable delimber that could be used on a mobile carrier would open the door to greatly improved systems, particularly for thinning. Shortwood harvesting is generally accepted as the best thinning system for hardwoods because of its greater ability to protect the residual stand (Johnson 1984). However, in hardwoods, shortwood harvesting is very labor intensive and costly due to the need for chain saw limbing and bucking. The development of a delimber would permit total mechanization of the shortwood operation, greatly increasing its potential application.

The heavy soils on which hardwoods commonly grow, and the associated problems with operating on these soils under wet conditions, logically lead to the desirability of equipment that exerts low ground pressure. Lower ground pressure can be achieved by either considering differing basic types of machines such as tracked units (Biller 1984), or looking for smaller, lighter machines of conventional design. It is almost an assumption that the development of smaller machines for harvesting would be a plus, particularly for partial harvesting operations. However, the bottom line of production and cost still has to be weighed against the benefits of reduced impacts to the site. Several studies have looked at the possibility of using existing small equipment, particularly tractors for skidding, but the economics for commercial applications generally have been found wanting (U.S. Department of Agriculture, Forest Service 1980).

Challenges to Other Fields

A key challenge in developing efficient harvesting systems for hardwoods is to integrate harvesting system development into the overall management planning process. Development of harvesting systems in the United States has proceeded in relative isolation from long-term strategic planning for forest management and consideration of biological requirements of future timber crops (Brown et al. 1982). It is necessary to change that approach to one that takes a long-term view of harvesting system development, integrating economics and biology as variables. This approach, which has been used successfully in agriculture, will permit equipment designers and forest managers to develop a broader range of future options and increase the chances of achieving the design of optimal systems for managing and utilizing the forest resource.

The integration of harvesting parameters into the planning process will raise questions which have not been previously addressed in timber management research. For instance, previous studies have indicated a correlation between the incidence of residual stand damage and the residual basal area. It is logical to expect that leaving a higher residual basal area will lead to more damage because of the greater number of residual trees in the stand and their closer spacing. What is needed is determination of the optimal level of residual basal area considering the subsequent growth and production of the stand, together with the likelihood of damage and the economics of harvesting the stand to various levels of residual basal area. The key point is that the development and application of the harvesting system must be considered along with the biological factors affecting stand management.

The potential for intensified management of the northern hardwood resource as the demand for forest products increases raises several concerns. More intensive management will require more frequent entries into these stands with machinery to perform harvesting or other management functions. The impacts of these more frequent entries on the site must be considered, and information must be developed that will permit forest managers to optimally plan for and supervise these operations. Establishment of permanent skid trails, or access routes, may need to be considered to minimize the adverse impacts of frequent machinery passage through the stand. The silvicultural effect of having heavily traveled skid roads needs to be studied in conjunction with the effect on harvesting system efficiency and economics. Modified systems and equipment may need to be developed to accommodate these possible changes—for example, systems that can prebunch from within the stand to the established skid trails (Post 1986).

Conclusions

If the hardwood forests of the northeastern United States are to expand their contribution to the regional economy, harvesting must be greatly accelerated, both to meet the increased demand for raw material and to optimize the growth of the region's forests. Most management systems for hardwood forests require periodic partial cuts to achieve the desired objectives. Uneven-aged silvicultural systems prescribe periodic selection harvests with a variety of tree sizes and products designated for removal. Even-aged silvicultural systems prescribe a series of thinnings designed to remove poor-quality trees, undesirable species, and excess basal area, typically as pulpwood. In either system, a major concern is maintaining the productive quality of the site and the stand. Increased levels of harvest will require logging over a wider range of conditions and in more difficult areas. Particularly on multiple-use lands, accelerated harvest will require improved harvesting systems and better planning for timber harvest and transportation.

The key to developing the harvesting systems of tomorrow lies in recognizing that these systems are part of the overall timber production system. Equipment designers must become part of a comprehensive planning process that considers long-term financial and biological options while harvesting systems are being developed. Both forest managers and consumers will benefit in the long run.

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A 32-YEAR STUDY OF STAND DEVELOPMENT AND FINANCIAL RETURNS FOR EIGHT CUTTING METHODS IN NORTHERN HARDWOOD STANDS

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Stand development and financial returns are evaluated for eight silvicultural cutting treatments applied to previously high-graded northern hardwood stands. The cutting treatments applied include: selection cuts of 90, 70, and 50 sq.ft. residual basal area/ac; diameter limit cuts of 22, 16, 12, and 5 inches, a light improvement cut, and an uncut reserve area. Past harvests took place in 1957, 1968, and 1978, with the fourth cutting to take place in 1988. Twenty two year results (1978) showed that the most severe diameter limit cuts (5-, 12-, and 16-in) had the greatest economic returns, but the 16-in diameter limit cut provided what may be the best combination of total return and even flow of returns over time. A precut inventory taken in the winter of 1987 (32 year results) shows the light improvement cut has the best tree grade distribution (46% of the trees being grade 1), followed by the 12-in diameter limit cut (31% grade 1). The 70 sq.ft. selection cut, the 50 sq.ft. selection cut, and the 16-in diameter limit cut all have about the same proportion of grade 1 trees (23-29%).

Introduction

Northern hardwood stands currently occupy nearly 10 million acres of forest land in the Lake States alone (Hutchinson 1985). Most of today's second growth stands originated from the clearcutting and high-grading that took place between 1900 and the 1930's. Sugar maple (Acer saccharum (Marsh)) dominates these stands; other common associates include: yellow birch (Betula alleghaniensis Britton), red maple (Acer rubrum L.), basswood (Tilia americana L.), white ash (Fraxinus americana L.), eastern hemlock (Tsuga canadensis (L.) Carr.) and many other species of lesser importance.

The objective of this study is to determine how stands develop under different methods of cutting, and which system results in the most financially sound alternative over the long run. This includes a detailed look at stand development and growth, tree quality improvement, and financial returns over an extended time period for northern hardwood stands managed under alternative silvicultural systems. The results presented are for 32 years of study just prior to the fourth harvest.

Study Description

The study area consists of nine rectangular 1 acre permanent measurement plots each of which are located within cutting compartments ranging in size from 3 to 14 acres. The study tract totals 54.8 acres, including a 14 acre reserve area. The plots are located at the Ford Forestry Center, Michigan Technological University in Baraga County Michigan. Prior to logging, the area consisted of a mixed pine-hardwood forest from which the pine was removed around the 1890's. A second harvest in the 1930's removed as much as 70 percent of the volume and nearly 90 percent of the merchantable value of the remaining hardwoods. The presence of many large cull and defective trees at the beginning of the study in 1956 suggests that the stand was heavily high-graded in this second cutting, leaving the stand in a condition common to many of today's second growth northern hardwood forests.

Treatments

Eight silvicultural cutting systems have been applied to the stands, one to each compartment, with a reserve area left in an uncut condition. The following cutting treatments are included in the study:

1. Reserve left uncut (R)
2. Light improvement cut (LI)
3. 22 inch diameter limit cut (22-in)
4. 16 inch diameter limit cut (16-in)
5. 12 inch diameter limit cut (12-in)
6. 5 inch diameter limit cut (5-in)
7. Single tree selection cut to 90 sq.ft. BA/ac (90-ft^2)
8. Single tree selection cut to 70 sq.ft. BA/ac (70-ft^2)
9. Single tree selection cut to 50 sq.ft. BA/ac (50-ft^2)

The 12-in and 5-in diameter limit cuts were never recut following the initial stand harvest in 1957, but the 12-in limit will be cut in 1988. The 5-in and 22-in diameter limits, and the 90 ft.^{2} cuts will not be harvested in 1988 due to low harvestable volumes.

Measurements

The plots were measured in 1956, following the first cut in 1957, in 1963, in 1968 prior to the second cutting, in 1973, and in 1978 prior to the third cutting. Measurements were again taken on all plots in 1987 prior to the fourth harvest entry which will take place in 1988. Measurements recorded for each tree greater than 4.6 inches dbh on each one acre measurement plot include: species, diameter at breast height, merchantable height (to a 10-in outside bark diameter limit), cull percent, butt log tree grade, and cordwood height to a 4-in top. Stand tables for each treatment prior to cutting in 1988 are given in Table 1. Table 2 contains board foot volumes and square feet of basal area marked for removal in the 1988 cutting.

