UNEVEN-AGED MANAGEMENT OF NORTHERN HARDWOODS IN NEW ENGLAND

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Cover Photo

An uneven-aged stand of northern hardwoods in New England. Sugar maple, yellow birch, and American beech make up most of the volume.

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ABSTRACT

Three main aspects of uneven-aged management in northern hardwoods are discussed: (1) choice of cutting method, including selection, group selection, and patch selection; (2) control of yields, which involves the establishment of structural goals, the control of marking operations, and the prediction of allowable harvest; and (3) the transportation or removal of products—truck roads, skidroads, and harvesting precautions. Emphasis is on flexibility: the possibilities of applying a range of cutting methods and structural goals to conform to varied objectives and stand conditions.

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UNEVEN-AGED MANAGEMENT implemented by the selection system of cutting, has been recommended for handling certain northern hardwood forests in New England. During the past 17 years, the Northeastern Forest Experiment Station has issued three summary papers that deal with aspects of the management of uneven-aged northern hardwoods *(Gilbert and Jensen 1958, Leak and others 1969, Filip 1973)*. However, most of this earlier work dealt with silvicultural aspects rather than the entire managerial job of growing the timber, controlling the yields, and removing the products through an uneven-aged system. Furthermore, the traditional approach to uneven-aged management — single - tree selection coupled with biologically based structural goals—can be broadened to better meet current needs.

Three main issues must be examined by a forest manager in deciding whether or how to adopt uneven-aged management. First, he must decide upon a harvest-cutting method based primarily upon regeneration objectives and cost considerations. Second, he must decide how to control the yields, which involves setting residual stand objectives, marking stands, and predicting future yields. Third, he must decide how the timber will be removed; and then he must develop a transportation plan suited to the harvesting equipment.

These three questions will be examined in depth in this paper, providing a basis for setting up an uneven-aged management program for northern hardwoods. Because each forest property is unique, methodology will be stressed. However, applicable data and examples will be given where possible. Material that is readily available in other summary bulletins or as common professional knowledge will not be presented.

CHOICE OF CUTTING METHOD

The choice of an appropriate cutting method depends upon an understanding of the underlying differences between even-aged and uneven-aged management. The basis of even-aged management is this: the forest is (or will be) composed of reasonably even-aged stands of sufficient acreage so that they can be surveyed (mapped) and relocated. Under even-aged management, the appropriate harvest cutting methods—clearcutting, shelterwood, and seed-tree—are those that create new even-aged stands of sufficient acreage. The minimum acreage to qualify as *sufficient* is unique to each property and is difficult to define. On large properties in the northern hardwood region of New England, the minimum size of a stand seems to lie between 10 and 40 acres.

In contrast, forests under uneven-aged management are split into recognizable and relocatable stands on some basis other than age class. The basis for stand differentiation can be forest type, site, logging conditions, or some combination of these factors; but we do not keep track of acreages by stand age class because it is infeasible to do so. The appropriate harvest cutting methods are those that attain growth, quality, and species objectives without producing even-aged stands large enough to be surveyed and scheduled for treatment. Traditionally, the selection system of cutting has been associated with uneven-aged management. But for practical application, three approaches—and possible combinations of two or more—should be considered.

Uneven-Aged Cutting Methods

Single-tree selection consists of removing individual trees that usually are isolated from one another *(Smith 1962, U.S. Forest Service 1973)*. The trees to be removed will include those that are (1) merchantable and ready to take because of poor future potential (slow growth, risk, poor quality potential), and may include (2) unmerchantable trees, including large culls, that should be cut or killed because they suppress better stems. The emphasis here is on the individual characteristics of the removal trees. If several removal trees happen to occur together, forming a small group, we're still practicing single-tree selection.

Under *group selection*, there is a conscious effort to remove trees in groups of a few to many trees *(Smith 1962, U.S. Forest Service 1973)*. The area occupied by the group usually is less than an acre, but could range up to several acres in large stands. However, the area would be smaller than the minimum feasible acreage for a single stand under even-aged management. This holds true because, the larger the acreage, the more efficient even-aged management is. The removal trees generally have the same characteristics as those described under single-tree selection—merchantable trees with poor future potential plus some culls.

But instead of complete emphasis on individual tree characteristics, the predominant characteristics of the *group* must be evaluated. Often, a few high-potential stems will be removed with the low-potential stems. This apparent loss in flexibility or efficiency must be offset by a gain in the groupwise application of the cutting: (1) the chance to uniformly release some established regeneration; (2) the creation of conditions for the establishment and development of some intermediate or intolerant species; or (3) the reduction of logging damage by taking trees in groups. Trees are individually examined and marked under typical group-selection practice.

A third possible approach in northern hardwood stands, sometimes associated with even-aged management, is *patch selection*. This is not a traditional cutting method, but there has been a fair amount of experimentation with this approach in northern hardwood types *(Jensen 1943)*. Patch selection is the removal of all trees down to a small fixed limit (commonly 2 inches) on areas from a fraction of an acre up to 1 or 2 acres in size. This method is analogous to clearcutting, but it is applied to acreages smaller than the minimum-sized even-aged stand. It differs from group selection in that all trees within the patch boundary are cut rather than a few adjacent, individually selected stems.

