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DEVELOPMENT OF IMMATURE BALSAM FIR FOLLOWING CROWN RELEASE

by

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Development of Immature Balsam Fir Following Crown Release

by

G. L. Baskerville[1]

In 1953 a study of the response of immature balsam fir[2] to several levels of crown release was established by A. B. Vincent on the Green River watershed in northwestern New Brunswick (latitude 47°50′N., longitude 68°20′E.). The purpose was to determine the effects of crown release on the subsequent growth of selected trees.

This part of the province is a strongly rolling upland with elevations from 1,000 to 2,100 feet. The dominating climatic influences are abundant precipitation, long cold winters and short cool summers. Weather records indicate a frost-free period of 110 days, a mean annual temperature of 36 degrees and an annual precipitation of 42 inches of which 18 inches falls between June and September.

The forest consists of balsam fir in association with white spruce, black spruce, white birch, and scattered yellow birch. Before 1940 birch was a major component of most stands. Dieback has since reduced it to minor proportions. Balsam fir is well suited to the climate and soils of the watershed. Mature trees have been measured at 18 inches in diameter and 97 feet in height. In pole stands, individuals have attained a diameter of nine inches at breast height and a height of 50 feet in 33 years. Fir commonly lives 90 years from date of release without excessive rot and some individuals are still sound after 130 years.

The spruce budworm outbreak of 1913 to 1919 killed many stands of mature fir on the watershed and released an advance growth of fir which has formed 40-year-old pole stands of up to 6,000 stems per acre. These young stands occur either as an understorey beneath a moderately dense stand of overmature fir and spruce which survived the budworm, or as the main forest where the overstorey was destroyed. Such stands occupy about 30 per cent of the softwood sites on the watershed.

STUDY METHODS

The study area comprises 10 acres on a lower slope at an elevation of 1,350 feet. The slope varies from 5 to 15 per cent with a southwesterly aspect. The soil is a reworked till consisting of a gravelly loam to silt loam, occasionally with stone fragments derived from the soft shale bedrock.

The stand is 40- to 50-year-old balsam fir with some white and black spruce. In 1953 there were about 2,500 stems per acre ranging from one to six inches in diameter at breast height (average about three inches) and up to 40 feet in height. Scattered overmature white and black spruce remained as remnants of the stand killed by the budworm.

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[2]Nomenclature as in Native Trees of Canada (1956).

The experimental design included 120 immature balsam fir chosen in 30 groups of four trees. Ten groups consisted of trees in the three-inch diameter class, ten groups comprised four-inch trees and ten comprised five-inch trees. Treatments were assigned randomly to the four trees within each group as follows:

1. crown release of 1 foot to 3 feet
2. crown release of 3 to 5 feet
3. crown release of 5 to 7 feet
4. unreleased controls

The trees in each group were selected for uniformity of outward characteristics. Most of the crowns were either dominant or codominant, although some in the three-inch group were intermediate in crown position.

The three levels of release were effected by removing the surrounding stems until the required amount of space was obtained on all sides. It was necessary to remove an average of 7.9, 12.5 and 16.6 trees to provide average crown releases of 3.3, 4.7 and 5.9 feet, respectively.

In 1953 the data recorded for each released tree and surrounding trees included: diameter at breast height to the nearest 0.1 inch, total height, length of living crown, and age determined by a whorl count. Crown projection maps were prepared showing each released tree together with the surrounding trees. In 1958 the above information was recorded for all trees and in addition the diameter outside bark at one-half the height above breast height was determined.

Three of the 120 trees were killed in an ice storm in the winter of 1957–58. Where necessary, the missing values have been calculated by regression techniques.

For each stem, diameter at breast height, basal area, height, crown length and live crown ratio were determined from the tallies in 1953 and 1958. The crown projection area, average crown width, inter-crown distance and distance to each competing tree were measured from the crown projection maps. The crown projection areas were determined by planimeter and the crown widths by treating the areas as circles. Inter-crown distance was calculated as the average of the crown-to-crown distance to the nearest trees in the four cardinal directions. The crown volume, crown surface area and their increments were determined with the crown considered to be a cone. Initially, there was considerable variation in crown length, crown width and their dependent functions.

Over one hundred graphs were plotted and some 40 regressions calculated to indicate what relationships existed among the variables. Gross treatment differences were examined by means of analysis of variance.

The recent budworm infestation in northern New Brunswick caused some defoliation on the study area in 1955. As a control the area was sprayed with D.D.T. and budworm feeding was reduced. Since defoliation is initially at the top of the crown, most stems lost from one to three years leader growth and there was in effect a reduction in height growth between 1953 and 1958. The feeding was not heavy enough to have a measurable influence on diameter growth.

RESULTS

Comparison of Treatments

There were significant differences among the responses to the four levels of crown release (Table 1).

The analyses of variance of diameter increment and basal area increment are shown in Table 2. In both cases there are significant differences between treatments; for diameter, P = .98, and for basal area, P = .96. However, differences among diameter groups were more significant and in both cases P = .995. The F-ratio for the interaction treatment by diameter was less than one, indicating that the variance component for interaction approaches zero. The conclusion is that degree of crown release and initial diameter had independent effects on increment in diameter and basal area. A subsequent analysis of covariance using initial diameter at breast height as the covariate verified this conclusion.

The 1 to 3, 3 to 5, and 5 to 7 foot releases gave basal area increments 7, 33, and 47 per cent greater than the control. Analysis of the treatment averages by the least significant difference technique indicated that adjacent treatments were not different but that treatments separated by at least one level were significantly different (P = .95).

