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Stand Structure and Stocking Control in Appalachian Mixed Hardwoods

by George R. Trimble, Jr. and H. Clay Smith

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
F. BRYAN CLARK, STATION DIRECTOR

The Authors

GEORGE R. TRIMBLE, JR., now retired, was timber management project leader for the USDA Forest Service's Northeastern Forest Experiment Station at its Timber and Watershed Laboratory at Parsons, West Virginia. He received his forestry training at the University of Maine. He worked for a number of years in watershed-management research both in West Virginia and New Hampshire, and has worked on forest-management problems in most of the Northeastern States.

H. CLAY SMITH is a research forester at the Northeastern Forest Experiment Station's laboratory at Parsons, West Virginia. He received a B.S. degree from West Virginia University, an M.S. degree from Purdue University, and attended the State University of New York College of Forestry at Syracuse. He has been working for the U. S. Forest Service in timber-management research since 1962.

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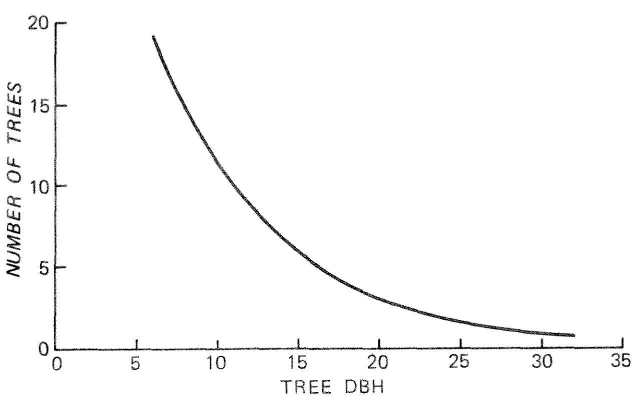
Abstract

Uneven-aged management using a "q" technique for structure control is discussed for Appalachian mixed hardwoods. The success in attaining stand structure goals with periodic selection cuts was evaluated. Where these goals had not been reached, the authors speculated, on the basis of current stand conditions, whether they would be reached, and if so, when. For successful control of stand structure, reasonable guidelines must be used for choosing maximum size trees, residual basal area, and a "q" that is applicable to the tree species and stand conditions. Under this system of management, the future stands will contain mainly tolerant species that produce lower volumes per acre than those presently composing the overstory.

IT IS GENERALLY RECOGNIZED that, to achieve sustained yield in stands regulated under uneven-aged management, the stands must be balanced; periodic removals must leave a stand whose structure and stocking are such that it can support equal periodic harvests indefinitely. The more important it is that periodic harvests be nearly equal in volume, the greater is the need to maintain a tailored stand structure so that yields by size classes will tend to stabilize. Where the strict interpretation of sustained yield is not adhered to (some variation is permitted either in the amount harvested at each periodic cut or in the length of time between cuts), such tight control of residual stand structure and stocking is not required. However, in this paper we will describe the feasibility of strict control of structure and stocking based on the application of a "q" guideline to two Appalachian mixed hardwood stands.

In 1898, a French forester, F. de Liocourt, showed that in uneven-aged stands the number of trees in successive diameter classes represents a geometric series, which means that the quotient between numbers in the classes is a constant. Meyer *(1952)* calls the quotient "q". This "q", represented graphically by a reverse J-shaped curve (fig. 1), has been found to be typical of uneven-aged stands in numerous locations *(Meyer 1952)*.

Figure 1.—Ideal stand structure for uneven-aged management is represented by a reverse J-shaped curve.



Study Methods

The woodlots where the study was made are located in the Fernow Experimental Forest near Parsons, West Virginia. Site quality is excellent, between 75 and 80 feet for oak. The forest type was Appalachian mixed hardwoods. The soil is a deep (more than 3½ feet) Belmont silt loam derived from limestone.

In 1948, when the study was begun, the stands were composed mainly of two age classes of trees: second-growth 40 to 45 years old, and older-growth trees left from the original cutting that took place between 1905 and 1910. In addition, a scattering of small poles occupied openings created by the death of the American chestnut around 1930.

Both research areas were designated for treatment by individual tree selection systems, but with the following difference. Area A was designated for sawlog management, in which we were concerned only with the trees over 11 inches dbh. Area B was designated for sawlog and small product management, in which we managed the stems down to 5 inches. Each research area covered 5 acres.