Under patch selection, the cutting is centered around a group of trees that generally qualify as removal trees. The boundaries of the area must be marked so that the whole patch can be cleared. However, the acreage and location of the patch generally are not made part of the permanent records. Patch selection is appropriate for the release of small established regeneration; but the method is most appropriate for the establishment of new regeneration.

Regeneration Related to Cutting Method

Single-tree selection in northern hardwoods favors tolerant species with a small proportion of intermediates. A point that has not been previously appreciated, however, is that the small openings produced by removing two or three trees result in as high a percentage of intermediate species as small patch-selection cuttings. However, patch selection provides for more intolerant species (table 1).

A more detailed examination indicates that the initial proportions of yellow birch and ash can be almost as high in small openings under the selection system as in heavily cut areas such as the liquidation (commercial clearcutting) and diameter-limit cuttings listed in table 2. The fairly high proportion of intermediates in the small openings larger than 0.01 acres probably resulted from the chance release

Table 1.—Species composition[1] based on the tallest commercial stem per milacre plot[2]

Cutting method	Tolerants	Inter-mediates	Intol-erants
		Percent	
Single-tree selection	81-92	7-18	1
Selection openings .01 acre +	68-80	18-31	1-2
Small patches .1 to .6 acre	62-77	7-34	4-16

[1] Tolerants are beech, sugar maple, eastern hemlock, and red spruce; intermediates yellow birch, white ash, and red maple; intolerant paper birch.
[2] Leak and Wilson 1958, Leak 1959, and Marquis 1965.

of some young regeneration together with the establishment of some new stems right after cutting—partly because of increased scarification from logging disturbance. Indications are that a conscious effort toward group selection—even using small groups containing only a few trees—will produce a marked increase in the proportion of intermediates as compared to standard single-tree selection. Maintenance of this initial advantage in species composition will require repeated release, especially of the smaller groups, during successive cutting cycles.

Although degree of cutting and size of opening have an important influence on the proportions of tolerant, intermediate, and intolerant species, it is important to realize that site factors will influence the regeneration of individual species within tolerance groups. Efforts are now under way to correlate soils and species in New England forest stands, and some general relationships already are emerging *(Lanier 1974)*. Loose to firm soils derived from glacial till commonly support typical northern hardwoods. Glacial-till soils underlain at about 3 feet or less with a hardpan support a fairly rich species mixture of both softwoods and hardwoods—possibly because such areas exhibit such a wide range in drainage. Outwash soils—sands and gravels—often contain high proportions of red spruce and white pine where the drainage is good, and higher amounts of balsam-fir where the drainage is poorer.

Much more information is needed about species/soils relationships. Until such information is available, however, the successional tendencies of a stand can sometimes be determined by careful field examination, with particular emphasis on understory development following past disturbance from cutting or natural causes. It is important to realize that the effects of cutting method on regeneration may be limited by soil and site conditions.

Harvest Costs Related to Cutting Method

A complete cost-and-return analysis of the various uneven-aged management options will

Table 2.—Species composition by cutting method and canopy opening, based on tallest commercial stem per milacre plot. Regeneration 3 feet tall to 1.5 inches dbh 7½ years after cutting (Leak 1959).

Cutting method and residual basal area	Canopy opening, size	Beech	Sugar maple	Eastern hemlock	Red spruce	Yellow birch	White ash	Red maple	Paper birch
					Percent				
Liquidation: 38 square feet	All	26	17	9	3	16	16	7	6
Diameter-limit: 64 square feet	.01 acre +	32	13	19	6	19	1	3	7
	Less than .01 acre	40	6	38	12	2	1	1	—
Moderate selection: 83 square feet	.01 acre +	38	20	8	1	16	11	4	2
	Less than .01 acre	63	15	15	4	2	1	—	—
Light selection: 95 square feet	.01 acre +	39	11	26	4	11	7	—	2
	Less than .01 acre	50	11	26	8	1	4	—	—

Table 3.—Dollar costs per unit of product harvested on the Bartlett Experimental Forest, by cutting method (Filip 1967)

Cutting method	Costs	Compartment	Total acreage
	Dollars	*No.*	*Acres*
Selection	$17.63	11	423
Patch	17.78	4	120
Diameter-limit	15.30	2	80
Clearcutting	17.75	1	41

not be attempted in this paper. However, it is important to make some evaluation of the efficiency of the various cutting methods, and the most logical way is to use costs per unit volume harvested.

Dollar costs per cunit (100 cubic feet) of product harvested were determined for cutting operations on 30- to 40-acre compartments on the Bartlett Experimental Forest *(Filip 1967)* (table 3). Results show almost identical costs per cunit for selection, patch, and clearcutting. Diameter-limit cutting down to a 13.0-inch limit (and a 7.0-inch limit on paper birch) cost less, no doubt because of the large size of material removed.

It is important to realize that these costs include all of the cutting and skidding phases. They do not include costs of truck-road construction because nearly all compartments were located near available truck roads. The costs do not include nor reflect the efficiency of certain managerial jobs such as tree-marking. Furthermore, on patch-selection areas, some additional cost or reduced stumpage rate might be required to cover the felling of unmerchantable stems.