At the time of harvest in 1988, all trees to be removed from the 1 acre measurement plots will be felled and bucked, then the individual logs will be scaled and graded according to the standards of the Northern Hardwood and Pine Manufacturer's Association. The recorded measures of volume by log grade will allow for financial analyses of the treatments that will incorporate the changes in log grade distribution over time. Table 3 contains tree grade distributions for each treatment prior to the cutting entry in 1988.

Results and Discussion

Following the third harvest, the 22 year results of this study showed that the three most severe diameter limit cuts (5-, 12-, and 16-in) provided the greatest total return and the greatest return at the beginning of the study. Of these three, the 16-in diameter limit cut gave the most even flow of income and similar total returns as the other two. At this point in the study the quality improvement in the selection cut basal area treatments had not allowed them to surpass the 16-in diameter limit cut in economic returns (Reed et al. 1986). The tree grade distribution in the 12-in and 16-in diameter limit cuts is much better than expected and is similar to or better than the various selection cuts. Although the tree grade distribution is presently quite high in the 12-in and 16-in diameter limit cuts these treatments cannot, however, be expected to lead to improved quality in the stand since marking is not dependent on tree risk, potential for improvement in grade, and cull factors. The selection cut basal area treatments on the other hand could be expected to show improved quality, but the study period may not yet be of a long enough duration to show such

Table 1. Stand tables giving number of trees prior to cut in 1988.

Diam. Class	Treatment								
	R	LI	22-in	16-in	12-in	5-in	90-ft	70-ft	50-ft
6	18	27	38	49	52	86	30	21	39
8	16	12	22	22	36	57	26	20	18
10	16	11	21	24	27	25	6	17	20
12	10	12	10	17	24	12	11	12	19
14	13	15	13	16	15	0	13	9	11
16	13	12	13	21	11	0	6	9	10
18	11	7	13	3	5	0	7	8	8
20	11	4	6	0	0	0	7	4	1
22	7	4	1	0	0	0	7	5	0
24	3	2	0	0	0	0	0	0	0
26	2	0	0	0	0	0	0	0	0
Total	120	106	137	152	170	180	113	105	126
BA ft^2	136	94	102	96	105	62	95	88	82

Table 2. Volume and basal area marked for removal in 1988.

Cutting Treatment*	BF/ac (Int. 1/4")	BA (ft^2/ac)
5-in diam. limit	—	—
12-in diam. limit	4611	47.1
16-in diam. limit	2741	22.4
22-in diam. limit	—	—
50 square feet	1076	18.2
70 square feet	792	9.0
90 square feet	—	—
Light Improvement	2698	19.5

*5-in and 12-in diam. limits were not cut in 1968 & 1978, the 22-in diam limit was not cut in 1978.

Table 3. Tree grade distribution by treatment.

Cutting Treatment	Percent of saw log trees in tree grades			
	1	2	3	nm a/
Light Improvement	46	41	5	7
90 Square feet	18	37	25	20
70 Square feet	26	38	30	6
50 Square feet	29	33	22	16
22-in diam. limit	9	33	42	16
16-in diam. limit	23	30	33	14
12-in diam. limit	31	38	29	2
5-in diam. limit	8	8	17	67
Reserve (uncut)	33	30	31	6

a/ nm indicates nonmerchantable due to size or defect.

improvement. An extended study period may be needed to determine if indeed the selection cuts result in improved quality, which would also lead to greater financial returns.

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REGENERATION AFTER CLEARCUTTING IN THE NORTHERN HARDWOOD PORTION OF THE NASHWAAK EXPERIMENTAL WATERSHED, NEW BRUNSWICK

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The Narrows Mountain Brook watershed (391 ha) was clearcut in 1978-79 as part of the Nashwaak Experimental Watershed Project. This study investigates regeneration of woody species in sixteen permanent 400-m^2 plots located in the portion of the watershed dominated by northern hardwoods. Based on the density of stems >2.5 cm dbh, the dominant tree species one year before harvesting (1977) were Fagus grandifolia Ehrh. (49%), Acer saccharum Marsh. (32%), Acer pensylvanicum L. (12%), Picea spp. (5%), and Betula alleghaniensis Britton (2%). Following the harvest in 1979, each woody stem <50 cm tall was recorded by species and origin of regeneration (new germinant, advance regeneration, sprout) in three 4-m^2 subplots within each vegetation plot. The amount of forest floor disturbance, mineral soil exposure, slash cover, slash density and slash height were also assessed in each subplot. The species composition of seven plots changed relatively little following harvesting as revealed by detrended correspondence analysis (DECORANA). Most of these plots were dominated by advance regeneration and sprouts. The remaining nine plots showed greater shifts in species composition; these plots were dominated by new germinants. New germinants, advance regeneration and sprouts comprised approximately 44%, 44% and 12%, respectively, of the regeneration in all plots in 1979. The densities of new germinants of only two species were significantly correlated with any of the disturbance factors. Betula alleghaniensis was positively correlated with forest floor disturbance (Spearman rank $r = +0.368$, $p < 0.05$) and Prunus pensylvanica L. f. was negatively correlated with slash height (Spearman rank $r = -0.348$, $p < 0.05$). Comparisons with regeneration data from the Hubbard Brook Forest reveal some differences in the proportions of stems from different sources of regeneration for Fagus grandifolia, Acer saccharum and Acer pensylvanicum. Betula alleghaniensis, Fraxinus americana L., and Populus tremuloides Michx. had about the same proportions of each source of regeneration in the two studies.

Acknowledgements

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Introduction

Clearcutting is commonly used by forest industries to harvest northern hardwoods in New Brunswick. The hardwood clearcuts are often left to regenerate naturally. To insure that these areas are adequately stocked with desired species, knowledge of how woody species regenerate is needed. Woody species in hardwood stands regenerate from sprouts, suckers, advance regeneration or seed (Lees 1984). The relative abundance of each source of regeneration may be affected by the amount of disturbance to the forest floor caused by the harvest and the species composition of the stand before harvesting which affects the availability of propagules (seeds, advance regeneration and vegetatively sprouting plant parts) for regeneration. The objectives of this study are to 1) assess the relative abundance of regeneration from advance regeneration, vegetative sprouts or suckers, and seed, and 2) determine the effects of site disturbance factors on regeneration following clearcutting in a northern hardwood stand.

Study Area and Methods

This study utilizes part of a long-term dataset from the Nashwaak Experimental Watershed Project which was established to assess the effects of clearcutting on stream hydrology. The Narrows Mountain Brook watershed (latitude 46°16' N, longitude 67°5' W) was clearcut between May 1978 and March 1979. The watershed is 391 ha in area and ranges from 218 m to 418 m in elevation. Before cutting, red spruce (Picea rubens Sarg.) and balsam fir (Abies balsamea (L.) Mill.) were dominant at lower elevations and northern hardwoods at higher elevations (Powell 1984).

The diameters at breast height of trees >2.5 cm dbh were measured in fifty permanent 400 m^2 plots in 1977, one year before harvest. The plots were relocated after harvest in the summer of 1979 and regeneration (stems <50 cm tall) was sampled in three 4 m^2 subplots within each 400 m^2 plot. Each stem was recorded by origin in the following categories: new germinant, advance regeneration, or sprout. The % of the subplot area with disturbed forest floor, exposed mineral soil and slash cover were recorded. Slash density was estimated in 5 classes and average slash height was determined from measurements at four fixed points on each subplot. The data presented in this paper are stem densities by species in 1977 (one growing season before cutting) and 1979 (1-2 growing seasons after cutting). Only 16 plots dominated by northern hardwoods are included.

To compare species composition before and after clearcutting on an equivalent basis, the relative density of each species (density of species/total plot density) was calculated for each plot based on stems >2.5 cm dbh in the 400 m^2 plot before harvest or stems <50 cm tall in the three 4 m^2 subplots after harvest. These two data sets were combined and analyzed using detrended correspondence analysis (DECORANA), a multivariate ordination program (Hill 1979, Hill and Gauch 1980). This produced a diagram showing stand locations before and after harvest in a two-dimensional ordination space. Relationships between the density of new germinants of each species and disturbance factors were examined with Spearman rank correlation.

