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To the Graduate Council:

I am submitting herewith a thesis written by William G. Martin entitled "Growth effects of stand density in a northern hardwood outlier community." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Ronald L. Hay, Major Professor

We have read this thesis and recommend its acceptance:

John Rennie, Edward Buckner

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

January 17, 1975

To the Graduate Council:

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We have read this thesis and recommend its acceptance:

Edward R. Buckner

John C. Rennie

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

c

GROWTH EFFECTS OF STAND DENSITY IN A NORTHERN HARDWOOD OUTLIER COMMUNITY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

William G. Martin

March 1975

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To my wife, Rhonda, I owe a continuing debt of gratitude for her patience, understanding and assistance during the preparation of this thesis.

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ABSTRACT

The Tennessee Valley Authority initiated a density study in a northern hardwood outlier community in 1938 to study maximum board foot growth statistics to determine optimum residual density. The stability of this outlier type, especially following disturbances by man, was largely unknown.

The experiment is comprised of a contiguous series of 21, one-acre plots with seven replications of three treatments approximating 1,500, 3,000 and 6,000 board feet residual volumes per acre. Plots were harvested to residual volumes in 1938 and remeasured in 1955. In 1958 plots were again harvested to residual volumes and treatments reassigned. All plots were remeasured in 1974, thereby providing two cutting cycles for analysis. Sawtimber growth data were analyzed by the least squares analysis of covariance and regeneration was analyzed by the chi-square contingency test.

Heavy cutting favored reproduction and ingrowth of yellow-poplar and, when it was followed by light cutting, growth of yellow-poplar sawtimber was favored. In over-mature stands, pole-size sugar maple stems were released by heavy cutting and grew into the sawtimber class. Optimum growth of sugar maple sawtimber occurred on high residual volumes. Sugar maple reproduction was adequate under all stand densities. Beech growth was retarded by exposure and reproduction was best under dense stands. Heavy cutting favored black walnut.

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CHAPTER I

INTRODUCTION

The northern hardwood vegetation type of beech-maple (*Fagus grandifolia* Ehrh. - *Acer Saccharum* L.) comprises 316,000 acres or 2 percent of the commercial forest land of the Tennessee River watershed. The cove type, considered to be more important commercially and typical of the area, occupies only 496,000 acres of the commercial forest land. Other important vegetation types comprising less than 3 percent of the forest land include white pine (*Pinus strobus* L.), eastern redcedar (*Juniperus virginiana* L.), bottomland hardwoods, and cedar-hardwoods. Oak-hickory (*Quercus*-*Carya*) is the major cover type in the watershed, occupying 56 percent of the commercial forest land (49).

During the 1930's, selective cutting was thought to be the best silvicultural policy for harvesting and regenerating the uneven-aged southern Appalachian hardwoods, even the beech-maple type. However, optimum residual volumes for maximum board foot growth were largely unknown. In 1937, T. G. Zarger and E. G. Wiesehuegel, Tennessee Valley Authority, and Leonard I. Barrett, Southeastern Forest Experiment Station, initiated a density study in a typical beech-maple stand to study optimum volume growth statistics for intensive forest management. Light, medium and heavy residual volume treatments were examined to ascertain which produced the greatest annual board foot growth per acre.

A tract at the Beech Island Experimental Area on Norris Reservoir in Union County, eight miles northeast of Maynardville, Tennessee, off

State Highway 33 was selected for the study. The stand composition was over-mature northern hardwoods, mainly beech and sugar maple with yellow-poplar (Liriodendron tulipifera L.), and lesser volumes of black walnut (Juglans nigra L.), white ash (Fraxinus americana L.), white oak (Quercus alba L.), chestnut oak (Quercus prinus L.), northern red oak (Quercus rubra L.), cucumber magnolia (Magnolia acuminata L.), buckeye (Aesculus octandra March.), basswood (Tilia americana L.), blackgum (Nyssa sylvatica Marsh.) and black cherry (Prunus serotina Ehrh.). In the understory were dogwood (Cornus florida L.), redbud (Cercis canadensis L.), American hornbeam (Carpinus caroliniana Walt.), red maple (Acer rubrum L.), sassafras (Sassafras albidum (Nutt.) Ness), mulberry (Morus rubra L.) and pawpaw (Asimina triloba (L.) Dunal). Stand volume averaged 9,368 board feet per acre with ages to 250 years and diameters to 40 inches. Mean diameter was 24 inches. This site was a cool, moist, northern aspect of 30 to 50 percent slope and elevation from 1100 to 1320 feet above sea level. The soil was classified as Claiborne silt loam, steep phase, with areas of cherty surfaces (47) and Clarksville cherty silt loam, steep phase. The stand had never been managed intensively prior to 1938 but there was some evidence of earlier logging.

The experiment comprised a contiguous series of 21, one-acre plots with seven replications of three treatments approximating 1,500 3,000 and 6,000 board feet residual volumes per acre. Plots were established in 1938 and remeasured in 1955. In 1958 the stand was harvested again and treatments reassigned. All plots were remeasured in 1974, thereby providing two cutting cycles for analysis.

The stability of this outlier type, especially following disturbances by man, is largely unknown. Examination of residual growth statistics and of saplings that became established following the various treatments should provide insight into this question. Optimum density levels for maximum board foot growth for selected species could be determined by analysis of growth statistics.

CHAPTER II

LITERATURE REVIEW

Many studies have dealt with volume growth responses to various stand densities in northern hardwood stands (15, 18, 35). Investigators have shown the success of residual density manipulation by increased growth rates and improved stand quality. Data from many projects, some covering more than 20 years, indicate optimum stocking levels for northern hardwoods to be between 4,000 and 7,000 board feet per acre and 50 to 85 square feet of basal area per acre (15, 18, 28, 32). Successful regeneration has been obtained by selection, shelterwood and clear cutting systems.

I. STAND DENSITY AND EFFECT ON GROWTH RATES

Northern Hardwoods

Duerr and Stoddard (15) studied a mature, 200-year-old hemlock-hardwood stand in Wisconsin that averaged 12,000 board feet per acre. Total net volume was reduced 50 percent to 6,000 board feet per acre with an average diameter of 12.4 inches. After 12 years average volume increment was 267 board feet per acre per year. While stand volume was increasing 50 percent, it was estimated that stand value increased by 75 percent. Eyre and Zillgitt's (18) study in Michigan's northern hardwoods pointed toward a residual stand volume of 4,000 to 7,000 board feet per acre or 50 to 75 square feet of basal area per acre as giving the optimum board foot growth for a 15 year cutting cycle.

Marquis (35) found that five-year results of heavy cuttings favoring crop trees in a 25-year-old northern hardwood stand showed an increase in crop tree basal area growth by 53 percent and diameter growth by 64 percent. Erdmann and Oberg (16) obtained similar results. Studying Appalachian hardwoods on 2-1/2 acre plots with residual basal area treatments of 100, 80 and 60 square feet per acre, Trimble (52) found it more profitable to cut to 60 square feet per acre where the greatest growth rate occurred. He also found there were no important effects upon log quality. Other investigators have recommended leaving a residual stand of 70 to 85 square feet of basal area per acre for best growth and quality development (1, 22, 28, 31, 32).

Sugar Maple

In a study of cutting methods in an all-aged, virgin sugar maple stand in Michigan, Eyre and Neetzel (17) observed that diameter growth increased with heavier cutting. Growth ranged from 160 to 245 board feet per acre per year when 1/2 to 2/3 of the original stand was left but was reduced to 98 board feet per acre per year when 10 percent of the stand was left. Tubbs (58) found that sugar maple stands which are deficient in saplings and pole-size timber can have this deficit removed most quickly by maintaining 50 to 70 feet of basal area per acre. Sugar maple responded well to release from competition (18).

Yellow-Poplar

Yellow-poplar responds favorably to low densities because of the intolerance to shade. Downs (14) reported codominant and vigorous intermediate yellow-poplar increased in height and diameter when released in sapling and pole-size stands. A heavy cutting in a New Jersey cove site at age 18 resulted in a doubling of yellow-poplar volume at age 45 (50). Bowersox and Ward (6) studied light, medium and heavy improvement cuttings in a 32-year-old mixed oak-yellow-poplar stand. Results showed that volume and basal area growth of yellow-poplar were directly related to the degree of release and mortality was inversely related to the degree of release.

<u>Oak-Hickory</u>

Herrick (24) reported that of four independent variables, i.e., volume of growing stock per acre, number of stems per acre, average diameter, and average diameter growth, growing stock was the one most highly correlated with volume growth in an oak-hickory stand in Indiana. Cuttings in an even-aged, white oak stand showed net yield to be greatest at a basal area of 45 square feet (12). Gross volume and basal area were little affected between 50 percent and maximum stand density. Stocking less than 50 percent did not fully occupy the site and there was a loss in stem quality due to epicormic branching. When maximum stocking was obtained, 25 percent of the potential yield was lost to mortality. In a study by Guise (23), it was observed that mixed hardwoods, including northern red oak responded favorably when one half of the basal area was cut but showed little response when a third of the basal area was removed.

<u>Black Walnut</u>

Black walnut is intolerant to shade and must receive direct sunlight in order to grow and reproduce (20). A complete crown release in a pole-size black walnut stand doubled the diameter growth where a partial crown release only resulted in a 50 percent growth increase (43).

