A STUDY IN SINGLE-TREE SELECTION
FOR TOLERANT HARDWOODS

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Contents

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Abstract

Interim results are presented for a large-scale experiment in managing tolerant hardwoods by single-tree selection at the Petawawa National Forestry Institute. The aim of the experiment is to evaluate growth response at two upper diameter limits (40 and 50 cm), two levels of growing stock (140 and 210 m^3/ha), and two cutting cycles (5 and 10 years). Residual volume and upper diameter limit significantly affected mortality rate and net volume increment, but length of cutting cycle did not. Regeneration, especially that of sugar maple, was satisfactory under all treatment combinations.

Résumé

L'auteur présente les résultats provisoires d'une expérience à grande échelle de gestion de feuillus tolérants par sélection d'arbres individuels à l'Institut national de foresterie de Petawawa. Cette expérience vise à évaluer la croissance à deux limites supérieures de diamètre (40 et 50 cm), à deux densités de peuplement (140 et 210 m^3/ha) et à deux rotations (5 et 10 ans). Le volume résiduel et la limite supérieure de diamètre ont influé de façon significative sur le taux de mortalité et l'augmentation nette du volume, contrairement à la rotation. La régénération, notamment celle de l'érable à sucre, a été satisfaisante pour toutes les combinaisons de traitement.

INTRODUCTION

This report describes a long-term experiment in managing tolerant hardwoods by single-tree selection at the Petawawa National Forestry Institute at Chalk River, Ontario. It was designed to test growth response at two upper diameter limits, two levels of growing stock, and two cutting cycles.

In recent years the general public has been taking a greater interest in forest management and showing more concern about unsightly harvesting methods, so greater emphasis is now being placed on partial cutting, particularly in areas widely used for travel and recreation. For tolerant hardwoods, one of the most aesthetically pleasing and acceptable harvesting methods is single-tree selection.

In the single-tree selection system, mature trees are removed from uneven-aged stands, at relatively short intervals, as scattered individuals together with selected stems thinned from the smaller size classes. The procedure is repeated indefinitely, thereby encouraging the continuous establishment of reproduction and maintaining an uneven-aged stand. Daniel, Helms, and Baker (1979) give other advantages:

"1. Reproduction of tolerant species is easily obtained.
2. Site protection is excellent, with little or no exposure to insolation and wind.
3. Stands can be readily adapted to fluctuating market conditions.
4. A fire is less likely to be as disastrous as in a young, even-aged stand.
5. Capital returns come at short intervals, even from small woodlots."

This system is admirably suited to tolerant hardwoods because it requires tree species that are able to regenerate and grow in the shade.

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The tolerant hardwood cover types (the 'northern hardwoods' of the United States) are defined as those in which the natural succession is always toward the formation of stands of sugar maple, beech, and yellow birch,* either pure or in combination with one another. They are found in the Great Lakes–St. Lawrence and the Acadian forest regions of Canada (Rowe 1972) and in the North Central and Northeastern United States (USDA 1973). There are no accurate figures readily available, but it is estimated the tolerant hardwoods occur on at least 20 million acres (8×10^6 ha) in Canada and 25 million acres (10×10^6 ha) in the United States. Tolerant hardwood growing stock accounts for approximately 12 percent of the merchantable growing stock in Ontario, Quebec, and the Maritime Provinces (Manning and Grinnell 1971). These hardwoods are characteristically climax species in that they will continue to reproduce themselves as long as the climate remains unchanged. Most of the species are tolerant of shade, but there is a gradation in this respect from the very tolerant sugar maple and beech to the tolerant basswood and moderately tolerant yellow birch (Filip and Leak 1973).

Besides its effect on public interest, the increasing industrial use of hardwoods has focussed attention on their silviculture and management. Gilbert and Jensen (1958) and Arbogast (1957) suggested retaining residual growing stocks of about 2000 cubic feet per acre (140 m³/ha), and Meyer (1952) advocated retaining between 2000 and 4000 cubic feet per acre (140 and 280 m³/ha). Lack of adequate information on growth and yield for eastern Canada led to the setting up of this study in 1956.

Acknowledgement

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*Botanical names of species are those in R.C. Hosie's Native Trees of Canada, 8th ed. (Fitzhenry & Whiteside, Don Mills, Ont., 1979).