To define a stand structure goal based on a "q" guideline, three kinds of information are needed: the ratio of "q", the dbh of the maximum-size tree to be left after each cutting, and the basal area after cutting. After these three parameters have been chosen, the residual stand-structure goal can be determined mathematically (fig. 2).

Example

Given: Q = 1.3; Maximum dbh = 32; Basal area in trees over 5.0 inches dbh = 80

Method

Dbh	(1) No. trees (trial first step)	(2) Basal area (trial step)	(3) No. trees (final step)
6	30.29	5.95	19.37
8	23.30	8.13	14.90
10	17.92	9.77	11.46
12	13.79	10.83	8.82
14	10.60	11.33	6.78
16	8.16	11.39	5.22
18	6.27	11.08	4.01
20	4.83	10.54	3.09
22	3.71	9.79	2.37
24	2.86	8.98	1.83
26	2.20	8.11	1.41
28	1.69	7.23	1.08
30	1.30	6.38	.83
32	1.00	5.59	.64
Total	––	125.10	––

Steps

1. Number of trees in column 1 based on "q" of 1.3. Multiply column 1 by basal area for the dbh class = column 2
2. Total column 2
3. Divide 80 by total of column 2 = factor

   $$\frac{80}{125.10} = .639$$

4. Multiply each number in column 1 by factor = column 3.
5. Check on basal area (accumulate multiply column 3 by basal area for dbh class) = total basal area = 80.02.

Figure 2.—Allocation of trees by diameter classes to set a given "q" when maximum diameter and basal area are given.

We chose a residual basal area (table 1) based on local experience *(Trimble 1968)*. A maximum-size tree (table 1) was designated, based on growth characteristics of the species present and the objective of growing a few really large trees per acre. Selecting a "q" was more difficult because we had no locally determined information except the various "q"s computed for existing managed stands. (The procedure for computing "q" from a stand table is shown in appendix I.) Because these were for second-growth stands with a relatively large number of small trees, the ratios were high, mostly in the range of 1.5 to 1.8.

We believed that under management a lower quotient would be feasible and would result in a greater proportion of the residual stand being occupied by larger trees. Therefore, a higher proportion of the stand growth would be put on these larger and more valuable stems. In other words, greater efficiency.

Keep in mind that the "q" ratio refers to the numbers of trees in successive diameter classes. The lower the "q", the less the difference in number of trees between diameter classes. A "q" of 1 would mean that all dbh classes had the same number of trees; and a "q" of 2 would mean that, if the 20-inch class had 1 tree, the 18-inch class would have 2 trees, the 16-inch class would have 4 trees, and so on.

We chose a "q" of 1.3 (table 1), which gives a much flatter J-shaped curve than is found in most natural second-growth stands. We hoped it would be steep enough to provide sufficient numbers of trees to feed into and maintain the progressively larger dbh classes.

We recognized that other goals could have been set for residual basal area, maximum-size tree, and "q". However, since we were not testing differences between levels of these parameters, we had to decide on specific goals, and our experience indicated that these were reasonable.

Our first cutting in both stands was a conditioning cut; we got rid of the poorer trees —and yet made profitable cuts—without paying much attention to balancing the stand structure as defined by our goals (table 1). After the first cut and up to the present, our main concern has been to increase the tree population where needed all along the J-shaped curve and to cut within the ranges of surplus trees. Our guiding policy has been to leave enough trees above the curve in the surplus classes to balance the basal-area deficiencies created by the minus diameter classes. (Table 2 shows the scheduling of

Table 1.—Actual stand conditions and goals of management

Area	"q"	Maximum size tree dbh	Basal area[a] In trees 5 to 11 inches dbh	Basal area[a] In trees over 11 inches dbh	Cutting cycle	Volume[b]
		Inches	*Sq. ft.*	*Sq. ft.*	*Years*	*M bd. ft.*
ORIGINAL STANDS						
A	1.5	36	17.2	85.8	—	14.2
B	1.5	32	22.2	83.6	—	13.4
STANDS 24 YEARS LATER (4 YEARS AFTER LAST CUT)						
A	1.5	30	28.9	69.8	—	11.9
B	1.4	32	18.3	76.4	—	13.6
STAND GOALS (AFTER-LOGGING CONDITIONS)						
A	1.3	32	([c])	65	10	11.9
B	1.3	32	15	65	10[d]	11.9

[a] Basal area includes living culls where found.
[b] Board-foot volume in International ¼-inch kerf rule to an 8-inch top inside bark in trees over 11 inches dbh includes living culls in original stand, no culls in later years.
[c] Uncontrolled.
[d] Two of the 4 times area B was cut, it was cut on a 5-year cycle.