II. SPECIES REQUIREMENTS FOR REPRODUCTION

Sugar Maple

Of all the species of the northern hardwood forest, sugar maple is the easiest to reproduce. The seedlings will predominate over other species regardless of the harvesting method employed. Tubbs (58) found sugar maple reproduction to be the most numerous species under densities of 30, 50, 70 and 90 square feet of basal area per acre after cuttings in mature sugar maple stands. Working with the same residual basal area densities in northern Michigan, Church (8) did not observe significant differences in seedlings per acre at either two or five years after cutting. In a study of site preparation of three treatments, i.e., control, poisoned advanced regeneration, and poisoned advanced regeneration and soil scarification, sugar maple responded best on the control but was the predominating species in all treatments (59). Metzger and Tubbs (39), studying partial cuts, diameter limit cuts, and clear cuttings, found sugar maple to be numerous on all plots but best on the partial cuttings. Other studies have shown that results following clear cutting have been poor (11, 61). Zillgett (62) found the quality of sugar maple reproduction twenty years after clear cutting was less than after partial cuttings. Successful regeneration has been obtained for even-aged management by the shelterwood system (11, 13) and for uneven-aged management by the selection method (28).

Young sugar maple seedlings grow best under low levels of light (10) and will fill most niches on the forest floor under mature stands. Moderate climatic deviations seem to have no affect on initial establishment but severe moisture stress appears to be the limiting factor to germinating seedlings and survival of young stems (25). Young seedlings respond well to overhead release (18), even after 35 years of suppression (58).

Yellow-Poplar

To regenerate the intolerant yellow-poplar requires an adequate seed source, exposure of mineral soil, adequate soil moisture and direct sunlight to the forest floor (40, 45). Yellow-poplar seeds remain viable in the litter for at least four years (9, 36) and will germinate once the canopy is opened. Merz and Boyce (38) combined selection and clear cutting to obtain openings 1/2 to 1 acre in size for successful regeneration. Similar results were obtained in West Virginia where group selection favored yellow-poplar (55). It has been recommended to clear cut for yellow-poplar regeneration between September 1 and May 1 (45, 57). This will promote maximum germination and development of the seedlings in early spring before strong competition from other vegetation develops.

Beech

Beech seedlings develop better under the protection of a small opening than in large clear cut areas (21). Under dense stands a large number of beech seedlings can be found but their growth rate will be slow (27). Beech seedlings will not grow as fast as other hardwoods when stands are heavily cut and may be overtopped by sugar maple and other less tolerant species (20). Studies show that after heavy or clear cutting there will be less beech in the new stand (26, 29, 48). Selection and light partial cuts allow beech to compete with other hardwoods (20).

Oak-Hickory

The perpetuation of oak and hickory in the new stand depends upon advanced reproduction (2, 5, 7, 34), as many as 400 seedlings or sprouts one foot tall per acre are required (3). Much advanced reproduction is seedling sprouts (5, 34, 37, 42). Sprouts from oak seedlings broken during logging grow faster than comparable undamaged oak reproduction (45). Trimble and Rosier (56) found two-thirds of the large advanced reproduction were broken off in clear cutting. Many northern red oak stands have developed from advanced reproduction present at the time the mature stand was cut (7). Merz and Boyce (38) found 90 percent of reproduction present two years after harvest originated before the stand was cut. Sander (45) reported that in stands with large amounts of advanced oak reproduction, there were a large number of oaks in the new stand regardless of how the old stand was cut. However, small oak seedlings cannot compete with the dense reproduction of intolerants after clear cutting (38).

Black Walnut

Black walnut is an intolerant tree and must be in a dominant position to maintain itself (20). Seedling growth on good sites is not as rapid as yellow-poplar or white ash but it will surpass the oaks (30).

III. REGENERATION OF NORTHERN HARDWOODS

The variety of species and the ease of regeneration in northern hardwood stands lends this type to even-aged or uneven-aged management. The silvicultural systems used may alter proportions of the species in the new stand because of different degrees of shade tolerance among the species. For the reproduction of quality hardwoods, Sander (45) advised that the method chosen must create conditions that satisfy the silvical requirements of the species wanted in the new stand.

Selection

The selection system has been recommended for uneven-aged management of northern hardwoods by many investigators (1, 16, 18, 19, 32, 46, 60). Selection favors tolerants and reduces the mixed character of the original forest to stands composed largely of sugar maple and beech (32, 51). Individual selection cuts to 90, 75 and 60 square feet of basal area per acre consistently produce abundant reproduction, usually over 30,000 seedlings per acre (39). Studies in West Virginia show an annual growth rate of 256 to 361 board feet per acre using selection (53).

When more intolerant species are desired in the new stand, and esthetics, recreation and wildlife are important considerations, group selection should be used (45, 54). Openings as small as a quarter of an acre result in regeneration of a wide range of species, including intolerants (41).

Shelterwood

Shelterwood cuttings are becoming popular for regenerating even-aged stands of northern hardwoods for tolerant species (11, 33, 39, 59). Other methods, including heavy diameter limit and clear cutting, have given less consistent results in the Lake States (39). Tubbs and Metzger (59) found that shelterwood favors the tolerants and will result in nearly pure stands of sugar maple.

Clear Cutting

Clear cutting is recommended for reproducing even-aged stands of preferred species in a relatively short time (44, 45). Clear cutting usually results in regeneration consisting of 40 percent intolerants, 20 percent intermediates and 40 percent tolerants (32) with a larger number of yellow-poplar than partial cuts (38, 40, 55). Sander (45) found no practical differences in number, distribution or species composition of reproduction due to size of area clear cut. However, because every opening has a border in which reproduction growth is reduced, he recommends openings should be at least one acre in size. He found no silvicultural basis for recommending a maximum size for clear cutting.

CHAPTER III

PROCEDURE

I. FIELD PROCEDURE

Twenty-one rectangular, one-acre, contiguous plots were established in 1938 at the Beech Island Experimental Area. Seven replications of three levels of residual volume, i.e., Treatment 1, 1,500 board feet (bd. ft.); Treatment 2, 3,000 bd. ft.; and Treatment 3, 6,000 bd. ft., were assigned to plots at random (see Figure 1). The plots were inventoried and the stand cut to the desired residual gross volumes at the time of establishment. Gross volumes were calculated by the International 1/4-inch log rule. Pole-size timber, 5.0 to 10.9 inches in diameter at breast height (dbh), was recorded by species and dbh to the nearest 0.1 inches using a diameter tape. Sawtimber, 11.0 inches dbh and larger, was recorded for species, diameter to the nearest 0.1 inches, and merchantable height to the nearest half 16 feet log.

Plots were remeasured and analyzed in 1955. Results showed slower growth rates on Treatment 3 than on the other treatments. This was attributed to over-mature and defective trees left in 1938 to meet residual volume requirements. Prior to recutting in 1958, plots were reassigned to the various density levels to eliminate the undesirable growing stock that had reduced board foot volume growth. The plots were reassigned to ensure that each density level was represented in each of the three contour levels (see Figure 1).

1 1500/6000	6 3000/1500	7 1500/3000	12 6000/1500	13 3000/1500	18 6000/1500	19 6000/1500
2 1500/1500	5 3000/3000	8 6000/6000	11 6000/6000	14 3000/3000	17 3000/6000	20 6000/3000
3 1500/3000	4 3000/6000	9 1500/1500	10 3000/3000	15 1500/6000	16 1500/3000	21 6000/6000

LEGEND

1 Plot number
1500 1958 residual volume (bd. ft.)
1500 1938 residual volume (bd. ft.)

FIGURE 1. Approximate board foot residual volumes in 1938 and 1958.

After plots were recut in 1958, the stand was inventoried. Pole-size timber, 5.0 to 10.9 inches dbh, was recorded for species and diameter to the nearest 0.1 inches. Sawtimber, 11.0 inches dbh and larger, was numerically tagged and species, diameter to the nearest 0.1 inches and merchantable height to the nearest half 16 feet log were recorded. Regeneration of sapling-size stems was sampled by a strip cruise, ten links by four chains, through the middle of each plot. Stems between 1.0 and 4.9 inches dbh were recorded for species in each one-inch diameter class.

II. STATISTICAL PROCEDURE

Sawtimber and Pole-Size Timber

Three variables, i.e., (1) annual basal area increment of the pole-size timber, (2) annual basal area increment of sawtimber, and (3) annual volume increment of sawtimber, were analyzed to determine significant differences between treatments during the first cycle.

The stand was harvested again and treatments reassigned in 1958 to eliminate the undesirable growing stock on some plots. Cutting levels were allocated so that each original stocking level was repeated at least once in the three by three factorial experiment. Table 1 indicates the 1958 plots assignments.

Pole-size and sawtimber growth data were analyzed to determine the effects of 1938 and 1958 treatments on the growth rates during the second cycle. The individually marked sawtimber was analyzed by species in this same manner.

TABLE 1. 1938 and 1958 Plot Assignments.

1958 Stocking (bd. ft.)	1938 Stocking (bd. ft.) 6,000	3,000	1,500	Number of Plots
		Plot Numbers		
6,000	8,11,21	20	12,18,19	7
3,000	4,17	5,10,14	6,13	7
1,500	1,15	3,7,16	2,9	7
		Number of Plots		
Total	7	7	7	21

Initially, the growth data were tested by the least squares analysis of variance for a randomized block design. The test showed too much variance between treatments to make any founded inferences. Since growth of one species on a plot is affected by competing species, effects of treatments might have been obscured by competing species. The relationship between treatments with data adjusted for the effects of competing species was questioned. Preliminary analysis showed the relationships to be linear and with a common slope for all treatments. Therefore, the test of adjusted treatment means was made by the least squares analysis of covariance. The covariant was the basal area of the competing species on the plot.