Results and Discussion

Relationship Between Pre-cut and Post-cut Species Composition

The amount of compositional change that occurred within a plot can be seen in the ordination diagram (Fig. 1) by the degree of separation between the pre-cut and post-cut plot locations. For example, plot 8 (pre-cut) and plot 8R (post-cut) are relatively close together. From Tables 1 and 2, sugar maple (Acer saccharum Marsh.), beech (Fagus grandifolia Ehrh.) and striped maple (Acer pensylanicum L.) are the most abundant species in plot 8 both before and after cutting, although small amounts of pin cherry (Prunus pensylvanica L.f.) and white birch (Betula papyrifera Marsh.) have come in after cutting. On the other hand, the species composition of plot 12 has undergone a greater change as reflected in the wide separation of 12 and 12R in the diagram and the change in dominance from beech to red maple (Acer rubrum L.) (Tables 1, 2). Overall, seven plots (1, 2, 6, 7, 8, 11, 16) changed relatively little in species composition, whereas nine plots (3, 4, 5, 9, 10, 12, 13, 14, 15) showed greater changes.

In general, groups 1 and 2 in Figure 1 differ mostly in the relative abundances of beech and sugar maple. Group 1 contains only pre-cut plots in which beech is the most abundant species. Group 2 is a combination of pre-cut and post-cut plots dominated by sugar maple with lower abundance of beech. Groups 3-6 are all composed solely of post-cut plots with higher percentages of species that

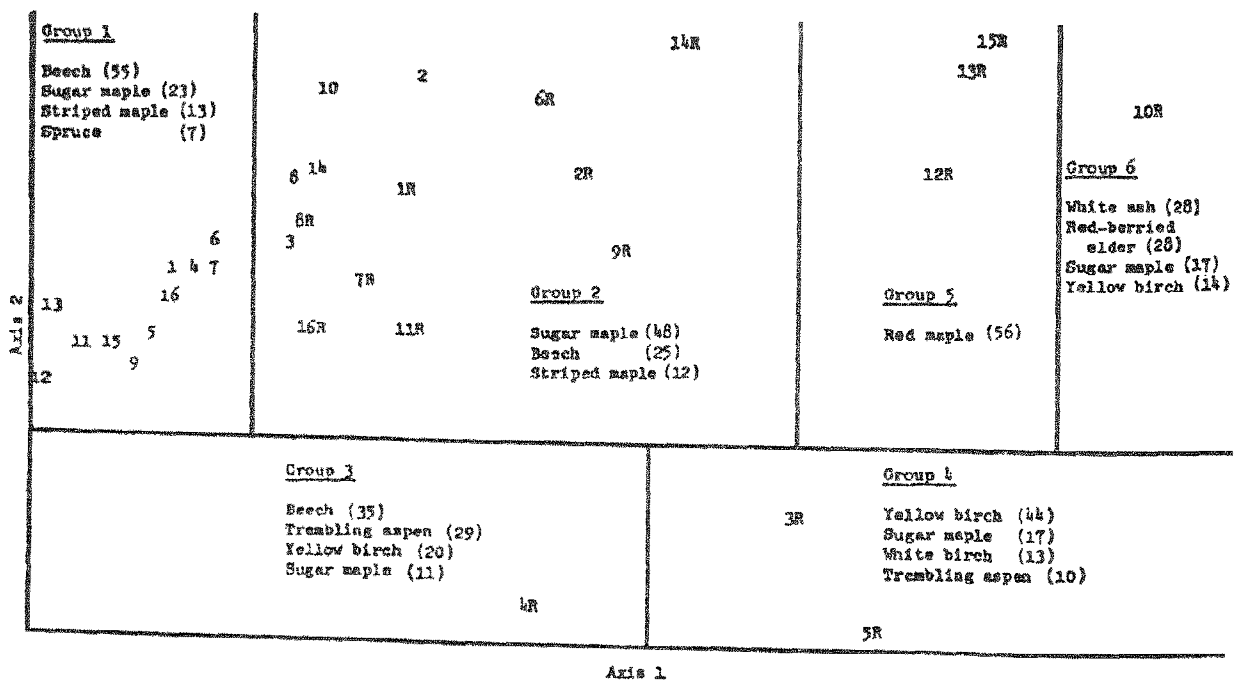

Figure 1. DECORANA ordination diagram showing the positions of plots before clearcutting (numbers only) and the same plots after clearcutting (numbers + R). Input data are relative numbers of stems >2.5 cm dbh in 400 m^2 area (pre-cut plots) and <50 cm tall in 12 m^2 (post-cut plots). Groups are subjectively defined and the most abundant species within each group are listed in decreasing order of average % relative density.

Table 1. Percentage of stems[1] by species in each pre-cut plot.

Plot	Species										
	Sugar maple	Beech	Yellow birch	Striped maple	Red maple	White ash	Spruce	Balsam fir	Red-berried elder	Willow	Other[2]
1	38.75	57.50	-	3.75	-	-	-	-	-	-	-
2	81.54	7.69	3.08	4.62	-	-	3.09	-	-	-	-
3	39.81	38.83	4.85	13.59	-	-	1.94	0.97	-	-	-
4	37.78	52.22	1.11	8.89	-	-	-	-	-	-	-
5	13.00	54.00	-	25.00	-	-	8.00	-	-	-	-
6	35.14	37.84	2.70	13.51	-	-	9.46	1.35	-	-	-
7	38.46	50.55	2.20	6.59	-	-	2.20	-	-	-	-
8	56.84	34.74	-	8.42	-	-	-	-	-	-	-
9	9.26	62.96	2.78	19.44	-	-	4.63	-	-	-	0.93
10	51.02	28.57	-	7.14	-	-	-	1.02	1.02	1.02	8.16
11	9.41	54.12	1.18	21.18	-	2.04	14.12	-	-	-	-
12	9.09	80.91	-	6.36	-	-	1.82	1.82	-	-	-
13	18.52	49.38	1.23	11.11	-	-	19.75	-	-	-	-
14	50.00	34.49	-	6.90	5.17	-	-	-	-	-	3.45
15	12.66	58.23	2.53	10.46	-	-	10.13	-	-	-	-
16	28.57	52.38	2.38	10.71	-	-	5.95	-	-	-	-
Total # Stems (all plots)	443	680	21	165	3	2	69	5	1	1	11
% Total # Stems (all plots)	31.6	48.5	1.5	11.8	0.2	0.1	4.9	0.4	0.1	0.1	0.7
Total Stems/ha	692	1063	33	258	5	3	108	8	2	2	17

[1]Stems > 2.5 cm dbh in full plot (400 m^2).

[2]Includes mountain maple, black ash, green ash, and elderberry.

Table 2. Percentage of stems[1] by species in each post-cut plot.