Table 2.—Schedule of inventories, cuts, and "q" ratios

Stand operation	Volume removed/ acre	Residual volume/ acre	Residual[a] basal area/ acre	Residual[a] stand "q"
	M bd. ft.[b]	*M bd. ft.*[b]	*Sq. ft.*	
		AREA A		
1948—Inventory	—	14.2	85.8	1.5
1948—Cut	7.6	6.6	43.0	1.3
1953—Inventory	—	8.9	55.1	1.3
1958—Inventory	—	11.0	66.7	1.3
1958—Cut	2.0	9.0	54.1	1.7
1963—Inventory	—	10.9	64.5	1.6
1968—Inventory	—	12.4	73.1	1.5
1968—Cut	2.2	10.2	60.6	1.5
1972—Inventory	—	11.9	69.8	1.5
		AREA B		
1948—Inventory	—	13.4	105.8	1.5
1948—Cut	6.7	6.7	57.6	1.6
1953—Inventory	—	9.5	76.0	1.6
1958—Inventory	—	12.2	93.7	1.6
1958—Cut	2.1	10.1	76.5	1.5
1963—Inventory	—	12.0	88.4	1.5
1963—Cut	0.7	11.3	81.4	1.5
1968—Inventory	—	13.5	96.1	1.5
1968—Cut	1.7	11.8	84.1	1.4
1972—Inventory	—	13.6	94.7	1.4

[a] In trees over 11.0 inches for area A; in trees over 5.0 inches for area B.
[b] In trees over 11.0 inches for both areas.

inventories, and the cuts, board-foot volumes, and basal areas involved. Note that we varied the cutting cycle for area B, and only after the last cut (in 1968) did we decide definitely to use a 10-year cycle rather than a 5-year cycle.)

Results

We evaluated the degree of success that has been attained to date in reaching stand-structure goals. And where these goals have not yet been reached, we speculated—on the basis of current stand conditions—whether they would ever be reached, and if so, when. We also examined the various stand factors that seem to be associated with the changes that have taken place on these areas since the study was begun. We made all of these determinations separately by areas.

Area A

We looked first at the goal for *maximum-size trees* to be left. This calls for a maximum dbh tree of 32 inches, at a density of 0.64 of these trees per acre. In the original stand, the density of 32-inch trees, plus larger stems, was only 0.40 trees per acre. Because all trees in the stand larger than 30 inches were poor old-growth residuals, they were removed in the first cut. In the following two cuts, most of the slightly smaller old-growth stems were removed for the same reason. Thus at the time of the last recruise, in 1972, the largest size tree in the 5-acre area was 30 inches. There is no doubt, however, that we can attain the maximum-size tree goal. The species involved can grow to much larger diameters; it is only a question of time until some of the larger second-growth stems are 32 inches dbh. In 1988, it should be possible to retain in the residual stand the goal of 0.64 of a 32-inch tree per acre. This would be 40 years after the stand was first cut and after a total of 5 cuts.

We then examined the *basal-area* goals. We are shooting for residual basal area of 65 square feet in the sawtimber portion of the stand; basal area in poles is uncontrolled (table 1). The original stand had 85 square feet, but the first cut reduced it to 43 square feet (table 2); the stand was overcut in the first harvest because in the unmanaged condition it had so many poor-risk and undesirable trees. From then on, we gradually increased the residual stocking; but after the last cut, in 1968, we were still 4.4 square feet below the goal of 65 square feet. Four years later, in the 1972 recruise, the stand had 69.8 square feet (table 2). At the present rate of increase of 2.3 square feet annually, when the next cut is made (in 1978) the stand will have a basal area of 83.2 square feet. This will provide for a profitable cut of between 2 and 3 thousand board feet (current growth is about 425 board feet per year) and still leave a stand of 65 square feet.