Summary of Cutting Methods

Among the three cutting methods proposed —single-tree selection, group selection, and patch selection—there are no great differences in harvest-cutting costs. Apparently the choice of method depends upon species objectives and stand conditions.

To reproduce beech, sugar maple, or eastern hemlock, the single-tree selection method will work; but keep in mind that site conditions may determine the relative abundance of these three species. Single-tree selection provides maximum flexibility in choosing trees to take or leave, but does not provide much opportunity to manipulate understory development.

Where a well-established understory of desirable species (tolerants or intermediates) exists under a mature clump of overstory trees, group selection is the natural choice. The mature trees should be marked, together with any immature but merchantable trees that would be left isolated by the cutting. The size of the group depends upon the stand conditions, but normally it could range from two to three trees up to nearly an acre.

Where a low-potential group of trees is underlain by a definitely undesirable understory—weed trees, for example—or a sparse understory, patch selection would be a reasonable option because it provides the best opportunity for new regeneration with a fairly high proportion of intermediate and intolerant species. The patch borders should be marked so that everything within the patch will be harvested or felled down to a minimum diameter of not less than 2 inches. Some investment probably will be required to finance the cutting of unmerchantable trees; so patch selection should not be undertaken without a clear objective in mind. Patches generally will be less than 1 acre in size.

Ideally, a stand should be marked with a combination of cutting methods. Group or patch selection will often be chosen to produce an assortment of valuable species. However, the areas between groups or patches definitely should be marked for single-tree selection so that poor-risk trees can be salvaged.

CONTROL OF YIELDS

Yields under uneven-aged management are regulated through control of the growing stock —so-called volume control. For each stand or compartment, a residual stand structure (after cutting) must be set in terms of numbers of trees by diameter class, which determines basal area and volume. A marking procedure must be established so that a stand can periodically be marked back to the residual structure with some degree of accuracy. The difference between current structure and residual structure is the current yield of the stand. And, finally, growth must be projected several years (the cutting cycle) into the future to determine future structure. The difference between future structure and residual structure is the projected allowable harvest for that stand. Summation of allowable harvest by projected harvest dates for all stands or compartments in the forest produces an allowable harvest schedule for the forest.

Stand Structure Guides

The establishment of an appropriate residual structure for a stand is perhaps the most critical step in the regulation process because it has a very important bearing on the efficiency and productivity of uneven-aged management.

To allow for continuous yields, numbers of trees over dbh class must follow something approaching a reverse-J-shaped form. However, the exact form of the diameter distribution will vary depending upon regeneration, mortality, and cutting rates. A well-known theory of population dynamics indicates that any population subject to a consistent schedule of birth and death rates (including removals) will develop a stable (constant-shaped) age distribution curve.

When that population reaches a point where regeneration equals losses, the age distribution becomes stationary or constant *(Keyfitz 1968)*. Simulation work with northern hardwood stands *(Adams and Ek 1974)* illustrates how this principle may apply in practice to uneven-aged stands: constant or sustainable size (rather than age) distributions were derived for a range of residual basal areas and harvest options, some based on cutting through only the upper (sawlog) end of the diameter distribution. Apparently, sustained production from uneven-aged stands can be obtained by cutting through all or only part of the diameter distribution, provided that adequate regeneration is obtained to sustain the distribution. The decision on cutting policy would depend upon a careful analysis of the economics and markets involved. The appropriate residual stand structure would vary for each harvesting option.

In developing structural guidelines, we should not plan to keep in the residual stand trees that are well beyond their financial maturity. Growing hardwoods to very large sizes is not economical in stands devoted primarily to timber production.

Developing guidelines for the lower end of the structure is problematical. On the one hand, it might seem reasonable to maintain small numbers of 6- and 8-inch trees so that only a minimum volume of residual growing stock is in unmerchantable trees. However, northern hardwood stands have high regenerative potential. In cut stands, there is a tendency for the numbers of smaller stems to increase rapidly. So, the maintenance of small numbers of unmerchantable stems requires a commitment to cultural or marginal work in the smaller sizes.

Cultural work in understory trees generally is less beneficial to the residual stand than cultural work in the overstory. In typical uneven-aged stands maintained by single-tree selection, the 6- to 8-inch and smaller trees tend to be in the understory. However, where group or patch selection is practiced, there are better possibilities for cultural work in the areas of essentially even-aged young growth. So the feasibility of maintaining smaller-than-natural numbers of marginal or unmerchantable stems depends upon a commitment to cultural work which, in turn, is made more feasible by the maintenance of a group- or patch-wise distribution of size classes.

The concept of q *(Meyer 1952)*—the quotient between numbers of trees in successive 2-inch dbh classes—has traditionally been used to define stand structure for uneven-aged management. As discussed earlier, population theory and simulated results *(Adams and Ek 1974)* indicate that optimum residual structure may not follow the q distribution very well. However, when used with flexibility, q still remains as the best general method for defining residual structural goals.