METHODS AND MATERIALS

The study area

The study area--18.6 ha at the Petawawa National Forestry Institute--is midway between Ottawa and North Bay, within the Middle Ottawa Forest Section (L.4c) of the Great Lakes–St. Lawrence Forest Region (Rowe 1972). Referred to as "The Woodlot," it is on a low ridge oriented generally northwest-southeast near a small lake named Corry Lake.

Much of the area is almost level, and the remainder is on gentle slopes leading to shallow drainage channels that flow northward to the lake. The soil is a brown podzolic loamy sand derived from glacial till. It varies from shallow to at least two metres in depth over bedrock of Precambrian granite and is characteristic of the Sherborne land type (Hills and Pierpoint 1960). The soil moisture regime over most of the area has been classed (after Hills 1952) as fresh, but locally in drainage channels it is moist or very moist.

The stand

Although 20 native tree species are present on the Woodlot, only 5 are of major importance (sugar maple, American beech, white pine, yellow birch, and basswood). The individual stands are uneven-aged mixtures containing stems of all sizes from seedlings to mature trees. The middle and upper storeys are usually mixtures of tolerant hardwoods and scattered white pine, white spruce, and white ash. On moister sites, the tolerant hardwoods are associated with balsam fir, white elm, and black ash. Hemlock occurs on one corner of the woodlot and is an old-growth remnant that survived the fires that burned over the area in the 19th century.

The height/age data for sugar maple on the Woodlot indicate that the area is a good site and that growth would be comparable to Plonski's (1960) Site Class 1 for tolerant hardwoods in Ontario and Westveld's (1933) Site Class 80 for sugar maple in the Lake States.

Cutting history

The general area was first settled in the

1870s, and until 1904, the Woodlot was used as a sugar bush, high-graded for sawlogs and fuelwood, and pastured for livestock, with the result that much of the forest was overmature, defective, and of low commercial value. There was little or no cutting from 1904 to 1918, because during that period the area was under the direct control of the Department of National Defence. From then until 1936, many cuts were made to provide fuelwood at the forest experiment station (now the Petawawa National Forestry Institute), which was established in 1918, but no records were kept of volumes removed or precisely where cutting operations were carried out.

In 1936, 60 acres (24.3 ha) adjacent to the experiment station headquarters were set up as a demonstration woodlot and divided into 10 compartments, one compartment to be cut over annually, on a 10-year cycle, under the selection system, with the volume removed to be equal to the estimated 10-year increment. For the first decade, this growth was considered to be 45 cubic feet per acre (3.3 m³/ha) per year, but as a result of additional growth data, this was revised to 79 cubic feet (5.5 m³/ha) for the second decade.

From 1936 to 1956 no special efforts were made to maintain or develop a balanced all-aged structure, that is, one which can be preserved in perpetuity and is characterized by a diameter distribution whose numbers decrease in a regular manner from the smallest diameter class to the largest (Knuchel 1949). Nevertheless, in 1956, on each compartment there was a distribution that resembled the inverse J-shaped curve of the all-aged selection forest. In that year a 100-percent enumeration was made of stems 4 inches (10 cm) dbh and larger, by 1-inch diameter classes, to be used in the revision of the management plan for the next 10-year period; trees were not tagged. A comparison of this inventory with that of 1946 showed that all compartments were carrying less growing stock in 1956 than they were 10 years earlier. The implication was that the estimated annual growth of 79 cubic feet per acre (5.5 m³/ha) was too high. It was decided that a more rigid control of the growing stock would be introduced and that

the emphasis would be placed on developing an acceptable all-aged structure.

Design of the experiment

One of the original goals of management in 1936 had been to raise the volume and quality of the growing stock to a level optimum for the site. A research objective in 1956, therefore, was to determine what that level should be.

Four stem-number distribution options were derived, as described previously (Berry 1963), from two levels of growing stock, 2000 and 3000 cubic feet per acre (approximately 140 and 210 m³/ha), and two maximum diameters of crop trees, 20 and 24 inches (approximately 50 and 60 cm). When combined with 5- and 10-year cutting cycles, eight separate treatments were to be applied. Two of the original 10 compartments were therefore abandoned. The volume for each of the four distributions was calculated using a sugar maple local volume table, it being expected that this species would comprise the largest percentage of the growing stock.