Regeneration

The sampling of the regeneration in the strip cruise was analyzed by the chi-square contingency test to determine differences between the 1958 and the 1974 diameter distributions. The contingency table for each species on each treatment follows (Table 2). The number of stems per diameter class were recorded in 1958 and again in 1974.

TABLE 2. Contingency Table.

Year Inventoried	Diameter Classes (inches)				Subtotal
	1.0–1.9	2.0–2.9	3.0–3.9	4.0–4.9	
1958	–	–	–	–	–
1974	–	–	–	–	–
Subtotal	–	–	–	–	Total

CHAPTER IV

RESULTS

I. THE FIRST CYCLE--1938 TO 1955

Annual growth rates of pole-size timber basal area and sawtimber basal area and volume were analyzed for significant differences between treatments for each species during the first cycle (1938 to 1955).

Yellow-Poplar

There were no significant differences between treatments for annual growth rates of yellow-poplar, but Treatment 3 (the light cutting) favored the growth of pole-size and sawtimber basal area plus sawtimber volume. Mean annual volume growth of Treatment 1 (the heavy cutting) was 77 bd. ft. and of Treatment 3 was 121 bd. ft. with fewer but larger stems than in Treatments 1 or 2.

Sugar Maple

There was a significant difference ($P < .04$) between treatments for sugar maple volume growth with Treatment 1 producing the greatest response through release from competing species. Mean volume growth was 32 bd. ft. per year on Treatment 1 compared to 14 bd. ft. on Treatment 2. Basal area growth of pole-size and sawtimber was also best on Treatment 1 but not significantly different. Treatment 3 resulted in mortality within the sawtimber class. Treatment 1 contained a total of 31 stems compared to 12 stems on Treatment 3.

Beech

Sawtimber basal area response of beech was highly significant ($P < .01$). Mean annual basal area growth for Treatment 1 was 0.03 square feet and for Treatment 3 was 0.58 square feet. Volume growth on Treatment 3 was nearly significant with a mean of 79 bd. ft. per acre per year. Treatment 3 (the 6,000 bd. ft. residual treatment) had a total of 62 sawtimber stems, compared with 33 stems on Treatment 2 (the 3,000 bd. ft. residual treatment) and 9 on Treatment 1 (the 1,500 bd. ft. residual treatment). The mean diameter of the stems on Treatment 3 was 23.9 inches compared to 16.2 inches on Treatment 1.

Black Walnut

There were no significant differences between treatments for basal area and volume growth rates of black walnut poles or sawtimber. Release response was evident on Treatment 1 with higher growth rates. Mean volume growth was 15 bd. ft. per acre per year. The 6,000 bd. ft. residual treatment experienced some mortality.

Other Species

There was a significant difference between treatments for cucumber magnolia sawtimber for basal area ($P < .05$) and volume ($P < .10$). Treatment 1 favored growth and Treatment 3 resulted in heavy mortality.

Significant differences were not found for statistics of white oak, chestnut oak, red maple, ash, dogwood, hickory, northern red oak, basswood, buckeye and hornbeam. The means of sawtimber growth showed trends that chestnut oak was favored by Treatment 1, white oak was favored by Treatment 2 and northern red oak was favored by Treatment 3.

Ash and hickory seemed best on Treatment 1 and basswood and buckeye had the best response on Treatment 3. Red maple and hornbeam pole-size timber grew best on Treatment 2 while dogwood poles grew best on Treatment 3.

II. THE SECOND CYCLE--1958 TO 1974

Annual growth rates of pole-size timber basal area and sawtimber basal area and volume were analyzed for significant differences between treatments for each species during the second cycle (1958 to 1974). Effects of the first cycle treatments on the second cycle treatments were also determined.

Yellow-Poplar

The first cycle treatments did not have any significant effect on yellow-poplar growth rates during the second cycle. However, plots which received the 1,500 bd. ft. residual treatment in 1938 had the highest volume and basal area growth rates during the second cycle.

There was a significant difference ($P<.05$) between treatments in 1958 for basal area and volume growth of sawtimber. Maximum growth occurred on Treatment 3 with a mean of 242 bd. ft. per acre per year and a minimum growth of 84 bd. ft. occurred on Treatment 1. The covariant for sawtimber was also significant ($P<.05$), indicating yellow-poplar growth was influenced by other species on the plot.

Heavy cutting in 1938 followed by light cutting in 1958 favored the growth of yellow-poplar. In 1955 there was a total of 80 sawtimber stems on the 1,500 bd. ft. residual treatment and 56 total sawtimber stems on the 6,000 bd. ft. residual treatment. In 1974 there were 88 stems on the 1,500 bd. ft. residual treatment and 181 stems on the 6,000 bd. ft. residual treatment. Plots most heavily cut in 1938 recovered sufficient volume during the first growing cycle to allow three of them to be assigned to Treatment 3 and two to be assigned to Treatment 2 in 1958. These treatments were cut less severely the second cycle, thereby allowing accumulation of more yellow-poplar stems. The large increase in the number of stems on the 6,000 bd. ft. residual treatment was not due completely to ingrowth, but rather to plot reassignment.

Sugar Maple

The 1938 treatments had a significant effect ($P < .12$) on sugar maple sawtimber basal area growth and a significant effect ($P < .05$) on volume growth during the second cycle. The 1,500 bd. ft. residual treatment had the best growth rates. In 1955 there were 31 total sawtimber stems on the 1,500 bd. ft. residual treatment and 12 stems on the 6,000 bd. ft. residual treatment compared to 49 stems on the 1,500 bd. ft. residual treatment and 42 stems on the 6,000 bd. ft. residual treatment in 1974.

The 1958 treatments did not have any significant effect on maple growth rates during the second cycle, but best growth occurred on Treatment 3 with a mean volume growth of 65 bd. ft. per year and lowest growth occurred on Treatment 1 with 5 bd. ft. per year. The covariant was nonsignificant; however, heavy cutting in 1938 followed by light cutting in 1958 seemed to favor sugar maple.

Beech

There was no significant effect of the 1938 treatments on beech growth rates during the second cycle. However, a highly significant effect ($P < .01$) was found for the second cycle treatments for sawtimber basal area and volume growth. Best growth occurred on the 6,000 bd. ft. residual treatment with a mean volume growth of 52 bd. ft. per year and mortality occurred on the more heavily cut plots. Competition from other species for sawtimber basal area and volume growth was highly significant ($P < .01$). Heavy cutting in 1938 followed by the light cutting in 1958 favored the beech growth.

Black Walnut

The 1938 treatments had a significant effect ($P < .12$) between black walnut growth rates of sawtimber basal area and volume during the second cycle. The highest annual growth occurred on plots where walnut was released by Treatment 1 in 1938. Heavy mortality occurred during the second cycle on plots which were lightly cut in 1938.

The 1958 treatments had a significant effect ($P < .05$) on sawtimber basal area and volume growth during the second cycle. Best growth occurred on the 6,000 bd. ft. residual treatment with a mean volume growth of 23 bd. ft. per year while mortality occurred on Treatments 1 and 2.

As black walnut was released with heavy cutting in 1938, it increased in growth with lighter cuts in 1958. Competing species also significantly ($P < .05$) reduced the growth of black walnut.

<u>Other Species</u>

The 1958 treatments had a significant effect ($P < .10$) on white oak volume growth with maximum growth on Treatment 1. Dogwood pole-size stems grew significantly better ($P < .05$) on plots which were lightly cut in 1938 and heavily cut in 1958. Basswood pole-size stems grew significantly better ($P < .05$) on plots which were lightly cut in 1958.

Although there were no significant differences between treatments in 1958 for growth rates of ash, hickory, buckeye, northern red oak and chestnut oak, best growth occurred on the 6,000 bd. ft. residual treatment. Hornbeam, cucumber and red maple also showed no significant growth differences between treatments.

III. MARKED SAWTIMBER--1958 TO 1974

In 1958 all sawtimber stems were numerically marked with a metal tag. Annual basal area and volume growth rates were analyzed for significant differences between treatments for each species during the second cycle. Effects of the first cycle treatments on the marked sawtimber growth during the second cycle were also determined.

<u>Yellow-Poplar</u>

The 1938 treatments created a significant effect ($P < .12$) on the growth of yellow-poplar during the second cycle. Maximum growth during the second cycle occurred on plots which received Treatment 3 in 1938. Plots heavily cut in 1938 had 50 percent more stems per acre during the second cycle than did those plots receiving lighter cuts in 1938.

There was no significant difference between treatments during the second cycle but greater growth occurred on the 1,500 bd. ft. residual treatment with a mean volume growth of 17 bd. ft. per acre per year. During the second cycle there were 94 stems on Treatment 3 and 23 on Treatment 1. The greater growth was produced by fewer stems.

On those plots which received identical treatments during both cycles, the means of the three treatments were within 0.3 bd. ft. per acre per year of each other. There were no trends of increased or decreased growth rates with the plot reassignments.

Sugar Maple

There was no significant difference between treatments for sugar maple growth during the second cycle with respect to the 1938 and 1958 treatments. Plots which were heavily cut in 1938 had more stems per acre during the second cycle regardless of treatment reassignment than on plots lightly cut in 1938. The growth rates for each treatment were very similar, although growth on the 1,500 bd. ft. residual treatment in the second cycle occurred on fewer stems. Mean annual volume growth for all treatments was 7 bd. ft. per acre per year.

Beech

The 1938 treatment had no significant effect on beech growth rates during the second cycle.