Past recommendations indicate that northern hardwoods become financially mature at not larger than 20 to 22 inches dbh—often smaller—and that optimum residual stocking lies somewhere between 70 and 80 square feet

Table 4.—Residual stand structures designed for 70 square feet of residual basal area per acre up through the 20-inch class, and between 70 and 80 square feet up through the 22-inch class

Dbh class (inches)	q = 1.3		q = 1.4		q = 1.5		q = 1.6		q = 1.7		q = 1.8		q = 1.9		q = 2.0	
	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area
	No.	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*
6	26.8	5.25	35.3	6.91	44.2	8.67	53.8	10.55	63.5	12.45	73.2	14.34	82.8	16.22	92.0	18.04
8	20.7	7.22	25.2	8.78	29.5	10.30	33.6	11.73	37.3	13.03	40.6	14.18	43.6	15.20	46.0	16.06
10	15.9	8.67	17.9	9.78	19.7	10.72	21.0	11.45	22.0	11.98	22.6	12.31	22.9	12.49	23.0	12.54
12	12.2	9.61	12.8	10.05	13.1	10.30	13.1	10.31	12.9	10.14	12.5	9.84	12.1	9.47	11.5	9.03
14	9.4	10.03	9.1	9.78	8.7	9.35	8.2	8.77	7.6	8.13	7.0	7.45	6.4	6.79	5.8	6.14
16	7.2	10.08	6.6	9.15	5.8	8.13	5.1	7.15	4.5	6.24	3.9	5.41	3.3	4.67	2.9	4.01
18	5.6	9.82	4.7	8.25	3.9	6.86	3.2	5.67	2.6	4.64	2.2	3.80	1.8	3.11	1.4	2.54
20	4.3	9.31	3.3	7.28	2.6	5.64	2.0	4.36	1.5	3.37	1.2	2.61	.9	2.02	.7	1.57
22	3.3	8.67	2.4	6.29	1.7	4.56	1.2	3.30	.9	2.40	.7	1.76	.5	1.29	.4	.95
Total	105.4	78.7	117.3	76.3	129.2	74.5	141.2	73.3	152.8	72.4	163.9	71.7	174.3	71.3	183.7	70.9

Table 5.—Examples of the basal areas and volumes removed per acre for two residual stocking alternatives

Dbh class (inches)	Initial stand		q = 2.0				q = 1.6			
			Residual		Cut		Residual		Cut	
	Trees	Basal area	Trees	Basal area	Basal area	Volume	Trees	Basal area	Basal area	Volume
	No.	*Sq. ft.*	*No.*	*Sq. ft.*	*Sq. ft.*	*Bd. ft.*	*No.*	*Sq. ft.*	*Sq. ft.*	*Bd. ft.*
6	94.7	18.56	92.0	18.04	0.52	—	73.2	14.34	4.22	—
8	53.9	18.81	46.0	16.06	2.75	—	40.6	14.18	4.63	—
10	27.0	14.72	23.0	12.54	2.18	—	27.6	12.31	2.41	—
12	27.2	21.35	11.5	9.03	12.32	1,539	12.5	9.84	11.51	1,441
14	16.1	17.21	5.8	6.15	11.06	1,638	7.0	7.45	9.76	1,447
16	7.2	10.05	2.9	4.01	6.04	968	3.9	5.41	4.64	742
18	4.9	8.66	1.4	2.54	6.12	1,054	2.2	3.80	4.86	813
20	1.6	3.49	.7	1.57	1.92	339	1.2	2.61	.88	151
22	.5	1.43	.4	.95	.48	47	.7	1.76	—	—
All	233.1	114.3	183.7	70.9	43.4	5,585	163.9	71.7	42.9	4,594

of basal area per acre *(Leak and others 1969)*. Table 4 gives minimum residual structural goals for a range in q. As q increases, the number and proportion of small trees increase. The acceptance of a 20-inch upper limit provides for 70 square feet of residual basal area while a 22-inch upper limit provides for a little more. These suggested structures should be used flexibly. In some cases, one q might be applied to the sawtimber sizes, and another q might be used to guide the marking in the poletimber sizes. Some of the possibilities are best illustrated by example.

In table 5, figures are given for an initial stand that averages 114.3 square feet of basal area and therefore can support a harvest cutting. This is an actual 40-acre stand on the Bartlett Experiment Forest, about 100 years old. Although the stand structure follows a fairly typical reverse-J form, the trees actually occur in a patch-like arrangement due to patch cuttings several years earlier.

One option in marking this stand would be to assume that little or no work will be done in the 8-inch class and smaller. Although 6- and 8-inch trees contain some merchantable material, the harvesting of these sizes would be a marginal operation, more like a cultural treatment than a harvesting operation. Under this option, the appropriate residual structure is one that will concentrate the cutting in the larger sizes, 10 inches and over. The appropriate choice is q = 2.0. Notice that a residual q of 1.9 (table 4) or less would require more and more cultural work in the 6- and 8-inch classes. By subtracting the residual goal for q = 2.0 from the initial stand and using local volume tables, and basal area and volume to be removed in each dbh class is easily determined. Note that the goal can be met by removing very little from the 6- and 8-inch classes (table 5).

Under more intensive management, some marginal or cultural work in the 6- and 8-inch classes and smaller might be contemplated. The decision to invest in such work would be based upon site and quality considerations, and also upon an evaluation of whether these smaller sizes did in fact occur in group- or patch-wise arrangements. Under this option, a residual structure of q = 1.8 would work well; q = 1.9 could also be considered. However, low q values of 1.4 or 1.5 could not be considered for an immediate goal. Such low q distributions would not only require heavy treatment in the small sizes—which might or might not be justified: they simply could not be met in the larger sizes because of a lack of trees.