Following the 1973 inventory it was concluded that to achieve a balanced distribution with maximum diameter of 24 inches (60 cm) would take two or more decades. Because of the length of this projection, it was decided to reduce the maximum diameters to 16 and 20 inches (40 and 50 cm). This necessitated the derivation of two new distributions, which had a 16-inch diameter limit. The theoretical stem number distributions are shown in Table 1. The values for numbers of trees were converted to metric diameter classes and the volumes calculated using these numbers and a volume table converted to metric values.

The actual distributions were then compared with the theoretical distributions, and some reassignments were made. The new cutting schedule and assignment of distributions to compartments are given in Table 2. The first complete 10-year cutting cycle will be completed in 1983.

Since the changeover to the new system in 1956, each of the eight compartments has been remeasured from two to five times, and cutting has been carried

Table 1. **Theoretical stem distributions per hectare**

Diam. class (cm)	Distribution 1 No. trees	Vol. (m³)	Distribution 2 No. trees	Vol. (m³)	Distribution 3 No. trees	Vol. (m³)	Distribution 4 No. trees	Vol. (m³)
10	92.4	4.8	108.7	5.7	106.0	5.5	133.6	7.0
12	72.9	5.7	88.0	6.9	83.8	6.5	108.2	8.5
14	61.8	6.8	75.6	8.3	70.9	7.8	92.9	10.2
16	51.6	7.6	65.0	9.6	59.3	8.8	80.1	11.9
18	43.0	8.5	55.9	11.1	49.9	9.9	68.0	13.5
20	34.1	8.5	45.7	11.4	39.3	9.8	56.1	14.0
22	28.9	8.7	39.3	11.8	33.6	10.1	48.4	14.6
24	24.2	8.8	34.1	12.5	28.2	10.3	41.5	15.2
26	20.3	8.8	28.9	12.5	24.0	10.4	35.6	15.4
28	16.8	8.6	24.5	12.5	19.8	10.1	29.9	15.2
30	13.6	7.9	20.5	11.9	15.8	9.2	25.2	14.6
32	11.6	7.7	17.5	11.6	13.6	8.9	21.6	14.3
34	9.6	7.1	15.3	11.4	11.4	8.5	18.7	13.9
36	7.9	6.6	13.1	11.0	9.7	8.1	16.6	13.9
38	6.4	6.0	10.6	9.9	8.6	8.0	14.9	13.9
40	5.4	5.6	9.1	9.4	7.9	8.1	13.5	13.9
42	4.5	5.1	7.9	8.9				
44	3.5	4.3	6.7	8.3				
46	3.2	4.3	6.2	8.4				
48	2.9	4.3	5.7	8.4				
50	2.7	4.3	5.3	8.5				
Total	517.3	140.0	683.6	210.0	581.8	140.0	804.8	210.0

Note: These values have been converted from the original foot-pound units.

Table 2. **Present assignment--treatment and years of cut**

Compart-ment	Distribution Volume (m³/ha)	Max. Diam. (cm)	Cutting Cycle (years)	Date of Cuts
1	210	50	5	1973, 1978, 1983
2	210	40	10	1973, 1983
3	140	50	5	1973, 1978, 1983
4	140	40	10	1973, 1983
5	140	40	5	1973, 1978, 1983
6	210	50	10	1973, 1983
7	210	40	5	1973, 1978, 1983
8	140	50	10	1973, 1983

out where necessary to reduce the volume to the prescribed levels or, where the growing stock at the time was less than specified, to salvage only dead and dying trees. In all, there are 17 growing periods from the eight compartments available for analysis.

Sampling

A permanent sampling system based on eight 1/5-acre (.081-ha) circular plots was established in 1959 in each of five of the compartments. A rectangular sample plot established prior to 1936 was present in each of the other three compartments (the size varied from 0.68 to 1.00 acre). These sample plots were augmented by a sufficient number of 1/5-acre sample plots to bring the total sample to approximately 1.60 acres (0.65 ha). All trees of merchantable size, that is, greater than 3.5 inches (8.9 cm) dbh, were permanently numbered with metal tags at breast height, so that the growth of individual trees could be determined and also to ensure that all trees living at one measurement were accounted for at the next.

Measurement and compilation

At each remeasurement, dbh of every living tree of merchantable size was taken with a diameter tape. A count was made of smaller trees by species and diameter class, and an estimate was made of the number of established seedlings.

The tree measurements for all sample plots in each compartment were combined and stand tables prepared for the merchantable component. These tables showed the number of stems by species and diameter class with the average diameter for each class by species. Volumes were calculated using local volume tables. The same volume tables were used at each measurement because it was assumed that the height-diameter relationship would remain constant in this all-aged forest.