Plot	Species													
	Sugar maple	Beech	Yellow birch	Striped maple	Red maple	White ash	Spruce	Balsam fir	Trembling aspen	White birch	Pin cherry	Beaked hazel	Red-berried elder	Willow
1	70.00	20.00	-	-	-	-	-	-	10.00	-	-	-	-	-
2	69.15	2.13	15.96	7.44	2.13	-	-	-	3.19	-	-	-	-	-
3	30.00	2.00	42.00	2.00	4.00	-	-	-	18.00	2.00	-	-	-	-
4	10.61	34.85	19.70	4.55	1.52	-	-	-	28.79	-	-	-	-	-
5	3.67	3.67	46.79	13.76	2.75	-	0.92	-	2.75	24.77	0.92	-	-	-
6	27.59	20.69	13.79	8.62	-	3.45	-	1.72	6.90	-	6.90	-	-	10.34
7	36.00	40.00	12.00	8.00	-	4.00	-	-	-	-	-	-	-	-
8	44.93	40.58	-	7.24	-	-	-	-	-	4.35	2.90	-	-	-
9	42.09	2.04	16.58	33.16	1.53	-	-	-	1.53	3.06	-	-	-	-
10	17.24	-	13.79	3.45	10.34	27.59	-	-	-	-	-	-	27.59	-
11	10.67	36.00	8.00	40.00	4.00	-	-	-	-	1.33	-	-	-	-
12	14.18	10.45	17.16	-	41.79	7.46	-	1.49	2.98	2.98	1.49	-	-	-
13	1.56	6.25	2.34	28.91	60.94	-	-	-	-	-	-	-	-	-
14	53.92	1.96	3.92	14.71	18.63	2.94	-	-	-	-	-	3.92	-	-
15	17.49	4.56	0.38	8.75	65.40	0.76	-	-	0.38	2.28	-	-	-	-
16	35.00	45.00	2.50	7.50	-	-	-	-	2.50	7.50	-	-	-	-
Total # Stems (all plots)	468	171	218	277	345	26	1	3	51	57	9	4	8	6
% Total # Stems (all plots)	28.5	10.4	13.3	16.8	21.0	1.6	0.1	0.2	3.1	3.5	0.6	0.3	0.5	0.4
Total Stems/ha	24375	8906	11354	14427	17969	1354	52	156	2656	2969	469	208	417	313

[1]Stems < 50 cm tall in three 4 m^2 subplots (12 m^2) within full plot.

invaded following the harvest, such as trembling aspen (Populus tremuloides Michx.), yellow birch (Betula alleghaniensis Britton), white ash (Fraxinus americana L., and red maple.

Sources of Regeneration

Regeneration from vegetative origin (advanced regeneration + sprouts) averaged 82% on the nine post-cut plots in group 2 (Fig. 1, Table 3). The remaining post-cut plots (groups 3-6 combined) contained an average of 36.5% vegetative regeneration. Thus, the plots that showed the least change in species composition had higher proportions of vegetative regeneration. On most of these plots, the greatest change was a decrease in the relative abundance of beech.

Over all plots and species, new germinants and advanced regeneration each averaged about 44% of the stems following harvest (Table 4). Sprouts made up only 12% of the regeneration. Yellow birch, red maple, white birch, trembling aspen, and white ash were the important species that reproduced mainly from seed. Sugar maple and striped maple reproduced mainly by advanced regeneration, whereas beech, red-berried elder (Sambucus pubens Michx., and willow (Salix spp.) reproduced mainly by sprouts (Table 4).

Comparisons with regeneration data from the Hubbard Brook Forest (Bormann and Likens 1979) reveal several differences. For beech, advanced regeneration was less whereas new germinants and sprouts were more abundant at Narrows Mountain Brook. For sugar and striped maple, there was more advanced regeneration, fewer new germinants and about the same percentage of sprouts at Narrows Mountain Brook. Yellow birch, white ash, and trembling aspen had about the same proportions in each regeneration class in the two studies. The differences may be related to many factors, including variations in seed production of particular species, sprouting vigor of stumps, and disturbance caused by harvesting. However, these comparisons must be viewed with caution because the period of time between harvesting and data collection was six years at Hubbard Brook but only one year at Narrows Mountain Brook.

Relationships Between Regeneration and Disturbance Factors

Significant correlations between the number of new germinants and the disturbance factors were found for two species only. Yellow birch was correlated with % forest floor disturbance (Spearman rank $r = +0.368$, $p<0.05$) and pin cherry was correlated with slash height (Spearman rank $r = -0.348$, $p<0.05$). Other studies have demonstrated

Table 3. Percentage of stems from each source of regeneration in each post-cut plot.

Plot	New Germinants (%)	Advance Regeneration (%)	Sprouts (%)	Total Vegetative (Adv. Regen. + Sprouts) (%)
1	10.0	70.0	20.0	90.0
2	16.0	73.4	10.6	84.0
3	48.0	12.0	40.0	52.0
4	48.5	14.1	36.4	50.5
5	81.7	18.3	0.0	18.3
6	21.2	15.3	63.5	78.8
7	12.0	24.0	64.0	88.0
8	5.8	52.2	42.0	94.2
9	27.0	71.0	2.0	73.0
10	76.2	4.7	19.1	23.8
11	42.7	45.3	12.0	57.3
12	47.8	43.3	8.9	52.2
13	70.3	29.7	0.0	29.7
14	27.6	69.3	3.1	72.4
15	70.7	23.2	6.1	29.3
16	15.0	45.0	40.0	85.0

higher germination rates and seedling survival of yellow birch on mineral soil substrates as compared to litter (e.g., Marquis 1969, Tubbs 1969). Shading from the slash may have prevented seed germination and/or the survival of new germinants of pin cherry.

In conclusion, species composition following clearcutting in a northern hardwood stand may change relatively little because of advance regeneration of sugar maple, striped maple and balsam fir and sprouting of beech, red-berried elder and willow. Advance regeneration is more important than sprouting and will dominate the regeneration if not disturbed during the harvest. On the other hand, species composition may be significantly altered through the invasion of red maple, yellow birch, white birch, white ash and other species from seed. If these species are desired, the forest floor should be disturbed and slash levels reduced in the harvesting operation.

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Table 4. Percentage of stems from each source of regeneration by species in the post-cut plots.

Species	New Germinants (%)	Advance Regeneration (%)	Sprouts (%)	Total Vegetative (Adv. Regen. + Sprouts) (%)
Tree species				
Sugar maple	11.8	72.9	15.4	88.3
Red maple	68.4	30.4	1.2	31.6
Striped maple	32.5	66.4	1.1	67.5
Yellow birch	85.3	10.1	4.6	14.7
Beech	8.2	27.5	64.3	91.8
White birch	100.0	-	-	-
Trembling aspen	100.0	-	-	-
White ash	88.4	11.6	-	11.6
Pin cherry	88.9	11.1	-	11.1
Balsam fir	-	100.0	-	100.0
Spruce	100.0	-	-	-
Shrub species				
Red-berried elder	-	-	100.0	100.0
Willow	-	-	100.0	100.0
Beaked hazel	100.0	-	-	-
Total (all plots)	43.4	44.2	12.4	56.6

MODELING NORTHERN HARDWOOD STAND DEVELOPMENT

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SIMSAP and SIMTIM have been developed to simulate the stand growth and development of natural and treated even-aged northern hardwood stands. Using available data, the connecting phases of both models have been tested to determine the effects of silvicultural treatments (or no treatment) on long-term stand response. SIMSAP begins with species distributions by quality classes in sapling stands after regeneration. Treatments include pruning of crop trees and weeding. The sapling stage continues until the mean stand diameter reaches 3.0 inches, at which time understory trees are deleted, leaving only trees in the main crown canopy and a mean stand diameter of approximately 4.5 inches. SIMTIM, the poletimber-sawtimber-harvest phase, uses stocking guides based on quadratic mean stand diameter, number of trees, and basal area per acre of trees in the main crown canopy. Growth and yield predictions for managed and unmanaged stands are based on site index and age, and are allotted by residual basal area, percent sawtimber, and species composition. Thinning may begin when the stand reaches the A line or a level of basal area above the B line, starting at a user-specified diameter. A quality-line thinning, which retains a residual basal area of approximately 80 ft^2/acre until the quadratic mean stand diameter reaches 6.0 inches can be specified; otherwise, the stand is thinned to the B line. Both thinning and harvest yields are presented in cubic feet and board feet per acre by species and quality classes.

The models SIMSAP and SIMTIM form a forest-stand growth model for even-aged northern hardwoods across New England to simulate growth from a sapling stand to a user-specified harvest cut or stand age (Solomon 1977, Solomon and Hosmer 1987). The overall model has two main phases: sapling-stand development (SIMSAP) and poletimber-sawtimber-harvest (SIMTIM). The output of the first phase provides information that can be used as input in the second phase.

The major species that made up the northern hardwood stands used to construct the model were: yellow birch, sugar maple, white ash, paper birch, red maple, beech, aspen, hemlock, and red spruce.

SIMSAP

The sapling-stand development phase has been described as a compound exponential process (Leak 1969) that provides a basis for determining changes in numbers of stems by species groups during the sapling stage. After a weeding treatment is applied, the rate of mortality is modified which will change the shape of the exponential curve. A pruning treatment will change the quality distribution of the stems in the residual stand.