Under q = 1.8, basal areas and volumes to remove are calculated as before (table 5). Under this option, more work would be done in the small sizes, and more volume would be left in the larger sizes. Current volume harvested would be less than under the first option of q = 2.0.

A third option might be to apply a q = 2.0 to the poletimber, which would entail very little work in these small sizes, and a q of perhaps 1.7 to the sawtimber sizes. This option would provide for a somewhat heavier residual stocking in the sawtimber sizes than the previous options of q = 1.8 or 2.0. Another possibility would be to use a proportionate rule such as the removal of 1/3 or 2/5 of the sawtimber-size trees plus any poletimber removals that could be well justified as a cultural measure. The consistent removal of a specific proportion of trees, carefully defined for each dbh class on the basis of financial return and cultural benefit, is the approach that probably comes closest to the concept of a constant mortality/removal schedule as found in population dynamics theory.

We do not yet know enough about stand response and structural goals to exactly predict future courses of action in this stand. Depending upon stand response and markets, the manager might be able to work toward a higher and higher proportion of sawtimber. It is quite possible that some harvesting options might lead to temporary excesses in certain size classes. However, this possibility does not necessarily dictate heavy cultural work in small trees. A more feasible approach might be to wait and see, and then harvest any excesses as merchantable small sawtimber. As experience develops in each stand, a constant residual structure should gradually evolve in which yields and level of cultural investment appear optimum.

Under single-tree selection, residual stocking probably should be set a little higher than under group and patch selection. Furthermore, because of logging damage and other possible losses, some cushion should be left over and above the guidelines given in table 4. In general, then, these suggested structures are minimums.

Marking

Once the residual structural goal has been set, the next job is to mark to that goal in the field. The structural goal is set primarily to meet regulation objectives. In marking, good silvicultural practice also must be applied. (See *Leak and others 1969* for suggestions on types of trees to mark for harvest and cultural operations). Sometimes, a structural goal cannot be met because of silvicultural conditions. This doesn't do any great harm because, in any given stand, good silviculture is more important than strict adherance to a structural guide. However, no marking should be done without a structural guide regardless of whether the cutting method is single-tree selection, group selection, patch selection, or some combination of these.

Experienced markers can do an acceptable job without any formal controls on the marking operation. They proceed with nothing more than a structural goal, an estimate of numbers of trees or basal area to remove by size class, and an occasional check with a prism. However, for most foresters, marking to a given structure could be a difficult task, so some type of formalized procedure would seem necessary. This is especially important in stands where group or patch selection is practiced because marking control tends to be more difficult in patchy stands.

Most marking jobs begin with an estimate of the initial stand and, of course, a structural goal. These figures provide two useful marking tools: estimates of basal area and numbers of trees to remove per dbh class per acre. For example, looking back at table 5 under the first structural goal, we see that about 43 square feet of basal area can be removed per acre, that the 12- and 14-inch classes will be marked most heavily, and that the 16- and 18-inch classes will receive the second heaviest marking. However, under the procedure presented here, marking can be controlled to some extent even without these prior estimates of basal areas and numbers to be removed.

The marking crew should consist of a tallyman, who is responsible for controlling the marking job, and about two markers. Marking is done by eye, concentrating upon the silvicultural needs of the stand. Periodically, the tallyman will take a 10-factor prism estimate of the *residual stand after marking*. Trees will be recorded by 2-inch dbh classes on a standard cumulative tally sheet. Very little time is required to take these plots, so it seems quite feasible to take two or three plots per hour on a fixed time schedule. It is very important to take the plots systematically regardless of stand conditions, presence of patches or groups, etc.

Periodically, the prism tally is converted to trees per acre, and the average prism estimate is compared to the structural goal:

D.b.h. (inches)	*Goal (No. trees)*	*Residual stand (prism) (No. trees)*
6	44	28
8	30	25
10	20	22
12	13	17
14	9	6
16	6	6
18	4	4
20	3	3
22	2	—

In this hypothetical case, the obvious trend has been to mark too many 6-, 8-, and 14-inch trees; marking trees 16 inches dbh and larger is all right except for some apparent overmarking in the 22-inch class. The tallyman should discuss these trends with the markers so that an attempt will be made to bend the actual residual back toward the goal. The next check on marking practice will indicate whether progress is being made or whether additional changes are needed.

By this process of successive checks and revision, the average per-acre residual should come fairly close to the goal. Although this approach results in some degree of unevenness in marking procedure, remember that the primary purpose of structural control is to regulate yields from the stand rather than to ensure uniform silvicultural treatment. In reasonably homogeneous stands, successive prism estimates of the residual stand after marking converge fairly rapidly to a constant structure. Notice in table 6 that the average prism tally

Table 6.—Successive prism estimates of the residual stand per acre after marking a 37-acre northern hardwood stand

Dbh class (inches)	Number of prism plots 5	9	15	21
	No. trees	*No. trees*	*No. trees*	*No. trees*
6	41	28	24	29
8	11	25	25	25
10	22	22	24	24
12	25	17	18	16
14	9	6	8	7
16	3	6	7	8
18	5	4	4	5
20	4	3	2	2
22	—	—	—	—
24	—	—	.2	.1

had settled down to a fairly constant structure by the time nine plots had been taken.