Cutting methods and equipment

The basic consideration in marking trees for removal was the conversion of the existing forest to a true selection forest as represented by stem-number distributions. But this does not mean the main objective is to attain the desired distribution without

considering the silvicultural requirements of the stand. Spacing, tree vigour, crown development, and relative value of the species must still be taken into account.

All trees to be removed were marked with red paint. Trees were then cut with chain saws and skidded tree-length to roadside with a wheeled skidder (Fig. 1). Care was taken in felling and extraction to minimize damage to the residual stand (Fig. 2).

RESULTS AND DISCUSSION

Species composition

Species composition in each compartment was analyzed by percentage representation of number of stems and of volume. Table 3 shows, at two measurement dates, the percentage representation for each of the tolerant hardwoods, other hardwoods, and the softwood component.

There has been very little change in species representation in terms of numbers of stems except for Compartment 3, where there has been a large decrease in percentage of sugar maple. This was not a loss in numbers of sugar maple as much as a gain in numbers of basswood and ash in the smaller diameter classes.

Volume changes were minor except for three compartments, in two of which there were reductions in the elm volume as a result of an attack of the Dutch elm disease (Ceratocystis ulmi (Buism.) C. Moreau), which either killed the trees or reduced their vigour to such an extent that they were removed as moribund. The marked volume change in the other compartment was the result of heavier cutting in red and white pine in line with the objective to manage the area for hardwoods.

Since, with these exceptions, there has been little change in species composition, it is apparent that none of the three variables--residual volume, maximum diameter, and length of cutting cycle--has had any influence on this aspect of stand development. These findings are in agreement with Franklin (1977), who pointed out that "forest types composed of shade-tolerant species will undergo no major shift in composition under uneven-aged management."

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Figure 1. Wheeled skidder with hitch of logs on a skid-trail.

Figure 2. Residual stand immediately after cutting. Note the
          numerous small sized trees mixed with the merchantable trees.

Table 3. Percent composition of tolerant hardwoods and other species

Compartment/ Date	Softwoods		Sugar Maple		Yellow Birch		Beech		Basswood		Ash		Other Hardwoods	
	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.
1														
1962 BC*	7	11	20	19	3	1	50	48	3	3	t†	1	17	17
1978 AC	6	7	22	21	3	1	52	50	2	3	t	1	15	17
2														
1965 BC	13	11	23	29	9	7	14	19	9	6	5	11	27	14
1973 AC	10	11	23	28	9	8	15	20	9	7	6	6	28	19
3														
1959 AC	4	4	42	56	7	7	6	6	8	3	19	5	14	19
1978 AC	1	t	28	56	7	8	9	7	18	10	28	13	9	6
4														
1959 BC	18	4	44	54	7	5	-	-	4	4	6	4	21	29
1973 AC	18	7	37	59	7	7	-	-	7	5	11	6	20	16
5														
1960 BC	15	2	35	48	7	8	11	17	2	2	8	3	27	20
1978 AC	10	3	34	44	7	9	7	15	6	3	10	5	26	21
6														
1964 BC	18	10	20	27	12	12	16	26	8	5	8	5	18	15
1973 AC	18	8	20	27	11	11	15	25	9	4	7	6	20	19
7														
1961 BC	15	5	24	27	7	10	17	12	4	8	3	6	29	32
1978 AC	16	7	24	26	7	11	18	14	4	9	2	4	29	29
8														
1960 BC	33	46	10	10	3	2	3	1	-	-	5	8	46	33
1973 AC	22	27	12	15	4	4	3	3	-	-	7	9	52	42

*BC: Before cut.   AC: After cut.
†t = Less than 0.5%.

Stem distribution

At the start of the study the trees in each compartment were more or less all-aged, but size representation did not conform to that of a true selection forest.

For all compartments, the major consideration apart from improving health and vigour was to alter the stem distribution so that it would conform to the assigned option. For four of the compartments, there was the added problem of building up the growing stock volume, which was then considerably lower than the prescribed 210 m^3/ha (3000 ft^3).

The four compartments that were deficient in volume have increased to the level required, and in future, emphasis can be put on moulding their stand structure. For the four compartments where the starting volume was at the required level, the stem distribution has been improved. As an example, Figure 3 shows how much has been achieved for one compartment and how much still remains to be done, particularly to increase the numbers in the 14- to 28-cm diameter classes. As noted elsewhere, it appears that a number of cutting cycles will be required before optimum stocking can be achieved (Ont. Min. Natur. Resour. 1973; U.S. Dep. Agric. 1973).