A "q" was computed for the stand whenever an inventory was taken and after every cut (table 2). The resultant *array of "q"s* starts at 1.5 for the original stand, drops to 1.3 after the first cut, rises to 1.7 after the 1958 cut, and holds at 1.5 for the last three computation periods (table 2). The fact that we computed a "q" of 1.3 for three periods — 1948, 1953, and 1958 — demonstrates that the average slope of the line (which the "q" is) resulting from plotting numbers of trees over dbh classes can coincide with the "q" goal even though the following stand structure goals are not met: (1) the curve is not smooth and does not coincide with the tree distribution goal, (2) the actual basal area does not equal the basal area goal, and (3) the maximum-size tree goal is not met. (Figure 3 — the plotted curve for the 1948 after-cutting stand — illustrates this situation.) The plotted data from the 1972 cruise (fig. 4) indicate that when the basal-area goal is met for the larger dbh classes (projected for 1988) it will be possible to cut to the theoretical J-shaped curve goal; that is, the stand will contain enough trees above the line to make a profit-

Figure 3.—J-shaped curve for the area A stand structure after the 1948 cut, contrasted to the ideal curve based on the stand structure and stocking goals.

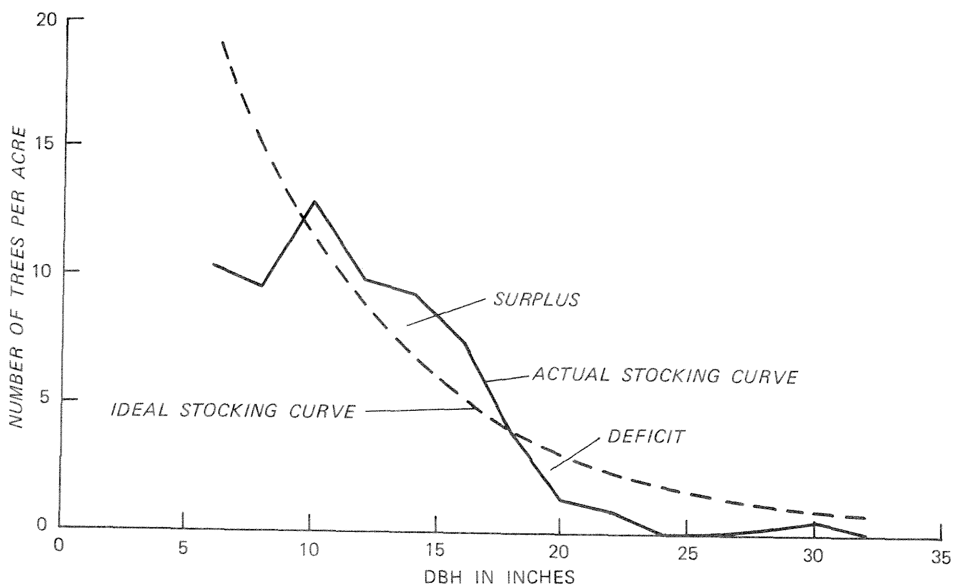
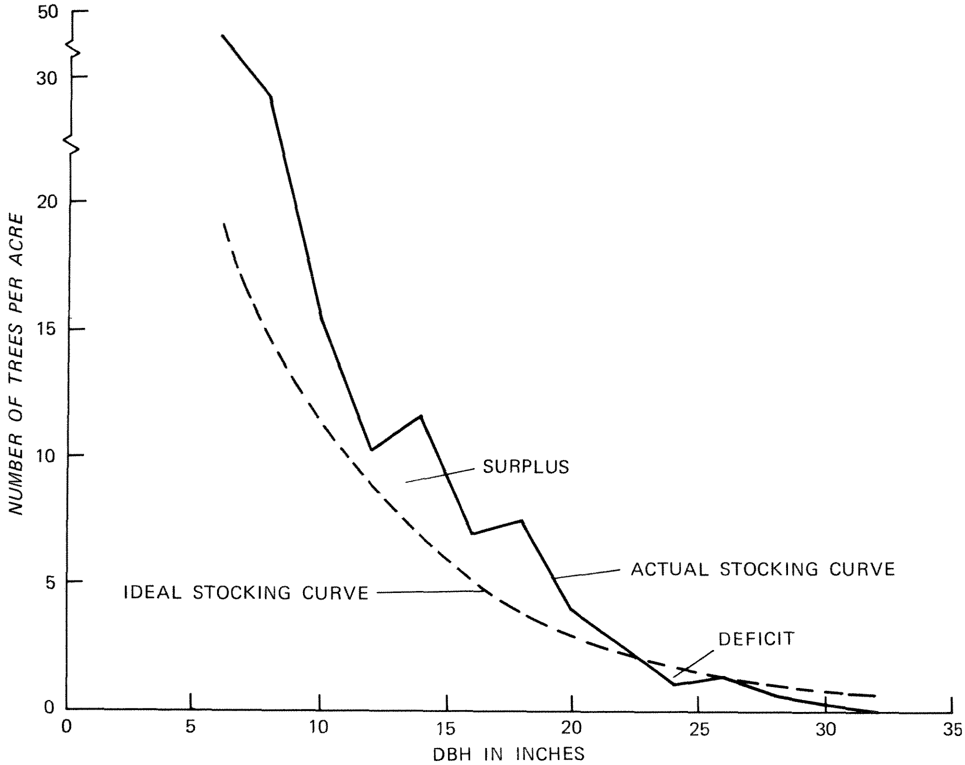