Some markers prefer to combine 2-inch diameter classes into 4-inch classes for purposes of marking control. Reducing the number of classes simplifies the marking procedure.

Cultural needs in groups or patches of young growth, and cull removal, probably should be marked during the regular marking operation. Trees smaller than 6 inches can be marked, although it does not seem feasible under current conditions to keep records on numbers of residual stems smaller than 6 inches, especially by prism methods. A complete tally of marked unmerchantable stems should be taken as a basis for estimating cultural costs. The actual cultural operation might be performed during the logging job or later as a separate operation.

Allowable Harvest Projection

Under uneven-aged management of northern hardwoods, the projection of allowable harvest is simple in concept. Begin with the residual structure after a marking or cutting operation. The prism tally used for the marking operation can meet this need, or a more detailed post-logging inventory that accounts for marked-but-not-cut, cut-but-not-marked, and damaged trees. Increases in basal area and numbers of trees are projected by dbh classes over the next cutting cycle—recommended as 12 to 20 years *(Leak and others 1969)*. And the projected allowable harvest is determined as the difference between the projected structure and a specified residual goal (table 4). This residual structural goal need not be the same as the previous goal; in many cases, it may be possible to work toward a smaller q (higher percentage of sawtimber) in successive cycles.

An example of allowable harvest projection is given in table 7, using actual basal-area changes from a compartment on the Bartlett Experimental Forest. Allowable harvest for a forest would be determined by following this procedure for each stand or compartment and then summing up the yields. Irregularities from year to year in total forest yields could be smoothed by small adjustments in the cutting cycles.

The weak point in this procedure is the lack of data for projecting growth. The ideal basis for projection is remeasurement of plots on each compartment. Measured growth following treatment is used to project stand development following a second treatment. Stand-table projection, based on diameter-growth analysis, is uncertain because of the difficulty of predicting mortality.

However, if remeasurement data for a specific stand are not available, published or reported information on growth rates may prove useful in making tentative growth predictions. Annual basal-area production in trees 5 inches dbh and larger tends to vary with stand density. This can be shown by examining reported production rates for stands of 60 to 100 square feet of residual basal area as compared to stands having over 100 square feet:

Annual basal-area production, in square feet

In stands of 60 to 100 square feet	*In stands of 100+ square feet*
2.3 *(Leak 1961)*	1.9 *(Filip et al. 1960)*
2.1 *(Leak 1961)*	0.6 *(Filip et al. 1960)*
2.3 *(Blum 1960)*	1.2 *(Leak 1961)*
2.0 *(Blum 1960)*	0.3 *(Gilbert and others 1955)*
1.9 *(Blum 1960)*	
1.9 *(Filip 1972)*	
1.1 *(Gilbert and others 1955)*	

The variation in rates in the 60- to 100-square-foot class must be due partly to site differences. As yet, however, we have no specific way to evaluate sites in uneven-aged northern hardwood stands. The lowest rate in this class (1.1 square feet) was the result of mortality caused by beech-bark disease. Under the 100+ class, the lowest rates of 0.3 and 0.6 square feet represent those stands that are nearing the maximum basal areas attainable

Table 7.—Example of stand allowable harvest calculation for a 19-year cutting cycle, using q=1.5 as a future goal, per-acre (Filip 1972)

Dbh class (inches)	Current stand		Future stand		Future goal		Future cut			
	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Volumes	
	Sq. ft.	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Cu. ft.*	*Bd. ft.*
6	9	44	11	56	9	44	2	12	—	—
8	10	29	12	34	10	29	2	5	—	—
10	13	24	16	29	11	20	5	9	112	—
12	11	14	18	23	10	13	8	10	202	980
14	13	12	17	16	9	9	8	7	183	1,113
16	9	6	15	11	8	6	7	5	186	1,125
18	4	2	10	6	7	4	3	2	93	602
20	2	1	4	2	6	3	—	—	—	—
22	2	1	4	1	5	2	—	—	—	—
24	2	1	4	1	—	—	4	1	81	569
Total	75	134	111	179	75	130	39	51	857	4,389

by northern hardwoods of 120 to 130 square feet of basal area; at these high densities, natural mortality is high.

In general, northern hardwood stands that have been cut to residual basal areas of 70 to 80 square feet should produce 2.0 to 2.3 square feet of basal area per acre annually over the next 10- to 20-year period, unless complications arise from insect-disease attack.

The next important consideration in projecting growth is how to distribute anticipated basal-area production between poletimber and sawtimber. The distribution of growth depends upon stand density and stand structure. In table 8, notice that stands having more than 100 square feet basal area produce 80 to 100 percent of their growth in sawtimber trees, 10.5 or 11.0 inches dbh or larger, regardless of structural differences in percentage of sawtimber.