Regeneration

One of the factors governing the feasibility of maintaining a balanced all-aged structure through the single-tree selection system is the ability of the species concerned to regenerate, grow, and develop into saplings in sufficient numbers to replace those trees that grow out of the smallest diameter class. An analysis of the estimated number of seedlings and actual count of the saplings (Table 4) following the last cut on each compartment shows that there are adequate numbers of small stems at present to maintain the prescribed distributions. The number of seedlings and saplings have increased in all compartments under the revised management system, and sugar maple accounts for 50 percent or more of the seedlings.

Mortality

There was considerable variation in annual volume losses through mortality both between and within compartments from one cutting cycle to the next. A stepwise regression was run to see if the amount of mortality was related to any or all of the three variables (residual volume, diameter limit, and cutting cycle). Both residual volume and diameter limit were found to have a significant effect, but cutting cycle did not. The regression equation

$$Y = -17.35 + 0.124\ X_1 + 0.3620\ X_2$$
$$- 0.002488\ X_1X_2$$
$$(R^2 = 0.48)$$

where Y = annual volume mortality (m^3/ha)
  X_1 = residual volume (m^3/ha)
  X_2 = diameter limit (cm)

was derived for the prediction of the amount of annual mortality.

There are two main factors in the mortality data. The first is the outbreak of Dutch elm disease in two compartments immediately prior to and after the 1973 cutting. On one compartment a number of trees had died by 1978, but on the other the amount of mortality from this cause will not be known until the next remeasurement in 1983, because it is on a 10-year cutting cycle. The other factor is that for those compartments scheduled to carry 210 m^3/ha, the volume was allowed to build up to this level, leaving many slow-growing and defective trees that otherwise would have been removed.

Now that the volumes on each of the compartments have reached the specified levels, it is likely that much of the potential mortality will be harvested during the regular cut. With the reduction in mortality there should be an increase in net volume production.

Volume growth

A stepwise regression analysis of volume increment was made of the main independent variables--residual volume, diameter limit, and cutting cycle--and of secondary variables--compartment, calendar year, percentage volume of hardwoods and of sugar maple, and actual volume cut at the start of the period. Net annual growth was influenced significantly only by residual volume and diameter limit. Using these two variables, one can estimate the
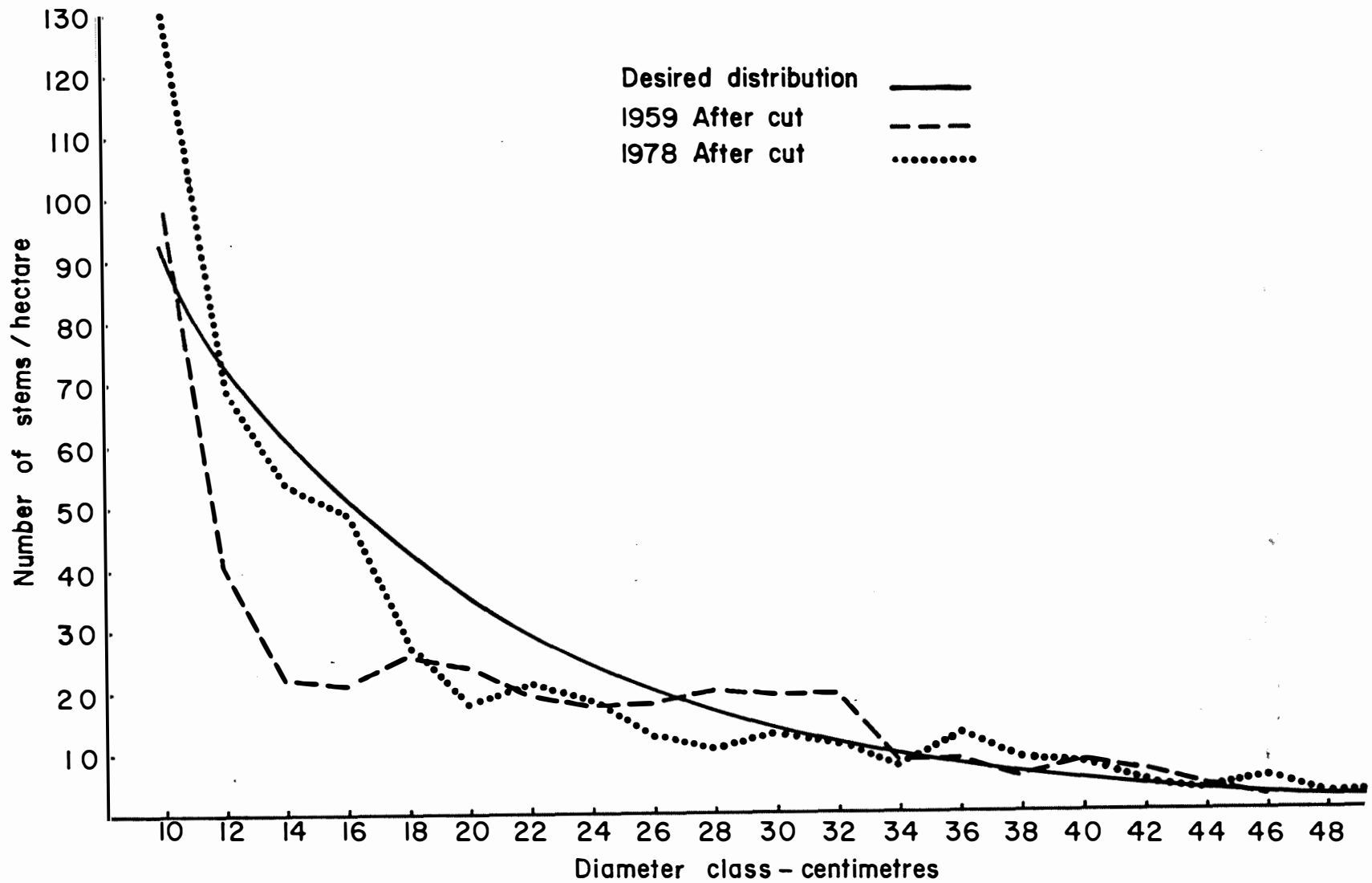
Figure 3. Theoretical and actual stem distributions for Compartment 3 at two dates.