The 1958 treatments had a significant effect ($P < .10$) on the beech volume growth rate during the second cycle. The 1,500 bd. ft. residual treatment produced the greatest annual growth (13 bd. ft. per acre per year) with 50 percent less stems than Treatment 2 or 3. Treatment 3 experienced some mortality.

Although there was no significant interaction, best growth was made on plots that had been lightly cut in 1938 and were more heavily cut in 1958. Low growth was on those plots of identical treatments in 1938 and 1958 and mortality occurred on plots heavily cut in 1938 and more lightly cut in 1958.

Black Walnut

Black walnut growth rates showed no significant differences between treatments during the second cycle with respect to the 1938 and 1958 treatments; however, the covariant was significant ($P < .10$), indicating that competing species influenced black walnut growth. During the second cycle, maximum growth was obtained on the 6,000 bd. ft. residual treatment with a mean volume growth of 13 bd. ft. per acre per year. Some mortality occurred on the heavier cuttings.

Light cuttings in 1938 experienced mortality during the second cycle regardless of plot reassignments. Good growth only occurred on the 6,000 bd. ft. residual treatment during the second cycle in which walnut was released by heavy cutting in 1938.

Other Species

There were no significant differences between treatments for growth rates of chestnut oak, buckeye and hickory. Chestnut oak experienced mortality on Treatment 3 during the second cycle after heavier cutting in the first cycle. Buckeye was favored by Treatment 3 and mortality occurred on the heavier cuts. The trend for hickory was for greater growth on the 1,500 bd. ft. residual treatment.

There were insufficient data to evaluate growth rates between treatments for cucumber magnolia, ash, northern red oak and white oak.

IV. COMBINED SPECIES GROWTH BY TREATMENT

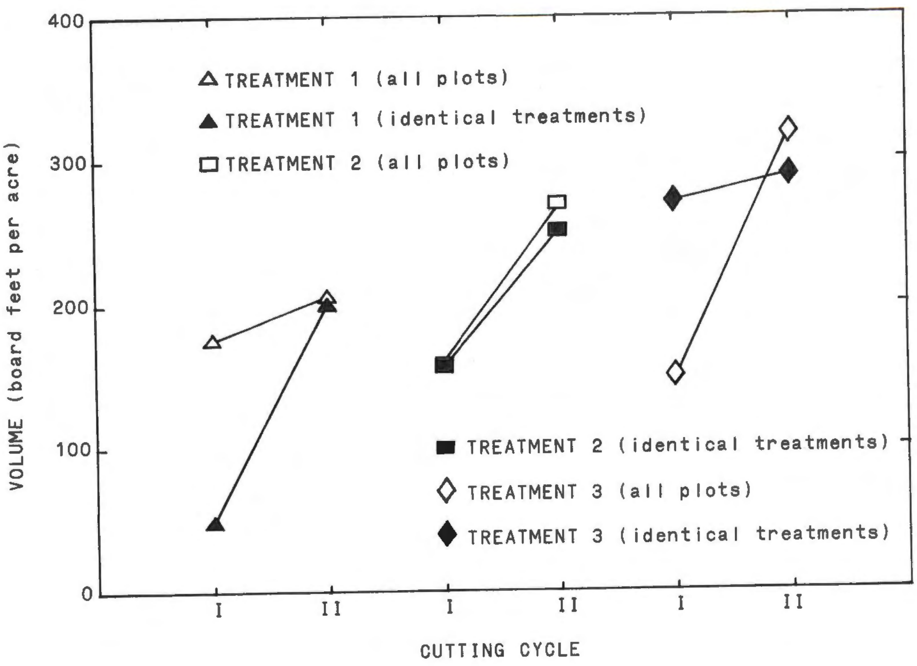
Treatment growth rates without regard for species were too variable for reliable analysis. Unadjusted growth per acre per year for the first cycle showed maximum values on the 1,500 bd. ft. residual treatment (see Figure 2), although there were no statistical differences.

After examining plot and treatment performance from the first cycle, residual volumes were reassigned for the second cycle. It was suspected that over-mature and defective stems retained in 1938 to meet residual volume requirements had reduced potential growth on Treatment 3. Reassignments were made to eliminate as much poor quality growing stock as possible. Unadjusted growth rates for the second cycle showed maximum growth occurred on Treatment 3, but there were no real differences.

Identical Treatment Plots

Figure 2 also shows the relationship of plots receiving identical treatments in both cutting cycles. Growth on these plots during the first cycle obviously contradict combined growth data from all plots for the first cycle; i.e., combined plot data show maximum growth occurred on Treatment 1 but the identically treated plots show maximum growth on Treatment 3.

Unfortunately Treatment 1 was only repeated on those plots which had the lowest growth rates during the first cycle. This suggests bias in treatment reassignment.



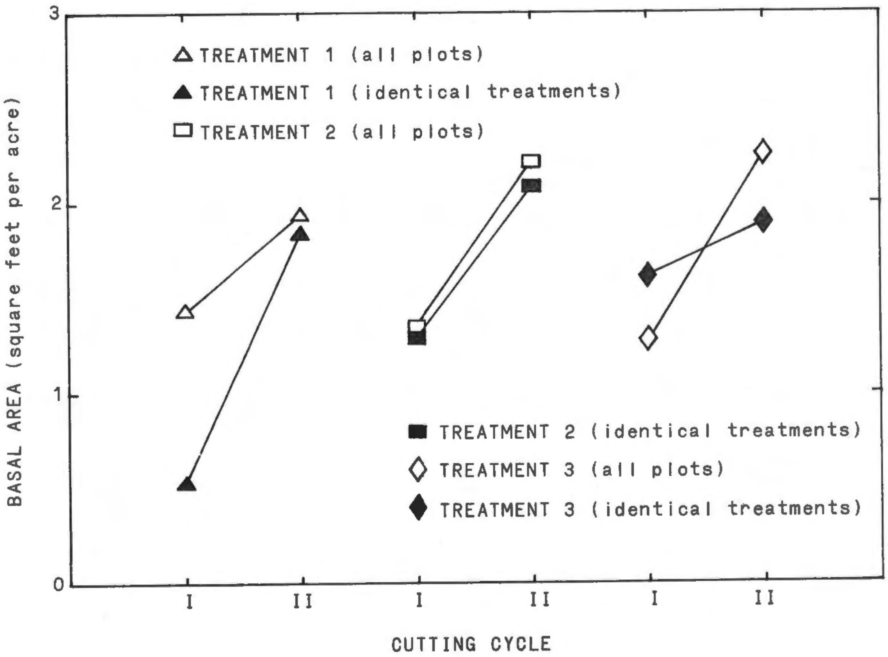


FIGURE 2. Annual volume and basal area increment by treatment for each cutting cycle for all plots and for plots receiving identical treatments during both cutting cycles.

Treatments 1 and 2 improved substantially in their growth rates but Treatment 3 had only slight improvement, viz., the slope of the functions in Figure 2. It is apparent that Treatment 1 recovered to the greatest extent during the second cycle. Treatment 3 showed only limited recovery and Treatment 2 was intermediate.

Annual growth rates between treatments became more uniform during the second cycle, especially basal area rates which averaged 2 square feet per acre per treatment. Volume growth rates were slightly higher on Treatment 3.

Stand Structure

Prior to treatment establishment, the community represented a typical uneven-aged structure (see Figure 3). Harvesting in the 6,000 bd. ft. residual treatment produced the same basic age-frequency function, albeit reduced slightly in magnitude. The 3,000 bd. ft. residual treatment produced a distribution that was more skewed to the smaller diameter classes, but it was still representative of uneven-aged communities. However, due to the extent of reduction of the original stand in the 1,500 bd. ft. residual treatment, the diameter classes represented in the stand were greatly skewed toward the small classes and rather tightly constricted.

The stand structure distribution presented in Figure 4 for the 1,500 residual stand in 1938 more closely approximates that of the traditional even-aged stand (4). Its performance could be expected to reflect that of other even-aged mixed hardwoods.