In stands of 60 to 100 square feet of basal area and 25 to 50 percent of sawtimber (q = 1.7+), roughly 50 to 65 percent of the growth is in sawtimber trees (table 8). These stands with high q and low percentage of sawtimber are typical of second-growth even-aged stands 80 to 100 years old. Under 50 to 70 percent sawtimber, represented by a q of 1.4 to 1.6, the percentage of basal area growth in sawtimber trees ranges from about 60 to 80 percent. Note that the percentage of growth in sawtimber trees appears to increase only moderately as the percentage of sawtimber increases to 70 to 90 percent. Apparently a q of 1.4 to 1.6 will result in only a little less sawtimber production than a q of 1.3 or less.

Table 8.—Approximate percentage of basal growth in sawtimber trees (10.5 or 11.0 inches dbh and larger) by basal area per acre and percentage of sawtimber[1]

Percent sawtimber	Basal area in square feet per acre	
	60 to 100	100+
	Percent	*Percent*
25-50 (q = 1.7+)	50-70	100
50-70 (q = 1.4-1.6)	60-80	95-100
70-90 (q = 1.3 and less)	70-85	80+

[1] Based on summarization and rounding-off of data reported by Blum *(1960)*, Filip and others *(1960)*, Filip *(1972)*, Leak *(1961)*, and unpublished data.

An example of a projection of allowable harvest based on reported growth figures is given in table 9 for the same stand tabulated in table 7. An annual basal area growth of 2.0 square feet per acre is assumed. Since the initial stand contains 57 percent sawtimber, we assumed that the percentage of growth in sawtimber trees would lie between 60 to 80 percent, or about 70 percent (table 8). The growth was then distributed among dbh classes within sawtimber and poletimber in proportion to the initial basal area per class. Then the calculations follow those in table 7. In this particular case, the estimated allowable harvest based on reported growth figures (table 9) came out roughly the same as allowable harvest based on actual compartment growth (table 7).

TRANSPORTATION

One of the most important obstacles to economical uneven-aged management is the cost of developing and maintaining an adequate transportation system. In terms of cost, the truck-road system is the most important consideration and will be discussed first. Following that, some suggestions will be given on the skidding and harvesting phases.

Truck Roads

Under even-aged management, based on clearcutting, the cost of building truck roads to the landing or landings can be spread over the entire merchantable volume found on the cutting area. After the clearcutting, no truck road access may be needed until the first commercial thinnings are made perhaps 60 years later.

Uneven-aged management in northern hardwoods requires truck-road access every 12 to 20 years (the cutting cycle) to landings located within skidding distance of all sections of the stand or compartment. Because of frequent use, the only feasible approach in uneven-aged management is to set up permanent truck roads to service all areas of the stand or compartment. These roads need not be maintained

Table 9.—Example of allowable harvest over a 19-year cutting cycle based on reported growth figures: 2.0 square feet per acre per year: 70 percent of growth in sawtimber trees

Dbh class (inches)	Current stand		Basal-area growth		Future stand		Future goal		Future cut			
	Basal area	Trees	1 yr.	19 yrs.	Basal area	Trees	Basal area	Trees	Basal area	Trees	Volumes	
	Sq. ft.	*No.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Sq. ft.*	*No.*	*Cu. ft.*	*Bd. ft.*
6	9	44	0.169	3.21	12.2	62	9	44	3.2	18	—	—
8	10	29	.187	3.55	13.6	39	10	29	3.6	10	—	—
10	13	24	.244	4.64	17.6	32	11	20	6.6	12	150	—
Subtotal	—	—	.600	—	—	—	—	—	—	—	—	—
12	11	14	.359	6.82	17.8	23	10	13	7.8	10	202	980
14	13	12	.423	8.04	21.0	20	9	9	12.0	11	287	1,749
16	9	6	.293	5.57	14.6	10	8	6	6.6	4	149	900
18	4	2	.130	2.47	6.5	4	7	4	—	—	—	—
20	2	1	.065	1.24	3.2	1	6	3	—	—	—	—
22	2	1	.065	1.24	3.2	1	5	2	—	—	—	—
24	2	1	.065	1.24	3.2	1	—	—	3.2	1	81	569
Subtotal	—	—	1.400	—	—	—	—	—	—	—	—	—
Total	75	139	2.000	38.02	112.9	193	75	130	43.0	66	869	4,198

annually, but they will need to be opened up and repaired as necessary for each cut.

The number and location of truck roads depends upon the maximum feasible skidding distance, which in turn depends upon current and future equipment. Past experience on the Bartlett Experiment Forest with tractor-arch combinations indicates that skidding distances up to 1,500 feet are reasonable *(Filip 1967)*. With recent and expected advances in equipment, perhaps this figure could be increased somewhat. But using 1,500 feet as an example, we think that the truck roads could be located so that each serves a strip about 3,000 feet wide. On this basis, a mile of truck road could service about 350 to 400 acres of the stand. On the first entry into the stand, the primary financial consideration is to determine to what extent stumpage returns from 350 to 400 acres will cover the costs of building 1 mile of a certain standard of road. On reentries into the stand, the same question would be applied to the costs of reopening and repairing the permanent road.

For example: the 5.5 Mbf of sawtimber to be harvested per acre from the stand represented in table 5 might bring a stumpage value of $40 per M, or $220 per acre. This amounts to $88,000 to balance against the cost of building or reopening 1 mile of road.