The initial stand information needed is the site index, defined as height of sugar maple at base age 50, and species composition expressed as a percentage of the initial stand at 1 inch mean stand diameter.

The silvicultural treatments available are pruning and weeding operations. The pruning option will prune all yellow birch and sugar maple crop trees less than veneer grade to one log length. If weeding is desired, the user must supply beginning average stand diameter; upper and lower bounds of number of good stems, within which limits weeding will be conducted; number of crop trees to be released; average number of competitors to remove per crop tree; and the crop-tree priorities of beech, yellow birch, sugar maple, red maple, paper birch, and white ash.

The final output consists of percent composition and number of stems for each species and quality class (for the important commercial species); a summary of total numbers of stems, basal area, and mean stand diameter; and an estimate of the years required to reach the end of the sapling phase (Table 1).

SIMTIM

The poletimber-sawtimber-harvest phase of the simulator (SIMTIM) grows the stand from the end of the sapling phase, approximately 4.5 inches average diameter, to harvest diameter or rotation age. The overall framework of the model is a distance-independent average-stand model. Input consists of site index, specifications on the thinning regime, and the stand characteristics of age, basal area, quadratic mean stand diameter, and percent of basal area by size, species, and quality. To simulate silvicultural practices, the density level used to initiate thinning, thinning intensities, paper birch salvage operations, and species priorities for removal must be specified by the user. Also, harvest information is needed for stand rotation in the form of desired stand diameter and/or age limits.

The model projects stand characteristics by positioning the stand within the northern hardwood stocking chart (Fig. 1) and relating stand development to stocking. The lines in figure 1 were developed from trees within the main crown canopy of northern hardwood stands. The main crown canopy is defined as all trees on the plot that are not overtopped or suppressed. The A line represents a fully stocked stand without any form of management. The B line is based on optimum stand growth from different studies of northern hardwood growth.

The C line represents a managed stand with minimum level of acceptable growing stock (sawlog potential) that will grow to the B line in 10 years. The quality line maintains a higher level of basal-area stocking for smaller quadratic mean

Table 1. Example of the output produced by SIMSAP at the end of the sapling phase.

UNDISTURBED WITH WEEDING SITE 60 NO PRUNING
SPECIES COMP FOR:

Be	YB	SM	RM	PB	WA	PC	ST MAP	AS	OTH	RMSPT
0.08	0.12	0.16	0.05	0.16	0.02	0.18	0.02	0.03	0.08	0.10

SITE = 60.0
WEEDING DESIRED AT DBH 2.500
WEEDING WAS APPLIED

CROP TREES OF BEECH	YEL B	SUG M	RED M	PAP B	W ASH	ALL
0.0	125.6	116.2	0.0	158.2	0.0	400.0

NUMBER CUT IN WEEDING = 800.0 NUMBER LEFT = 1225.1
2-INCH CLASS DROPPED
SPECIES NUMBERS AFTER SAPLING STAGE

	BEECH	YEL B	SUG M	RED M	PAP B	W ASH
QUALITY 1	2.1	26.8	15.5	3.4	44.3	2.9
	0.3%	3.9%	2.2%	0.5%	6.4%	0.4%
QUALITY 2	3.3	16.4	95.0	4.4	66.6	1.6
	0.5%	2.4%	13.8%	0.6%	9.7%	0.2%
QUALITY 3	36.4	34.5	59.8	16.6	86.2	5.3
	5.3%	5.0%	8.7%	2.4%	12.5%	0.8%

RMSPRTS	ASPEN	OTHER	STR MAP	PIN C
94.4	23.4	34.5	15.6	0.0
13.7%	3.4%	5.0%	2.3%	0.0%

NUMBERS, BASAL AREA, AND AVE DBH AT END OF SAPLING STAGE
688.995 91.207 4.927
YEARS TO END OF SAPLING STAGE = 38.00

diameters. Thinning a stand to the quality line provides clear bole form on younger, smaller high-quality species.

Stand Growth

Accretion and ingrowth are calculated as functions of the stand basal area and the percentage of sawtimber-size trees in the stand. Mortality is a function of where the stand is in relation to the A line and the B line of the stocking chart (Fig. 1). As species composition changes, the growth rate of any species may increase or decrease. Thus, stand growth, as computed from accretion, ingrowth, and mortality, is proportioned into the species growth rate based on the residual basal area of the stand, mean stand diameter, and percent of species composition. Changing species composition does not change stand growth, but changes the amount of growth allotted to individual species.

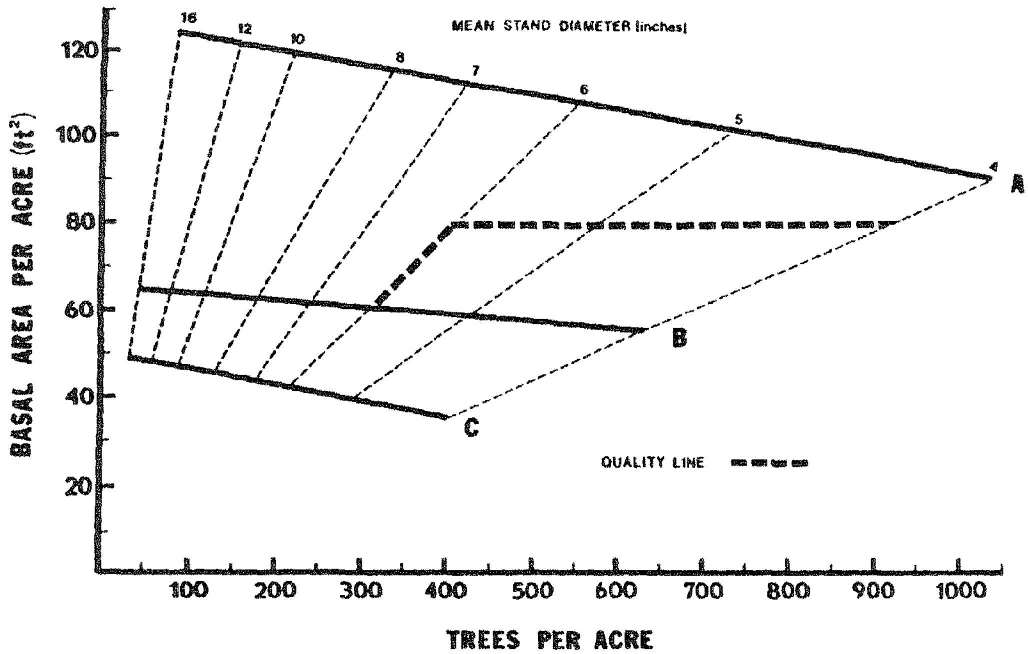

Figure 1. Stocking chart for northern hardwoods is based on trees in the main crown canopy.

Thinning Options

Thinning is regulated by basal area in the stocking chart (Fig. 1). The user options include no thinning, thin when the stand reaches the A line, or when the stand reaches a user-specified basal area above the B line. The user must specify the quadratic mean diameter to the nearest tenth of an inch for thinning to begin.

The user can specify the order of removing the species from the three quality classes by priority. A number specifies the point in the order of removal for the model to switch from complete species-quality class removal to proportional removal of remaining species-quality classes. This maintains species composition and quality of species.

Thinning may be to the B line when the stand reaches a specified mean stand diameter or it may be regulated by the quality line to a 6-inch quadratic mean diameter. When thinning is conducted back to the quality line, the stand is thinned to 80 square feet for stands with quadratic mean diameters less than or equal to 6 inches, and then is thinned to the B line for stands with quadratic mean diameters greater than 6 inches.

Paper Birch-Aspen Mortality

When the stand reaches 80 years of age, mortality of remaining paper birch and aspen is accelerated to represent the short life span of these two species. Five percent of the initial amount of each species is removed per year, resulting in complete removal of both species between 80 and 100 years of age (Solomon and Leak 1969). Mortality losses are applied proportionally across all quality classes. Percentages of the remaining species are adjusted so that they continue to sum to 100 percent. The user can circumvent this accelerated mortality by specifying that paper birch and aspen be removed in the first thinning after age 70.