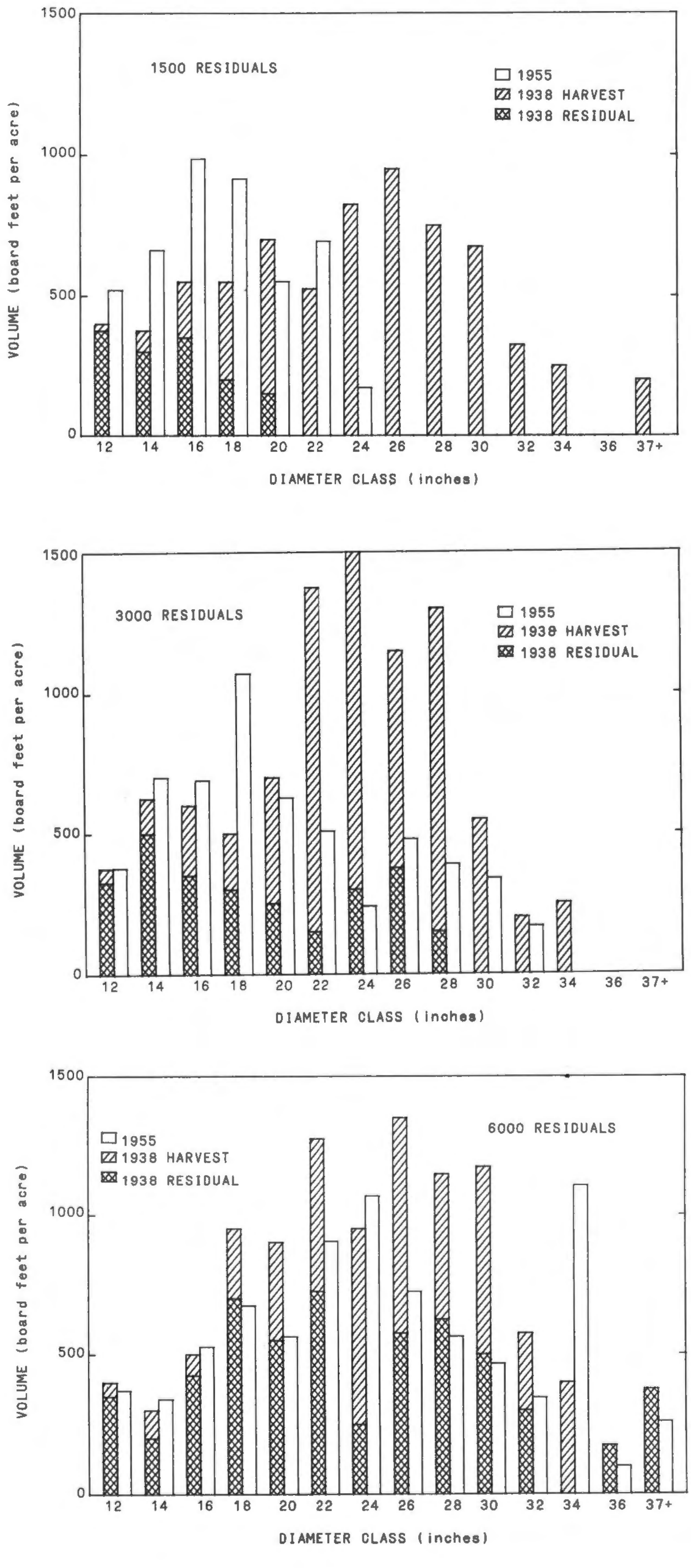


FIGURE 3. Stand structure by volume per acre for the first cutting cycle.

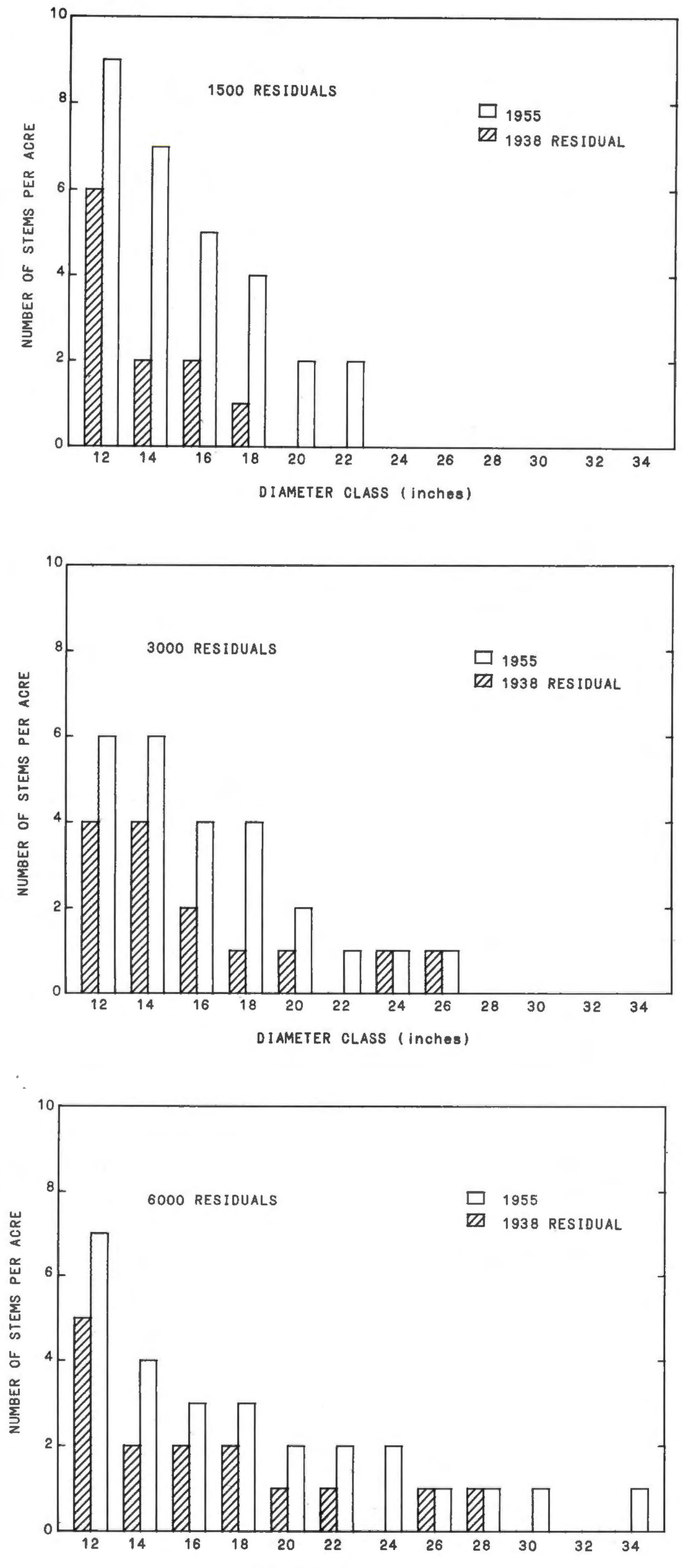


FIGURE 4. Stand structure by the number of sawtimber stems per acre for the first cutting cycle.

Figures 5 and 6 show the stand development during the second cycle. Figure 5 showed a greater volume response on Treatment 3. Figure 6 showed greater ingrowth on Treatment 1.

V. REGENERATION--SAPLING REPRODUCTION

The sapling reproduction was sampled by a strip cruise in 1958 and 1974 by the number of stems per diameter class. The chi-square contingency test evaluated significant differences between the 1958 and 1974 distribution functions and not between the diameter classes of the same distribution.

Yellow-Poplar

Yellow-poplar data were insufficient to statistically analyze for Treatments 1 and 2 and the differences between distributions for Treatment 3 were nonsignificant (see Figure 7).

Treatment 1 in 1958 showed a decreasing relationship as the diameter increased. There was a 50 percent reduction of stems from the 1-inch class to the 4-inch class. The function was reversed for Treatment 1 in 1974. There were three times more 4-inch stems than smaller stems. The distributions show more 1-inch yellow-poplar stems in 1958 and more 4-inch stems in 1974.

For Treatment 2 the number of stems was evenly distributed across diameter classes for 1958 and 1974, although the magnitude of the 1958 function was much larger.

The function for Treatment 3 in 1958 decreased as the diameter increased and the 1974 function increased as the diameter increased.

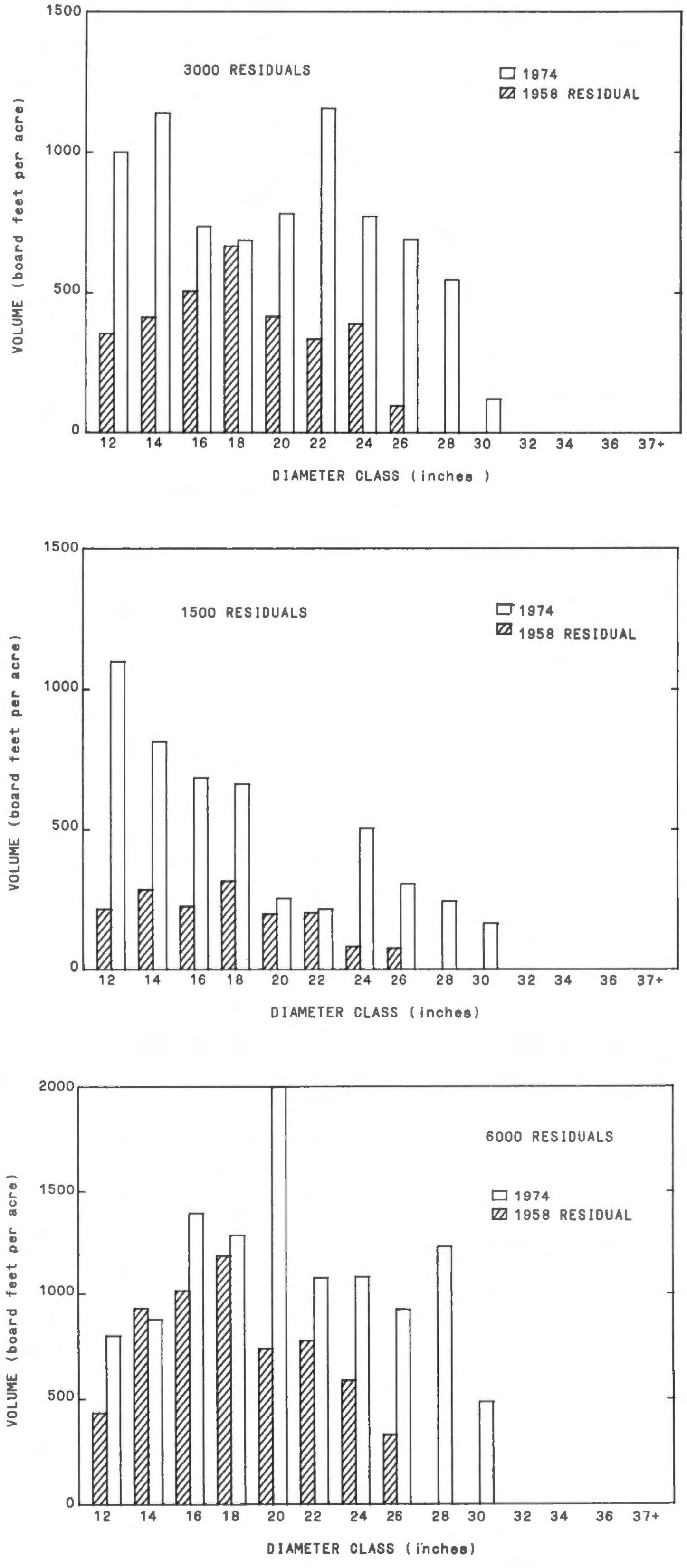


FIGURE 5. Stand structure by volume per acre for the second cutting cycle.