Skidroads

Two types of skidroads must be considered. The main skidroads are constructed by bulldozing. Most of the timber from a given section of the sale comes down the main skidroad. The secondary skidroads commonly consist of natural paths or corridors in the woods through which tree lengths are skidded and winched to the main skidroad.

The main skidroads should be laid out, following the usual precautions, in advance of the logging operation. These roads should provide ready access to the marked timber, especially to concentrations of timber marked in groups or patches. Grades should be gradual —less than 20 percent in most cases—to reduce erosion hazards. Uphill skidding should be avoided, although some uphill winching is feasible. Since the skidding operation may seriously damage up to 5 percent of the residual stand *(Nyland and Gabriel 1972)*, special precautions should be taken to minimize such damage. The skidroads should be as straight as possible, because much of the serious damage occurs on sharp turns. Where a turn or switchback is required, it should be located where the margins of the turn are bordered by mature trees that will be removed during the sale or left indefinitely. Furthermore, the roads should be reasonably wide—depending upon equipment and size of timber to be removed—to help eliminate damage to border trees.

The number and spacing of main skidroads depends heavily upon terrain and equipment. Some past experience indicates that skidding-winching distances of 300 to 400 feet from the main skidroad are reasonable *(Trimble and Barr 1960)*. Since uphill skidding is not very feasible, this means that main skidroads should not be spaced more than about 500 feet apart.

In most cases, the main skidroads will be used again and again for successive cuttings. However, for each cutting, some rerouting will be necessary to avoid patches of good regeneration and to provide good access to concentrations of marked timber.

The secondary skidroads, which generally require no bulldozing, are located as needed by the skidder operators. These skidroads are used to move small amounts of timber to the main skidroads, and are not subject to heavy traffic.

Harvesting

Felling operations cause more damage to the residual stand—up to 12 percent—than any other operation *(Nyland and Gabriel 1972)*. Special efforts should be made to prevent this kind of injury.

The use of group and patch selection should help to prevent damage to the residual stand because trees can be felled toward the center of the opening rather than into the residual stand. There is some precedence for this point of view, although comparative data are not yet available *(Smith 1962)*. In fact, one of the criteria in selecting and marking groups should be the control of logging damage. For example, if a mature tree cannot be felled without damaging several adjacent trees, the entire group probably should be taken.

Table 10.—Numbers of stems per acre of valuable species (paper birch, yellow birch, sugar maple, and white ash) in 3-year-old patch cuttings, by seedbed condition and stand age class (Marquis 1965)

Stand age class	Skid-road	Dis-turbed	Undis-turbed	Slash-pile
	M stems	*M stems*	*M stems*	*M stems*
Old-growth	161.3	76.6	47.7	7.5
Second-growth	174.2	84.9	35.6	11.0

The only other available means for controlling logging damage is through careful supervision of the logging job and repeated instruction of the fellers. To our knowledge, specifications on maximum acceptable logging damage are not generally incorporated into sales contracts; this possibility should be explored more thoroughly.

A second aspect of harvesting that is important to the landowner is the handling of slash. Obviously, heavy slash can be unsightly, can contribute to fire hazard in some cases, and can reflect less-than-optimum utilization. But a less-well-known effect of slash is its inhibitory effect on northern hardwood regeneration. In small patch cuttings, seedlings of desirable species are far fewer under slash than in any other seedbed condition (table 10). Trends toward whole-tree logging and chipping may help eliminate this problem. However, on standard sales, where the tops are left in the woods, the best solution to the slash problem appears to be lopping the tops close to the ground. Attempts to drag the tops into the adjacent residual stand probably would add to the logging damage.

Summary

The three main concerns in setting up an uneven-aged management program in northern hardwoods in New England are (1) choice of cutting method, (2) control of yields, and (3) removal of products.

Group and patch selection are encouraged to provide a good species mix. However, single-tree selection should be applied between groups and patches to remove poor-risk trees.

Alternative stand structures are defined in terms of q, the average quotient between numbers of trees in successive dbh classes. A structure should be chosen that provides for a reasonable cut of sawtimber-size stems and allows for a predetermined level of cultural or marginal work in the smaller sizes. To meet the chosen structure, a procedure is described for controlling the marking by repeated prism estimates of the residual stand, periodic comparisons of residual vs. goal, and subsequent adjustments in marking practice. Allowable harvest is estimated by projecting stand development over the cutting cycle, based on plot remeasurement or the application of reported information on basal-area growth and the distribution of growth between poletimber and sawtimber.

Truck roads should be permanently and carefully located in uneven-aged stands or compartments. The spacing of the truck roads depends upon estimated feasible skidding distances. And the cost of the truck roads should be weighed against the estimated stumpage returns from the acreage of the stand serviced by the road system. Main skidroads (requiring bulldozing) also should be laid out in advance of the sale. They should be fairly straight, with mature buffer trees on the turns to minimize damage to the residual stand. Felling damage probably can be controlled to some extent by cutting trees in groups and patches. Since heavy slash inhibits northern hardwood regeneration and is undesirable for other reasons, slash treatment in areas under group or patch selection should consist of lopping the material so that it lies close to the ground.

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