Output

Information can be printed periodically so that the growth of the stand can be traced. This information includes the age of the stand, mean stand diameter, number of trees, and basal area per acre. The model continues until the mean stand diameter to begin thinning has been reached. If thinning is specified, the number of trees, and the percentage by species of the total stand thinned are listed by species and quality class for each thinning.

Table 2. Example of output at the end of the poletimber-sawtimber-harvest phase of SIMTIM.

STAND AT HARVEST DIAMETER 18.0 OR ROTATION AGE 400.0
SITE INDEX = 60
NUMBER OF TREES/ACRE = 52.9
BASAL AREA = 94.15
QUADRATIC MEAN DIAMETER = 18.1
AGE OF STAND = 120
THINNING BEGAN AT DIAMETER = 5.0

HARVEST YIELD IN PERCENT

QUALITY	SPECIES								
CLASS	Be	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
1	15.2%	37.3%	41.0%	3.3%	0.0%	3.2%	0.0%	0.0%	100.0%
FT2	14.3	35.1	38.6	3.1	0.0	3.0	0.0	0.0	94.1
FT3	384.1	941.0	1035.3	83.3	0.0	81.1	0.0	0.0	2525.0
BF	1614.1	3955.2	4351.4	350.3	0.0	341.1	0.0	0.0	10612.3
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The final output in Table 2 consists of a listing of stand characteristics at harvest: site index, trees per acre, basal area, quadratic mean stand diameter, age, when thinning was started, total basal area, total volume, and total board feet. Also, yield tables presenting basal area, volume, and board feet by species and quality class are presented for the total yield from thinnings, harvest yield, and a combined total yield. Square feet of basal area is converted to both cubic feet and board feet based on the quadratic mean stand diameter (Leak 1980). Thus, the yields by species are based on the percentage of a species in the total basal area. The cubic feet per square foot of basal area gives the total cubic feet; similarly, the board feet per square foot gives the board feet. Then the board feet divided by the board foot/cubic foot ratio gives the amount of cubic feet in the sawtimber yields. By subtracting this amount from the total yield, we can estimate the amount of cubic feet in pulp, cull, or extra sawtimber.

Growth comparisons are presented for northern hardwood stands on site index 60 that were: (1) unthinned, (2) thinned to the quality line starting at a quadratic mean stand diameter of 5 inches and then thinned to the B line, and (3) thinned to the B line starting when the stand reached 9 inches quadratic mean stand diameter (Fig. 2). The managed stands were thinned when they reached 30 ft^2 above the B line. SIMTIM was used to simulate a series of managed yield tables by species and quality for even-aged northern hardwood stands with several thinning methods and site indices (Solomon and Leak 1986).

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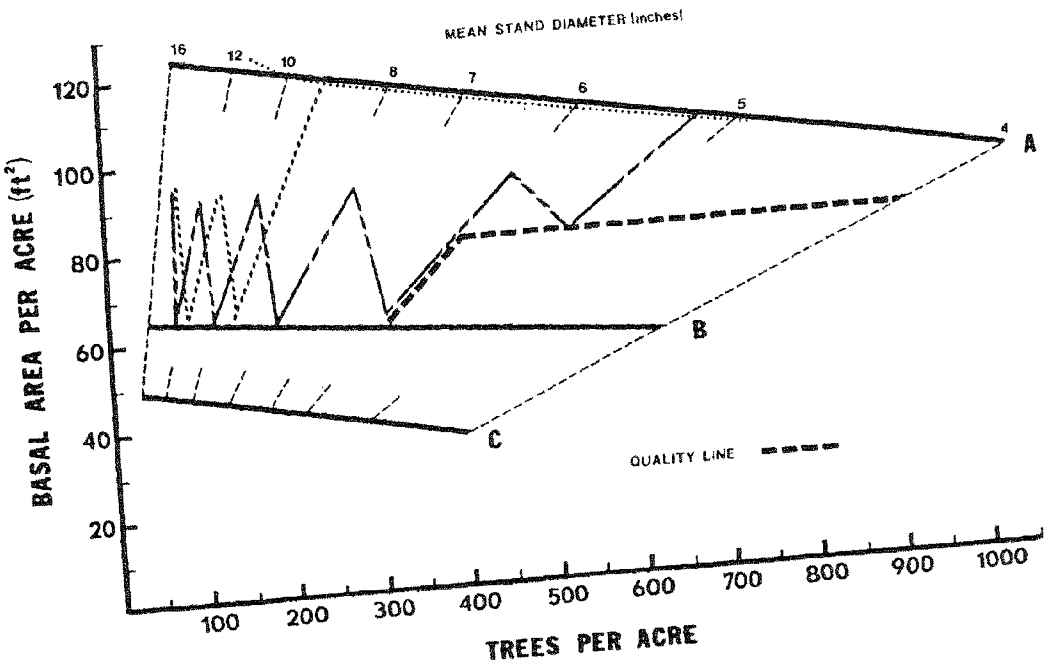

Figure 2. Comparison of growth response for unthinned stands (........), stands thinned to the quality line starting at 5.0 inches QMSD (— -- —), and thinned to the B line starting at 9.0 inches QMSD (--------).

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GROWTH MODEL FOR FOREST MANAGERS OF NORTHERN HARDWOODS

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Growth and yields for northern hardwoods and associated forest types of different species mixtures can be predicted with the model FIBER. Changes in stand growth of multiple species composition are available within the model. The model uses diameter distributions of classes ranging from 4.5 to 30.0 inches for each of the commercial species in these forest types. Thinning and harvest yields can be obtained for managed and unmanaged, even-aged, and multi-aged stands over a range of densities, site indices, and intermediate treatments.

The model FIBER has been shown to be reliable for predicting the growth of northern hardwoods and spruce-fir forest types in northern New England, United States, and the Maritime Provinces, Canada. A modeling framework was developed to include the interaction of different species on the growth of stands with different levels of density, silvicultural treatments, and management practices (Solomon et al. 1986).

The initial development of the FIBER model was based on the growth of stands without catastrophic stress from the environment such as insect attacks, diseases, drought, etc. From combined data from growth studies, more than 3,000 remeasured plots from Nova Scotia, New Brunswick, Maine, New Hampshire, Vermont, and northern New York were used to further develop the model FIBER. The data included many managed plots such as the permanent plots established in the northern hardwood type on the Bartlett Experimental Forest, Bartlett, NH, and the mixed-species spruce-fir type on the Penobscot Experimental Forest, Bradley, ME. The plots were measured at 5-year intervals at various times between 1950 and 1980 and represent managed and unmanaged stands covering a wide range in species composition, site, management options, and densities (Solomon et al. 1987).

This calibration data covered the following range in species composition, site, and density:

Item	Northern hardwood	Mixedwood	Spruce-fir softwood
Composition (% softwood)	≤ 25	>25 and <65	≥ 65
Site index	40-80	35-75	30-70
Basal area (ft^2/acre)	20-140	20-180	20-240

In the Northeast, northern hardwood stands often are found on better sites, softwood stands on poorer sites, and a species mixture on intermediate sites. The sites used for study locations ranged from well-drained to poorly drained soils. Site index was not calculated for each plot within the three data sets. However, some hardwod stands had site indices of 50-60 for sugar maple at base age 50 years and softwood stands had site indices of 40-50 for red spruce at base age 50 years. The data ranged from the better pure northern hardwood stands to the poorer spruce-cedar stands. An expression of site index was not included as a variable in FIBER since site measurements were not taken on all plots used in model construction.

The species represented in the model are: sugar maple, red maple, yellow birch, paper birch, american beech, white ash, aspen, balsam fir, black spruce, red spruce, white spruce, eastern hemlock, northern white-cedar, other hardwoods (gray birch, striped maple, pin cherry, and black ash), and other softwoods, (tamarack and white pine).

Transition probabilities are used to project the diameter distributions through time by predicting the probability that trees in a species' specific diameter class will stay in that class, grow to the next larger class, grow to the second larger class, or die. At each 5-year projection interval, transition probabilities are predicted by regression equations based on the basal area before and after thinning, the midpoint of the diameter class, and the proportion of hardwoods in the stand. Ingrowth into the 5-inch class for each species is predicted by a linear regression on the residual basal area, the proportion of hardwood species, and the proportion of that specific species in the stand.