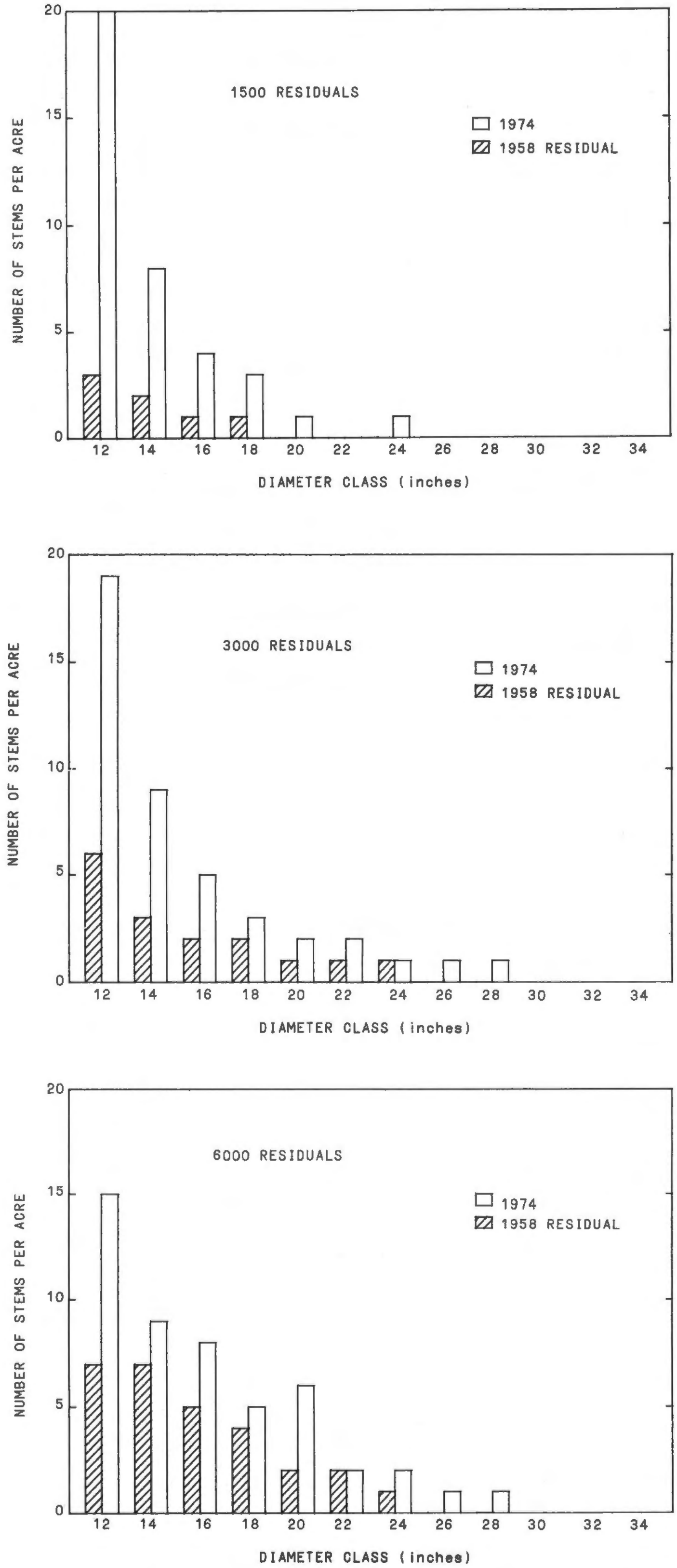


FIGURE 6. Stand structure by the number of sawtimber stems per acre for the second cutting cycle.

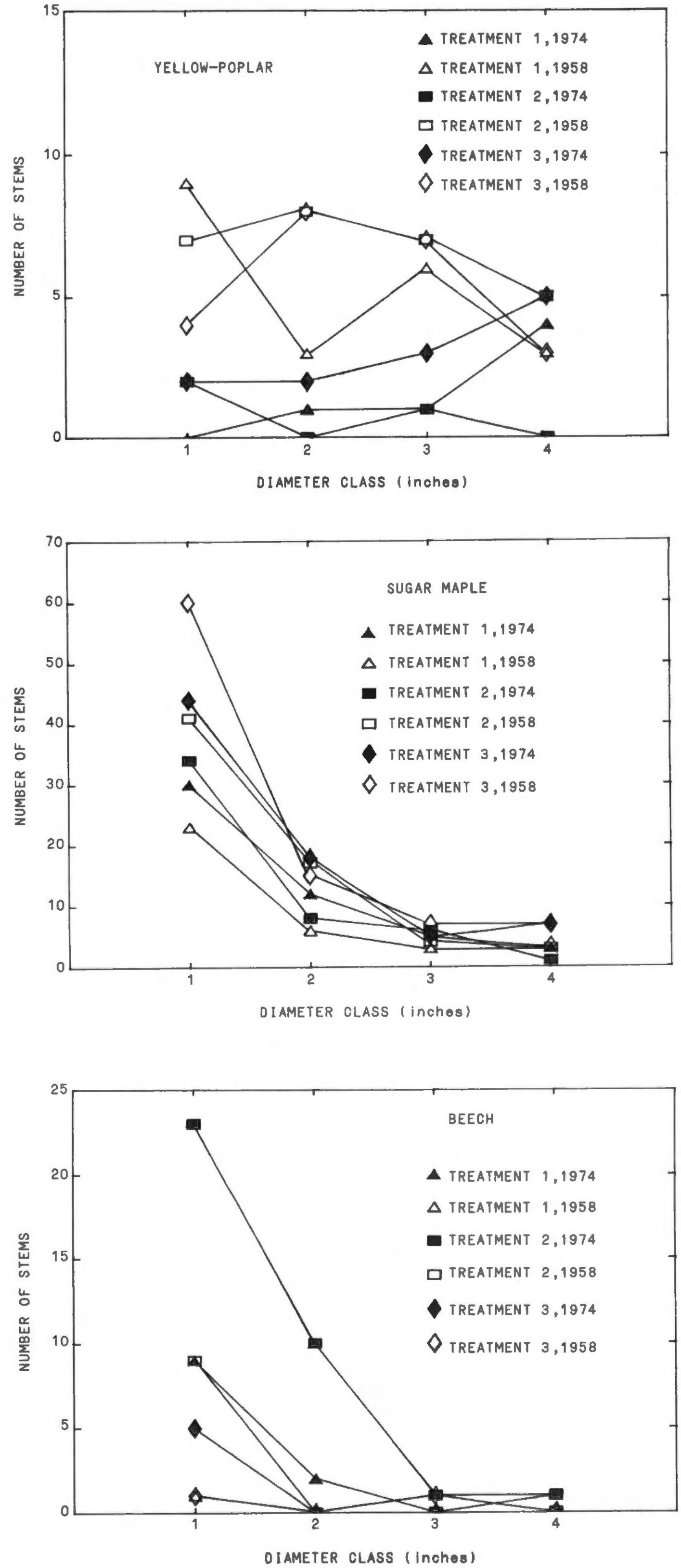


FIGURE 7. Frequency distributions for yellow-poplar, sugar maple and beech reproduction.

There were almost twice as many 4-inch yellow-poplar stems in 1974 as there were in 1958.

The combined distributions for 1958 show a decreasing function as diameter increased. The combined distributions for 1974 show an increasing function as diameter increased.

Sugar Maple

Treatments apparently did not have any effect on sugar maple sapling distributions between 1958 and 1974 (see Figure 7). The trend for all functions was the typical "J" shape of a tolerant species. The number of 1-inch stems increased with increasing residual volumes to a total of 60 stems on Treatment 1 in 1958.

Beech

There were insufficient data available to statistically evaluate the distributions for beech (see Figure 7).

Sapling frequency for Treatment 1 in 1958 and 1974 decreased with increasing diameter classes. There were more stems present in 1974 than in 1958.

The functions for Treatment 2 also decreased as diameter increased with twice as many 1-inch stems in 1974 as in 1958.

The decreasing relationships on Treatment 3 showed more 1-inch stems in 1974 than in 1958.