Figure 4.—J-shaped curve of area A stand structure for the 1972 inventory and the ideal curve based on stand structure and stocking goals.



able cut and leave a stand that meets the structure and stocking goals.

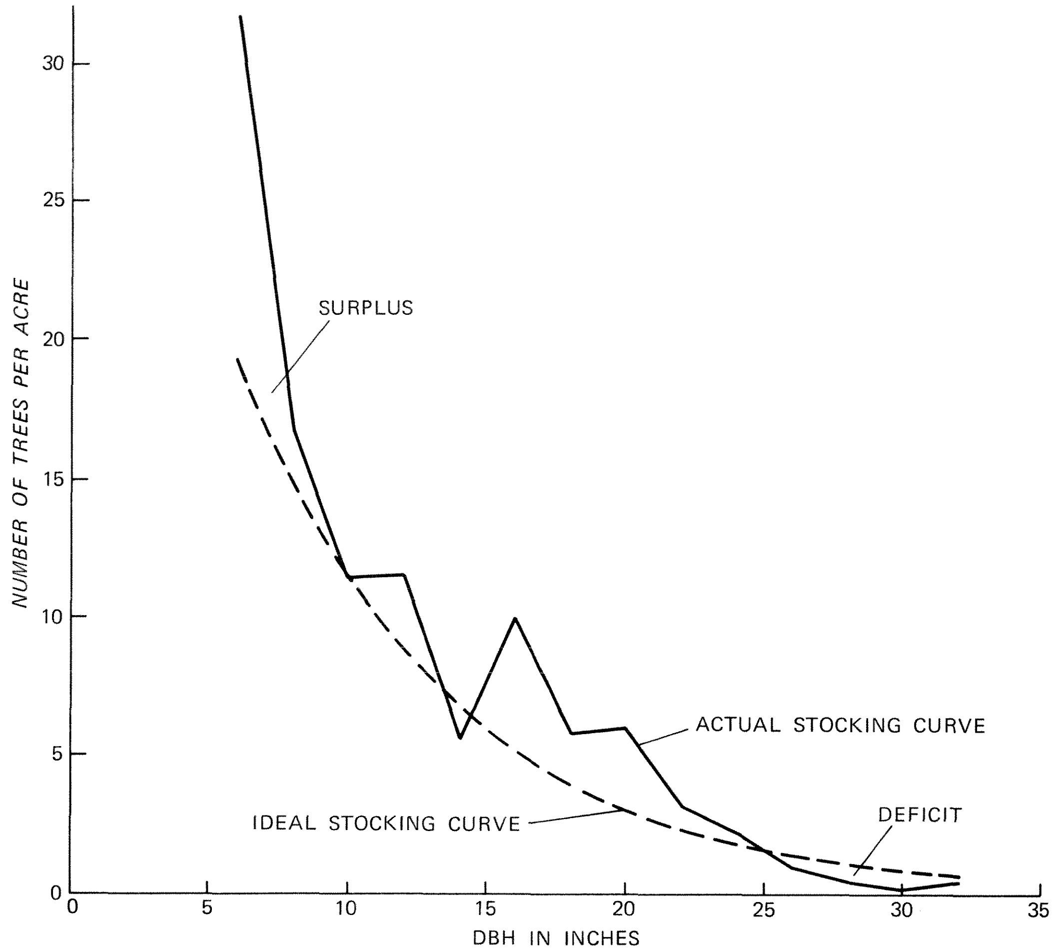
Area B

The *maximum-size tree* situation in area B was almost identical to that in area A: the original second-growth stand contained a scattering of large old-growth residuals, most of which were removed in the four cuts made since the study was started. At the 1972 cruise, density of the 32-inch trees was 0.4 of a stem per acre. As with area A, we anticipate that after the 1988 cut we will achieve our goal of 0.64 of a 32-inch tree per acre in the residual stand. This would be 40 years after the stand was first cut and after a total of 6 cuts.