Available Options

Three choices are available for inputting data of an initial stand by diameter class. In each case, the user is first asked to indicate which species will be allowed in the stand composition. The first stocking option asks the user to enter a diameter list in trees per acre for each species (fractional parts of a tree may be entered). The second option requests the total number of stems per acre for a given species and the percentage of these stems in diameter classes 5, 6, 7, 8, 9 10, 11, 12, 13-15, 16-19, and 20+. The last choice allows the user to enter one or more diameter distributions from a single plot by summing plot.

Inventory plots can be either fixed size or prism plots. The user is asked to provide an expansion factor to convert the inventory plot information to per-acre estimates for a stand average. The model uses 1-inch diameter classes, but diameter distributions can be entered in 2-inch classes and will be programmatically distributed into 1-inch classes using de Liocourt's (1898) "q value" for uneven-aged stands (modifications for even-aged stands will be added). A mixture of fixed and prism plots with 1- or 2-inch diameter distributions may be entered. An average stand is created from per-acre estimates which FIBER uses for projection.

Thinning options to control silvicultural treatments can be invoked at a specified number of years in the future or at a stocking level expressed in square feet or cubic feet. Several ways to simulate different silvicultural practices are available to the user. These treatments include:

1. No thinning.
2. Thin from above—remove trees in a smaller than specified diameter class.
3. Thin from below—remove trees in a larger than specified diameter class.
4. Uniform thinning—remove trees across all diameter classes.
5. Selection thinning—specify the species, diameter class, and number of trees to remove from that class.
6. Thin while maintaining the "q value"—remove trees in an uneven-aged structure by specifying the desired residual basal area and maximum tree diameter, while maintaining the "q value" (de Liocourt 1898).

For all of the thinning options, a percentage removed from each species and an order of priority must be specified by the user. Lower priority species are removed first until the required thinning level is reached.

The model continues to grow the stand for the specified number of years or to the user-specified basal area or volume level. Thinning begins removing trees until the specified residual density level is reached. The residual level can be maintained as square feet or cubic feet, or the model can be instructed to thin to an optimum growth response level (B line) from stocking charts (Fig. 1) if the stand is even-aged. The charts were constructed to provide a guide for the upper limit of stocking for unmanaged stands (A line) or a level of an optimum growth (B line) for even-aged stands (Solomon and Leak 1986).

Model Reliability

To validate the predictions of the model, the data set was stratified by forest type. The actual growth on each plot was compared to the predicted growth over a 15-year period (Table 1). The predicted final volume differed from the actual volume by 0.9 to 14.1 percent. The poorest predictions were in the lowest basal area categories. These differences were due primarily to large amounts of ingrowth, but predictions are expected to improve as more data sets are included.

Another validation test of the model was done using managed northern hardwood stands from the Bartlett Experimental Forest, Bartlett, NH. The first 15 years of data were used in the model development but the validation used a recently collected inventory to allow a 20-year projection. Data were collected on forty-eight 1/3-acre plots laid out on a relatively uniform site. Four levels of residual stand density (40, 60, 80, 100 square feet per acre) and three levels of stand structure (30, 45, and 60 percent sawtimber) within each basal area class were assigned at random to these plots. Thus, there were four plots within each of the 12 combinations. The initial thinning was done in 1963 and the stand remeasured periodically until 1983. The actual growth was compared to predicted growth over the 20-year period (Table 2). The percent difference between actual and predicted standing volume ranged from 15.6 to -3.4. Again, the poorest predictions are in the lower basal-area classes with the difference due to ingrowth. Hemlock ingrowth accounted for 5 to 8 percent of the difference due to site and plot location.

Table 1. Average stand volume (ft^3/acre) after 15 years by basal-area class and forest type.

BA class (ft^2/acre)		Northern hardwood	Mixedwood	Spruce-fir softwood
	Actual	1620	1689	1605
40	Predicted	1411	1452	1465
	% Difference	12.9	14.1	8.7
	(Plots)	(59)	(54)	(94)
	Actual	2326	2574	2511
80	Predicted	2346	2348	2430
	% Difference	-0.9	8.8	3.2
	(Plots)	(69)	(74)	(191)
	Actual	2846	3004	3195
120	Predicted	3036	3167	3155
	% Difference	-6.7	-5.4	1.3
	(Plots)	(20)	(45)	(135)
	Actual	-	3787	3618
160	Predicted	-	3299	3727
	% Difference	-	12.9	-3.0
	(Plots)	-	(6)	(29)

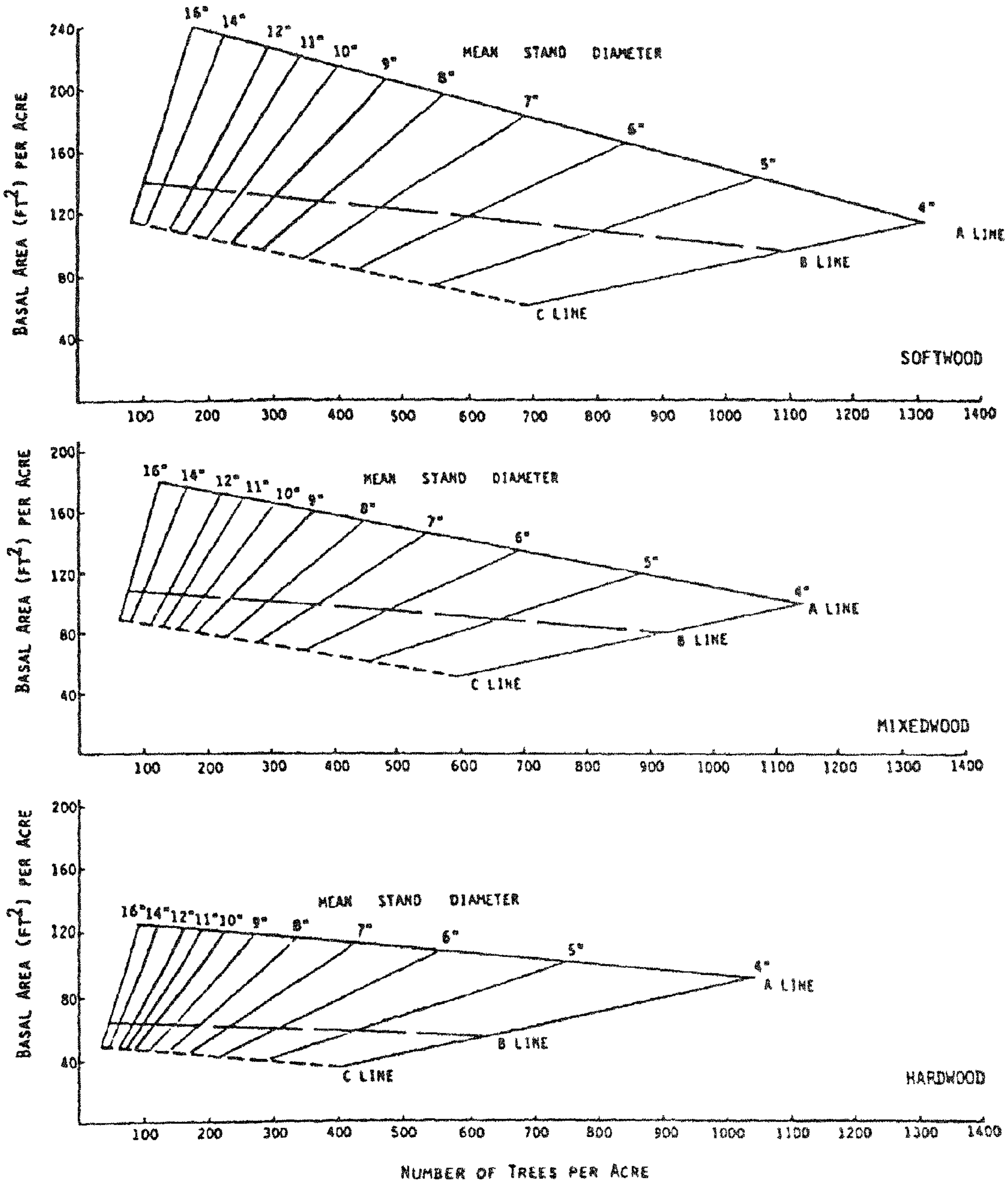

Figure 1. Stocking charts for spruce-fir softwood, mixedwood and northern hardwood stands are based on trees in the main crown canopy and represent maximum stocking (A line), minimum stocking for adequate growth response (B line), and minimum amount of acceptable growing stock for a managed stand (C line).