Other Species

The ash distributions (see Figure 8) were significantly different ($P < .05$) on Treatments 1 and 2 with three times more

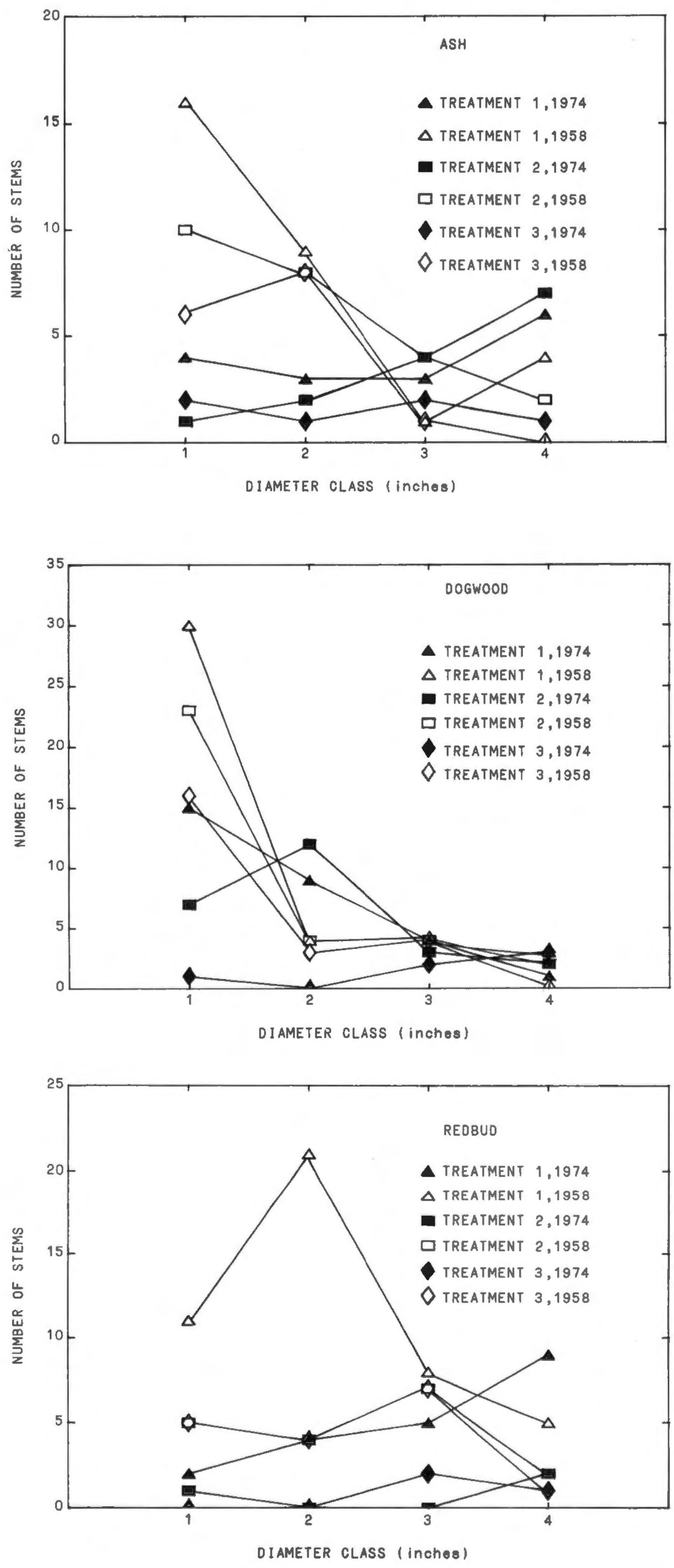


FIGURE 8. Frequency distributions for ash, dogwood and redbud reproduction.

1- and 2-inch stems in 1958 than in 1974. In 1974 there were 50 percent more 4-inch stems than in 1958 on Treatments 1 and 2. The distribution differences for Treatment 3 were nearly significant, having more 1- and 2-inch stems in 1958 than in 1974.

The dogwood distributions (see Figure 8) of 1958 and 1974 for Treatment 1 were nearly significant with twice the number of 1-inch stems in 1958 as in 1974. There were significant differences ($P < .10$) between the distributions of Treatments 2 and 3; i.e., there were two to three times the number of 1-inch stems in 1958 as in 1974. All treatments were nearly equal in number of stems in the 3- and 4-inch classes.

The redbud distributions (see Figure 8) were significantly different ($P < .01$) for Treatment 1. The 1958 function decreased as diameter increased with a larger number of smaller stems and the 1974 function increased to nine 4-inch stems. Treatments 2 and 3 had insufficient data to analyze but the trend for the 1958 decreasing functions is for more smaller stems than the 1974 distributions, with an equal number of 4-inch stems.

CHAPTER V

DISCUSSION

I. THE FIRST CYCLE--1938 TO 1955

Yellow-Poplar

Although no significant differences were found for yellow-poplar growth rates during the first cycle, some inferences can be made. Ingrowth into the sawtimber class caused a loss of growth in the pole class. There was more ingrowth into the pole-sized class on the heavier cut plots than on those receiving Treatment 3. Because of intolerance to shade, ingrowth of young yellow-poplar stems was minimal on Treatment 3. Downs (14) found a similar response when vigorous yellow-poplar were released in sapling and pole-size stands.

In 1938 there were more sawtimber stems on the 6,000 bd. ft. residual treatment than on Treatments 1 or 2. The larger number of stems produced more growth per acre. However, during the first cycle Treatment 1 had greater ingrowth into sawtimber classes, therefore, at the end of the first cycle they contained more stems than Treatment 3.

The heavier cutting produced favorable conditions which released pole-size yellow-poplar for ingrowth into the sawtimber class. In 1955 the sawtimber stems on the 6,000 bd. ft. residual treatment had a higher mean diameter which enabled them to have a higher annual growth. This large increase of yellow-poplar volume on Treatment 1 enabled them to be assigned to the lighter cuts in 1958. Tepper and Bamford (50) and Bowersox and Ward (6) reported heavier cutting favors yellow-poplar growth.

Sugar Maple

Sugar maple sawtimber grew significantly better on Treatment 1, corresponding to observations made by Eyre and Neetzel (17). Release from competition and a larger number of stems per plot accounted for the favorable response of Treatment 1. Tubbs (58) and Eyre and Zillgitt (18) found release from competition to bring about significant growth responses for sugar maple.

Mortality occurred on Treatment 3. It is unlikely that Treatment 3 was the direct cause of mortality of the very tolerant sugar maple. With just 12 stems for Treatment 3, the loss of one stem would cause a negative growth response.

Beech

The significant growth response of beech on Treatment 3 was predictable because there were more stems and a higher mean diameter for Treatment 3 than for Treatments 1 and 2. The original stand was made up of large, over-mature stems. Treatments 1 and 2 approximated a heavy release cutting while Treatment 3 approximated a light release. The tolerance of beech enabled the species to respond favorably on Treatment 3. Residual volumes of 4,000 to 7,000 bd. ft. per acre have been recommended for 15-year cutting cycles by Eyre and Zillgitt (18).

Black Walnut

The favorable growth of black walnut on Treatment 1 was due to release of the intolerant species. Phares and Williams (43) found a crown release necessary for favorable walnut growth. Mortality, caused by crown competion, occurred on Treatment 3, substantiating other researchers (20).

Other Species

There were too few stems of other species to accurately measure and analyze. These species occurred infrequently. The number of stems per acre was the controlling factor, rather than plot residual volumes.

II. COMBINED SPECIES GROWTH BY TREATMENT

It was necessary to leave growing stock of poor quality on the site in 1938 in order to meet residual volume requirements. At the end of the first growing cycle the results showed maximum growth occurred on Treatment 1 (see Figure 2, page 27). Since maximum growth was expected on Treatment 3, it was reasoned that inferior growing stock caused a growth decline.

Plot reassignment compounded second cycle results. The heavier cuttings in 1938 sufficiently opened the canopy to release smaller stems and apparently permitted the establishment of some regeneration. Marquis (35) and Erdmann and Oberg (16) found heavy thinning released young stems. Therefore, young and vigorous growing stock occupied much of the new stand on plots which were heavily cut in 1938. Three plots which received Treatment 1 in 1938 were reassigned Treatment 3 and two were reassigned to Treatment 2 during the second cycle. These young, released stems were able to add significantly to the total growth of the lighter cut plots and gave them a decisive advantage over the other treatments.

Light cutting in 1938 simulated a mild release cut and plot volume did not increase much in either quality or quantity. Therefore, two of these plots were reassigned to Treatment 1 in 1958 and two were reassigned to Treatment 2. The heavy cutting in 1958 on the original 6,000 bd. ft. residual treatment approximated the original heavy cutting in the over-mature stand in 1938.

Treatment 1 created virtually the same growth response for its plots during the second cycle as it did in the first cycle (see Figure 2, page 27). Residual crowns apparently did not completely recover between harvests in order to add significant volume increment. Plots lightly cut during the first cycle and reassigned to Treatment 1 for the second cycle were hampered by a lack of growing stock upon which to accrue volume.

During the second cycle Treatment 1 had a lower response than the other treatments. The 1,500 residual volume approximates Density Type I on the hypothetical growth curve by Langsaeter (46). It is below the optimum stocking range, therefore, less than maximum growth would always result.

Treatment 2 had a higher growth rate during the second cycle than in the first cycle. In 1938 the residual volume on these plots contained over-mature stems of low quality, contributing to a reduced growth during the first cycle. Ingrowth and crown development on plots reassigned to Treatment 2 in 1958 resulted in increased growth during the second cycle. The 3,000 bd. ft. residual volume approximates Density Type II on the Langsaeter curve (46) and is near the lower end of the optimum stocking range. Growth at this residual volume would be near the maximum with minimum growing stock.

Treatment 3 had a substantially higher growth during the second cycle than in the first cycle. The reassignment of plots heavily cut in 1938 to Treatment 3 in 1958 had the major effect on this increased growth. Rapidly growing young stems on the 1938 heavier cut plots were allowed to continue growth during the second cycle when they were reassigned the lighter cuts in 1958.