The *basal-area* goal for area B is 80 square feet in the after-cutting stand, 65 square feet in sawtimber trees and 15 feet in poles (table 1). After the first cut, which was deliberately very heavy to remove many poor trees, we retained only 57.6 square feet per acre (table 2). During the past 24 years of management we have gradually built this up until, after the 1968 cut, we reached a residual basal area of 84.1 square feet—4.1 feet more than our goal of 80 square feet. Four years later, at the time of the 1972 cruise, the stand had 18.3 and 76.4 square feet in poles and sawtimber trees respectively (table 2). From now on, we should have no difficulty cutting to our basal-area goal and, at the same time, should make profitable cuts.

The *array of "q"s* computed for area B starts at 1.5 for the original stand, rises to 1.6, and then drops to 1.4 for the 1968 after-logging stand and the stand at the time of the 1972 cruise (table 2). Plotting number of trees per acre over dbh from the 1972 cruise data shows that the only obstacle to cutting to the stand structure and stocking

Figure 5.—J-shaped curve of area B stand structure for the 1972 inventory and ideal curve based on stand structure and stocking goals.



levels as defined is the lack of sufficient trees in the larger dbh classes (fig. 5). This deficiency should be satisfied by the time of the 1988 cut; and from then on we should be managing the stand in conformity with the established guidelines.

Discussion

This experiment is, as far as we know, the most intensive and the longest extended test of this type of selection silviculture in hardwoods in the United States. We believe that enough time has elapsed and a close enough look been taken at the results to state with confidence that this is a feasible system if reasonable guidelines are followed. By reasonable guidelines we mean choosing maximum-size trees, residual basal area, and "q"s that are applicable to the species of trees and the conditions of the stands that are under consideration.

We feel that a fair amount of leeway exists to successfully vary the guidelines used in this particular study. For example, a "q" of 1.5, 1.6, or even higher would most certainly work out; but it seems unlikely that a "q" much lower than 1.3 would provide enough growing space for small stems.

The dbh of the maximum-size leave tree could certainly be lowered several inches, even for sawlog management; or it could be raised. It is likely that because of change in species composition on these areas — from predominately intolerant to mainly tolerant trees — a reduction in dbh goals for maximum-size tree would be in order after 40 to 60 years.

From stocking studies made in a similar stand, we feel that the residual basal area is within a few square feet of the minimum necessary for maximum growth, but this figure could probably be raised some without making any difference in growth — though carrying charges on the residual stand would be higher and net profits therefore lower.

Many foresters have questioned whether ingrowth from the smaller diameter classes would be sufficient to fulfill the needs of the larger classes. Originally, there were few stems in the 1- to 5-inch class, but with cutting in the overstory these became abundant. In 1948, area A had 50 stems per acre and area B had 22; in 1963 (when the last small-stem count was made), area A had 412 stems per acre and area B had 300. Most of the small-stem population is composed of the very tolerant sugar maple; without a good-growing tolerant species available, it is doubtful if this type of cutting practice could be made to work.

Throughout the period of this study, the stand has contained enough 6- through 10-inch pole-size stems to supply trees to the sawtimber-size stand. Originally, area A contained 50 poles per acre and area B had 63; in 1972 area A had 91 poles per acre and area B had 60. The big increase in number in area A is because no cutting was done among these size classes. During the study period, the increase in proportion of sugar maple has been remarkable: for area A, from 18 percent of the pole stand in 1948 to 54 percent in 1972 and for area B, from 17 to 68 percent. The proportion of small sawtimber sugar maple (stems from 11 to 19 inches dbh) has increased also — for area A from 5 to 19 percent, and for area B from 11 to 21 percent.

The original pole and sawtimber canopy, most of which came in after a very heavy cut, was composed of a mixture of tolerant and intolerant species (table 3). The new stand, as indicated by the increase in sugar maple among the smaller stem components, will be composed mostly of tolerants. (See appendix II for scientific names of species.)