Table 2. Actual and predicted total stand volumes (ft³/acre) 20 years after initial thinning by basal area and percent sawtimber classes.

Percent sawtimber class		Residual Basal Area Class 40	60	80	100	All
	Actual	1675	2114	2500	2948	2309
30	Predicted	1428	2019	2504	3010	2240
	% Difference	14.8	4.5	-0.2	-2.1	3.0
	(Plots)	(4)	(4)	(4)	(4)	(16)
	Actual	1685	2221	2562	2818	2322
45	Predicted	1494	1978	2493	2849	2203
	% Difference	11.4	10.9	2.7	-1.1	5.1
	(Plots)	(4)	(4)	(4)	(4)	(16)
	Actual	1625	2163	2421	2892	2275
60	Predicted	1368	1987	2476	2982	2205
	% Difference	15.6	8.2	-2.3	-3.4	3.1
	(Plots)	(4)	(4)	(4)	(4)	(16)
	Actual	1662	2166	2494	2886	2302
All	Predicted	1439	1994	2491	2950	2216
	% Difference	13.9	7.9	0.1	-2.2	3.7
	(Plots)	(12)	(12)	(12)	(12)	(48)

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FINDING COMMON GROUND

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The original objective of this symposium was to find common ground among various professional concerns in the forestry community for choosing a silvicultural system (even-age, uneven-age, none). In previous meetings we had attended, recommendations for a particular silvicultural system often were based on one discipline or approach, and these recommendations could be conflicting depending on which one was followed.

This symposium began with the opportunity for professionals in each field to present their concerns and outline their approaches. Then, all speakers were asked to review their recommendations relative to the concerns raised by others. The final panel discussion provided a unique forum in which the same questions were asked of several speakers, thereby providing common ground for weighing the answers. The discussion demonstrated the process by which a forest stand could be viewed in light of all approaches—a broadening of perspective that can and should be the basis of wise forest management. This chapter summarizes the panel discussion, drawing from and integrating the preceeding papers.

The basic unit of silvicultural interest is the stand—a collection of trees of relatively uniform species, age, and quality. The basic unit of study of other fields may be different: ecologists look for a watershed; entomologists look for preferred habitats of insects; economists start with landowner goals. This difference in the basic unit of study reflects the different priorities assigned to the stand characteristics by each discipline. Because stand management tends to be consistent with a given set of priorities, it is difficult to find a common management scheme that accommodates all approaches.

This symposium suggested that such apparent conflicts can be diminished by broadening the perspectives of each field. We begin by describing the importance assigned by each discipline to the same fundamental stand characteristics, e.g., species, age, vigor, density, diameter of trees. Then we suggest how priorities might be reassigned, thereby broadening each view. As a consequence of this process of reassignment, we find common ground.

Conventional silviculture provides a choice between two basic options: uneven-age or even-age management. Tubbs (p 27) describes uneven-age management in which the objective is to create a continuum of ages of shade tolerant species. Smith (p 17) discusses conventional even-age management in which stands with distinct age classes, alternating between shade intolerant and tolerant species, are desired. In either case, the species and age structure of each stand generally dictate which management option is favored.

However, Seymour (p 3) points out that a choice limited to uneven-age or even-age options may not be appropriate for present-day forests or management concerns. Factors like forest succession, insect and disease outbreaks, logging practices, lack of management, and fragmentation have resulted in a high percentage of stands with poor quality timber, species of low commercial value, and variable structure. Management of these stands needs to be flexible rather than forced to follow one or the other option.

Smith (p 17) breaks out of this even-age/uneven-age dichotomy by suggesting that the larger landscape replace the stand as the fundamental unit of mangement. This landscape is a composite of the stands derived from many even-aged, stratified mixtures of ages, species, and structures. The new silvicultural objective is to work with this diversity of compositions and structures across the landscape rather than assigning a prescribed form of mangement to certain types of stands.

According to Leak (p 31), stand characteristics are closely related to site factors, such as soil type and drainage. Optimal tree growth tends to occur where species are well suited to the site. But regional patterns of land use have resulted in the growth of species on sub-optimal sites. Economic diameter distributions may be slow to develop on such sites and rotation lengths must reflect this realization. Further, little is known about the relationship between site and timber quality. On poor sites, there may be greater susceptibility to root damage during harvest, or subsequent regeneration of commercially less desirable species. Management for species diversity across the landscape offers greater flexibility for working with species-site relationships.

Species composition, vigor, and form are of particular interest to forest entomologists (Allen p 57). The objectives of stand management are to promote vigorous, well-formed trees and to reduce the prevalence of species favored by certain insects. Primary classes of pests are those influenced by the stability of the forest environment. Tree species planted off-site, especially in pest outbreak areas, would be highly susceptible to damage. Secondary classes of pests are those affected by loss of stand vigor. Trees stressed by logging damage are more likely to die from insect defoliation. Harvesting of stands that have been recently defoliated or are likely to be defoliated soon should be deferred in favor of other, less vulnerable stands. Thus, the importance of stand characteristics changes in relation to regional frontiers, life cycles, and seasonal outbreak patterns of pests.

Stand vigor and wood quality are two major concerns of forest pathologists (Ostrofsky p 49). For example, residual stand damage is recognized as a problem but there are no standard procedures for assessing damage or general guidelines for expected or acceptable levels associated with specific harvests. The choice of logging practices seldom takes into account regional intensities of pathogens that infect tree wounds or stumps. Care in the planning and implementation of harvests can significantly improve the quality of the wood and, at the same time, promote regional disease control.

Tritton and Johnson (p 39) focus on the importance of long-term productivity of forest ecosystems. Meeting this objective requires protecting the viability of the forest as a watershed, a site for accumulation of nutrients essential for tree growth, and a relatively stable environment for seedling establishment and growth. Care and planning during the harvest are as essential to meeting these ecological objectives as the type of harvest. Use of heavy equipment in some areas may be acceptable only at certain times of year, or under certain soil moisture conditions. Loggers may have to shift to another site if conditions become unfavorable. Planning of forest management on a landscape basis is flexible enough to protect the site and still meet economic and equipment concerns.

The pragmatic views of Mattson (p 69) and Vasievich (invited speaker) add technologic and economic perspectives to the other biological perspectives presented on forest management. Whereas biological research offers important general guidelines and objectives, economic considerations drive actual forestry practices to a large degree. When forest resources are perceived as vast, logging operations may be aimed at maximizing the harvest rather than protecting the soil and the residual stand. Alternatively, limited forest resources require the development and careful use of better equipment (Mattson 1989). Recommendations based on biological concerns that are compatible with economics have the greatest likelihood of successful implementation.

Historically, uneven-age and even-age management have been effective tools for practicing northern hardwood silviculture. But biological research, regional economic and land-use trends, and the condition of the present-day forest all point to a need for greater flexibility in future management. This flexibility can be achieved from a landscape perspective where the importance of any one view of a stand may be diminished but the overall options for all stands are increased. At this larger scale, common ground is found by striving to meet the objectives of all approaches. For example, the need for identification of certain site conditions and development of techniques for working with the constraints of these site conditions recurs throughout this proceedings. Management to enhance natural regeneration and maturation of a diversity of species and age structures is another concern. Finally, high quality timber is important either directly (silviculture, economics) or indirectly (ecology of sites, insects, diseases) to all of the disciplines represented.

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The objective of the symposium was to discuss the combined influences of sites, nutrients, pathology, entomology, equipment technology, and economics on the choice of a silvicultural system for the management of northern hardwood forests. All of these factors should be considered and should influence the prescriptions developed for the management of forest stands.