Plots which received Treatment 1 during both cycles had a substantially higher growth rate during the second cycle than in the first cycle (see Figure 2, page 27). In 1938 these plots were well below optimum stocking with an average residual volume of 1,260 bd. ft. At the beginning of the second cycle the residual volume averaged 1,625 bd. ft., which was nearer optimum stocking than in 1938. Yellow-poplar reproduction apparently became established during the first cycle and provided ingrowth of sawtimber during the second cycle. This ingrowth, having reached sufficient size to accept volume increments by 1958, caused a significant plot growth increase during the second cycle.

Plots which received Treatment 2 during both cycles had a moderate growth increase from the first cycle to the second cycle. Stems released during the first cycle were permitted to continue growth during the second cycle and resulted in a moderate growth increase. The 3,000 bd. ft. residual volume is at the lower end of the optimum residual volumes found by Eyre and Zillgitt (18).

Plots which received Treatment 3 in both cycles showed little growth increase from the first cycle to the second cycle. The 6,000 bd. ft. residual volume is near the upper end of the optimum stocking range and repeated treatments should not increase growth. Duerr and Stoddard (15) and Eyre and Zillgett (18) have found a residual volume of approximately 6,000 bd. ft. per acre to produce maximum total growth.

The stand structure by volume and number of stems per acre showed the 1,500 bd. ft. residual treatment to be commensurable with even-aged conditions. In many plots as few as ten sawtimber residual stems were present at the beginning of the cycle. The release response was very effective on these plots. Yellow-poplar reproduction was established and good crown development was promoted. Similar results were found by other investigators (6, 14, 18).

The stand structure for the 6,000 bd. ft. residual treatment was uneven-aged. The number of stems for diameter classes had the typical "J" shape with many stems in the lower diameter classes and fewer in the larger classes.

III. THE SECOND CYCLE--1958 TO 1974

The combined growth results of the marked sawtimber, the pole-size and total sawtimber, and the regeneration are discussed here by species.

Yellow-Poplar

There were no significant effects of the 1938 treatments on the growth rate of yellow-poplar during the second cycle. Heavy cutting in 1938 appeared to favor the growth of the total number of sawtimber stems during the second cycle. Downs (14) also found this to be true. Heavy cutting in 1938 released young stems and promoted the regeneration of yellow-poplar. During the second cycle these young, vigorous yellow-poplar stems produced high growth rates, which was similar to other studies (6, 50).

Treatment 3 in 1938 seemed to favor the growth of marked sawtimber during the second cycle. Light cutting in 1938 provided more stems at a larger diameter per plot for the second cycle. The larger stems were removed from the heavier cut plots in 1938 to meet the residual volume requirements. Therefore, the larger marked sawtimber stems on Treatment 3 were able to produce more increment than the fewer and smaller marked stems on Treatment 1. Ingrowth was not considered when analyzing the marked sawtimber.

During the second cycle the total sawtimber growth of yellow-poplar was favored by Treatment 3. The recovery of volume by ingrowth on plots receiving the 1,500 bd. ft. residual treatment during the first cycle enabled them to be reassigned Treatment 3 in 1958. These vigorous stems caused plots receiving the 6,000 bd. ft. residual treatment to produce significantly better growth rates during the second cycle than the other treatments.

As a result of the 1958 cuttings, marked sawtimber was favored by Treatment 1 during the second cycle. The majority of plots receiving the 1,500 bd. ft. residual treatment had been lightly cut in 1938. This gave larger marked stems on Treatment 1 in 1958 which produced significantly higher growth rates due to the rather complete release afforded by the treatment. Downs (14) also found that yellow-poplar was favored by release.

Yellow-poplar reproduction apparently became established after heavy cutting in 1938. Studies have shown that yellow-poplar seed remains viable in the litter for years and will become established after the canopy is opened (9, 36, 40). The number of sapling stems present in 1958 pointed to this conclusion. The intolerant yellow-poplar saplings have declined in number since 1958. Some have increased in size, as evidenced by the increasing functions of 1974, and some have died because of a closing canopy. Those that remain are just existing.

<u>Sugar Maple</u>

Plots which were heavily cut in 1938 produced a favorable response of total sugar maple sawtimber volume during the second cycle. Because of the tolerance of maple, heavy cutting apparently did not favor growth appreciably of large, sawtimber stems. However, young sugar maple stems were released from competition during the first cycle and were able to add significant growth during the second cycle. Heavier cutting promoted ingrowth of pole-size stems into the sawtimber class, substantiating results found by Tubbs (58). Marquis (35) and Erdmann and Oberg (16) found heavy cutting triggered release of crop trees.

None of the treatments produced any significant differences between annual growth rates for sugar maple marked sawtimber. However, during the second cycle a maple which was 24 inches in diameter in 1958 was cut from a plot receiving the 6,000 bd. ft. residual treatment by trespassers to remove a bee colony. Without the loss of this tree, Treatment 3 in 1958 would have favored growth of maple during the second cycle. Tolerance of sugar maple permitted optimum growth at a higher density (46).

Although there were no statistical differences between the treatments in the second cycle, it appeared that the total number of sugar maple sawtimber stems also obtained maximum growth on Treatment 3. Again, the tolerance of sugar maple permitted a higher density to produce maximum growth.

Sugar maple reproduction was favored by Treatment 3. Cunningham (10) found sugar maple seedlings to grow best under shade. The functions of all treatments had the typical "J shape" of a tolerant species (4). Treatments 1 and 2 were also adequately stocked. Other studies have shown sugar maple reproduction to be adequate under all levels of residual volumes (8, 39, 58, 59).

Beech

Treatment 1 during the first cycle favored the growth of the marked beech sawtimber during the second cycle. The removal of the over-mature and very large beech in 1938 released younger beech stems. The beech was then in a position for increased growth during the second cycle.

Treatment 1 in 1958 also favored growth of the marked beech sawtimber during the second cycle. Release action was evident on the 1,500 residual plots because so many of these plots were reduced from Treatment 3 to Treatment 1 in 1958. The observed phenomenon was not ingrowth.

Treatment 3 in 1958 favored the growth of the total number of beech sawtimber stems during the second cycle. Treatment 3 contained more stems and was able to add more increment than the other treatments. Ingrowth also aided volume accrument on Treatment 3. The effects of ingrowth were not considered when analyzing the marked sawtimber; consequently, the marked sawtimber was favored by Treatment 1. Duerr and Stoddard (15) found a residual volume of 6,000 bd. ft. to produce good volume increment for beech.

Although little data were available, there seemed to be an influx of beech reproduction into the stand during the second cycle. Frothingham (21) and Hutchinson (27) found beech to reproduce best under the protection of dense stands.

Black Walnut

Treatment 1 in 1938 favored the growth rates of the total number of black walnut sawtimber stems and the marked sawtimber stems during the second cycle. Treatment 1 opened the canopy and allowed the crowns of walnut sawtimber to develop. The walnut was released from competition and was able to increase in growth during the second cycle. To avoid pressures exerted by other species, this species must occupy a dominant position in the canopy, as reported by Phares and Williams (43).

Treatment 3 in 1958 favored the growth of black walnut significantly. More stems of higher quality were present on the 6,000 bd. ft. residual treatment than on the other treatments and produced significant growth. It appeared that heavy cutting in 1938 followed by light cutting in 1958 favored this species.

Other Species

Other species comprised too small a portion of the stand to accurately analyze growth differences. Since these species were intermediate to tolerant of shade, it seemed that the number of stems per acre was the controlling factor governing growth. However, Herrick (24) found volume of growing stock per acre to be more significant with volume growth than number of stems per acre.

During the second cycle there was a decrease of small ash saplings and an increase of larger ash saplings. The trend showed the ingrowth of ash into the pole-size class. Redbud and dogwood had a decrease of smaller stems during the second cycle due to mortality.

CHAPTER VI

MANAGEMENT IMPLICATIONS

Before decisions on silvicultural policies can be formed, there must be a concise statement of management objectives. The decision of the desired species composition of the stand is of paramount importance. As was pointed out by this study and others (45), the policies chosen must create conditions that satisfy the silvical requirements of the species wanted in the stand.

Harvesting to a residual volume of 1,500 bd. ft. per acre for even-aged management, approximates a shelterwood harvest and allows intolerant species to form a portion of the new stand. If residual stems are grouped fairly close, the harvest approximates group selection, as recommended by others for the even-aged management of northern hardwoods (45, 54). The new stand composition would include a wide range of species, including intolerants.

Harvesting to a residual volume of 6,000 bd. ft. per acre is commensurable with uneven-aged management. Harvest takes the form of selection, which has been recommended for uneven-aged management of northern hardwoods by many investigators (1, 16, 18, 19, 32, 60). Tolerant and intermediate species will form a major portion of the new stand.

Two important factors for the management of a previously unmanaged stand have also been emphasized by this study. First, the poor quality growing stock must be harvested. If not, quality increment will be added very slowly or not at all. And second, after quality has been improved, residual volume can be increased to produce optimum growth.

CHAPTER VII

SUMMARY

Yellow-poplar reproduction became established after heavy cutting. Treatment 1 opened the canopy and favored ingrowth of yellow-poplar into the sawtimber class. Heavy cutting, followed by light cutting, favored the growth of yellow-poplar sawtimber.

Sugar maple reproduction was adequate under all stand densities but best on Treatment 3. In over-mature stands, pole-size sugar maple stems were released by heavy cutting and grew into the sawtimber class. Optimum growth of sugar maple occurred on high residual volumes.

Beech reproduction was best under dense stands. Young beech stems were released by the removal of large, over-mature beech sawtimber. Exposure on Treatment 1 retarded beech growth while Treatment 3 favored growth.

Heavy cutting promoted crown development of black walnut and favored growth. No reproduction was found on the site.

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