The per-acre board-foot volumes (tables 1 and 2) are based on local volume tables derived for individual species by site classes. In the computations, the future stand volumes as well as the past and present stand volumes were determined for the sawtimber-size trees present on the area. Because the past and present sawtimber stand contains many intolerant trees such as yellow-poplar that produce higher board-foot volumes than does sugar maple for trees of the same dbh, the volume of the future stands that will be comprised largely of sugar maple are overestimated. Thus, instead of a future residual per acre volume of 11.9 thousand board feet, we will carry a somewhat lower volume even with the same diameter and basal-area distributions.

Judging the merits of this silvicultural system by the results of tests on small 5-acre units could be misleading. However, we have tried the same system on several areas ranging in size up to 90 acres. Though these trials on larger areas have been under way a shorter time, and fewer cuts have been made, the same kinds of results are indicated. Some of these larger areas are of comparable site quality; others have site indexes 10 feet or so lower. On the areas of lower site quality, beech and red maple largely replace sugar maple as the species of the future.

In applying this system to larger areas, we group the trees into broader diameter classes than the 2-inch classes we used on the 5-acre study areas. We have been using 4 dbh groups: pole timber 5 to 11 inches, small sawtimber 11 to 17 inches, medium sawtimber 17 to 23 inches, and large sawtimber over 23 inches. This classification seems to give good results. If we group the future residual trees in area B by this method, we get the following numbers of stems per acre: poletimber 45.7, small sawtimber 20.8, medium sawtimber 9.5, and large sawtimber 5.8.

Table 3.—Species composition—number of merchantable stems in 5-acre plots

Species	Area A 1948: original stand	Area A 1958: after cutting	Area A 1972	Area B 1948: original stand	Area B 1958: after cutting	Area B 1972
			6- TO 10-INCH DBH			
Yellow-poplar	40	32	24	63	17	12
Black cherry	17	11	7	33	18	3
White ash	19	17	14	29	26	9
Red oak	12	23	27	17	14	6
Hickory	59	36	21	44	16	11
Sugar maple	44	127	247	54	123	205
Beech	13	12	15	23	4	10
Sweet birch	8	14	18	24	25	25
Other	38	47	83	26	19	19
Total	250	319	456	313	262	300
			12- TO 18-INCH DBH			
Yellow-poplar	27	28	35	52	64	43
Black cherry	8	12	11	22	24	23
White ash	8	8	9	8	12	21
Red oak	2	2	3	2	4	5
Hickory	126	83	74	73	36	22
Sugar maple	11	20	34	25	22	34
Beech	16	3	4	24	3	1
Sweet birch	7	—	1	7	2	7
Other	9	3	10	23	6	9
Total	214	159	181	236	173	165
			20-INCH-PLUS DBH			
Yellow-poplar	2	7	17	2	11	31
Black cherry	—	—	2	—	—	2
White ash	1	3	1	—	1	4
Red oak	8	3	3	2	1	3
Hickory	10	12	16	12	11	12
Sugar maple	16	5	7	10	11	11
Beech	4	—	—	5	1	1
Sweet birch	—	—	—	1	—	—
Other	4	1	1	4	1	3
Total	45	31	47	36	37	67

The forester who is considering using this silvicultural system should be aware of its disadvantages, among which are:

- Like any single tree selection system, it produces a stand composed almost wholly of the tolerant species that grow in the area; there is little opportunity to mold the stand composition.
- Frequent, highly accurate inventories are needed to determine what size classes of trees to cut and to leave.
- A high level of silvicultural expertise is required to handle the marking job.
- As in any individual tree selection system, the cost of logging is high, and the residual stand is subject to high risk from logging damage.

However, if a selection system is desired, and if strict control of sustained yield has high priority, then this kind of selection system may be the best. It should be stressed, however, that the specific guidelines used in this study can be applied with expectation of similar results only on comparable sites and in similar stands.

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Appendix

I

Computation of "q" from a stand inventory

The ratio "q" is computed through the use of the unweighted linear regression for: Y = a + bx

in which Y = log (No. of trees per acre)

X = dbh class

For 1-inch classes, take the antilog of the "b" obtained in the above regression. This gives the "q". For 2-inch classes, multiply "b" by —2; then take the antilog; this gives the "q".

II

Common and scientific names of species referred to in this study

Ash,white	*Fraxinus americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Cherry, black	*Prunus serotina* Ehrh.
Chestnut, American	*Castanea dentata* (Marsh.) Borkh.
Hickory	*Carya* spp.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, northern red	*Quercus* rubra L.
Yellow-poplar	*Liriodendron tulipifera* L.

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