net annual increment from the following equation:

$$Y = 19.73 - 0.123\,X_1 - 0.3000\,X_2 + 0.002327\,X_1X_2$$
$$(R^2 = 0.61)$$

where Y = net annual volume increment (m^3/ha)

X_1 = residual volume (m^3/ha)

X_2 = diameter limit (cm)

Analysis of annual gross volume increment (net growth plus mortality) showed that there was no significant relationship with any of the variables tested. The implication is that if all trees that could be expected to die during the cutting cycle were harvested at the beginning of that cycle, then the gross volume increment would be about the same for all distribution options.

Table 4. Summary of numbers of seedlings and saplings present at last cut

Compartment	Estimated No. Seedlings/ha*	Counted No. Saplings/ha†
1	9640	990
2	9140	1980
3	7660	2350
4	13840	2960
5	13590	2100
6	4940	1730
7	6920	2100
8	6920	3210

*Seedlings over 0.15 m high and less than 1.0 cm dbh, estimated on sample plots of each compartment.
†Actual count of trees from 1.0 to 9.0 cm dbh on sample plots.

CONCLUSIONS

Interim results and conclusions are as follows:

1. There is little change in species composition. These hardwood stands appear to be highly stable in the absence of strong external influences.
2. A number of cuts over several cycles must be made in a given stand to produce the desired distribution of volume throughout the size classes.
3. Compartments with low initial densities responded well to efforts to build growing stock to designated levels, but several cutting cycles will be required before optimum stocking distribution can be achieved.
4. The number of seedlings and saplings increased in all compartments, sufficient to maintain prescribed distributions. Fifty percent or more are sugar maple, indicating the suitability of this species to the single-tree selection system of silviculture.
5. Amongst treatment factors, both residual volume and upper diameter limit had a significant effect on mortality, but length of cutting cycle did not. Future mortality should be reduced by regular harvesting and thinning.
6. Net annual volume increment was likewise influenced significantly by the residual volume and upper diameter limit.
7. Tolerant hardwoods growing on the till sites that were sampled can evidently be managed successfully in this region by single-tree selection. Periodic treatments reducing volume to about 140 m^3/ha and a maximum dbh of about 50 cm should result in annual growth rates in the order of 3.8 m^3/ha. Cutting interval can be 5 to 10 years, a larger cut being possible at the longer interval.

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