Although the form quotient in 1958 ranged from .34 to .97, there are statistically significant differences between the averages for the four levels of crown release. There is no logical correlation of form quotient with level of crown release; however, the lowest average is associated with the treatment having the deepest crowns (Table 1).

Correlation Analyses

Apart from changes in diameter and basal area, several other tree characteristics changed over the period 1953 to 1958. Height increased by about 2.5 feet with all levels of crown release. As previously mentioned, height growth was reduced by budworm feeding. There were changes in crown length and in live crown ratio. Changes in crown width resulted in changes in crown projection area and in inter-crown distance. The changes in crown width and crown length also affected crown volume and crown surface area. These changes are summarized on a basis of treatment levels in Table 1. There was considerable variation of these factors about the means. Also, since the crown release ranged from zero to a maximum of 9.8 feet, it is probably more correct to consider crown release as a continuous variable. As the other factors are continuous their correlations with crown release and growth may be examined using regression methods.

Of the many possible correlations the most interesting are those relating treatment and various tree factors to growth of diameter and basal area. Variation in diameter increment was found to be a poor parameter of response. Unexplained variation was less using basal area increment. Also basal area is more meaningful in that it is linearly related to tree volume. Similar calculations were made using growth in terms of both basal area and diameter, but these invariably showed poorer correlation and greater residual variation when diameter growth was the measure of response. This same conclusion was reached by Wile (1957) who found that residual variation was reduced when basal area growth was substituted for diameter growth.

TABLE 1. AVERAGE[1] VALUES FOR SOME STEM AND CROWN CHARACTERISTICS BY TREATMENTS IN 1953, 1958, AND THE CHANGES FROM 1953 TO 1958

—	1953				1958				Change 1953 to 1958			
	Control	Crown release			Control	Crown release			Control	Crown release		
		1 to 3 feet	3 to 5 feet	5 to 7 feet		1 to 3 feet	3 to 5 feet	5 to 7 feet		1 to 3 feet	3 to 5 feet	5 to 7 feet
Diameter at breast height	4.0	4.1	4.0	4.0	4.3	4.4	4.4	4.4	.3	.3	.4	.4
Basal area (sq. ft.)	.089	.094	.090	.090	.104	.110	.110	.112	.015	.016	.020	.022
Total height (ft.)	33.0	33.5	32.6	33.1	35.6	35.7	35.1	35.4	2.6	2.2	2.5	2.3
Length of live crown (ft.)	16.6	15.6	15.6	15.5	15.5	16.0	16.9	16.1	−1.1	.4	1.3	.6
Live crown ratio	.50	.47	.48	.47	.43	.45	.47	.44	− .07	− .02	− .01	− .03
Crown width (ft.)	5.4	5.3	5.5	5.5	5.6	6.4	6.9	6.8	.2	1.1	1.4	1.3
Inter-crown distance (ft.)	.42	3.3	4.7	5.9	.42	2.0	3.3	4.5	0	−1.3	−1.4	−1.4
Crown projection area (sq. ft.)	23.7	21.8	26.4	24.8	25.1	33.8	38.8	35.9	1.4	12.0	12.2	11.1
Crown surface area (sq. ft.)	144	133	142	136	144	166	185	174	0	33	43	38
Crown volume (cu. ft.)	135	126	138	133	144	189	224	206	9	63	86	73
Form diameter[2] (in.)					3.1	3.2	3.1	3.2				
Form quotient[3]					.72	.73	.70	.72				

[1]Each value based on 30 trees.
[2]Diameter in inches at one-half the height above breast height.
[3]Outside bark measurements.

TABLE 2. ANALYSES OF VARIANCE FOR DIAMETER INCREMENT 1953 TO 1958 AND BASAL AREA INCREMENT 1953 TO 1958.

	Degrees of freedom	Sums of squares	Mean square	F
	Diameter increment			
Treatments	3	.22	.073	3.48
Diameter groups	2	1.07	.535	25.5
Interaction	6	.07	.012	.6
Error	105[1]	2.25	.021	
TOTAL	116	3.61		
	Basal area increment			
Treatments	3	.000561	.000187	3.12
Diameter groups	2	.006269	.003135	52.2
Interaction	6	.000305	.000050	.8
Error	105[1]	.006331	.000060	
TOTAL	116	.013466		

[1]Degrees of freedom in error reduced by three for three missing values.

TABLE 3. REGRESSION VALUES[1] WITH BASAL AREA INCREMENT AS DEPENDENT VARIABLE AND A SERIES OF INDEPENDENT VARIABLES

Independent variables	Regression values[2]				
	a	b	s^2	P	r^2
Diameter 1953	−.024	.010	.00005	.995	.5287
Basal area 1953	−.004	.24	.00005	.995	.5272
Crown surface area 1953	.004	.0001	.00006	.995	.4566
Crown width 1953	−.015	.006	.00006	.995	.4530
Crown volume 1953	.007	.00008	.00006	.995	.4451
Crown projection area 1953	.003	.0007	.00007	.995	.3607
Crown length 1953	−.008	.0016	.00007	.995	.3119
Live crown ratio 1953	−.006	.050	.0001	.995	.1620
Competition factor[3]	.009	.00013	.0001	.995	.0817
Inter-crown distance 1953	.016	.0006	.0001	.92	.0244

[1] All regressions are in the form $y = a + bx$ where y is the basal area increment for a five-year period.
[2] a = y-intercept
b = slope
s^2 = error variance
P = probability that b does not equal zero
r^2 = square of the correlation coefficient
[3] See text.

Basal area increment was tested in linear regression against ten factors. In nine cases the probability that the slope was not zero exceeded .995. In the tenth case, inter-crown distance, the probability was .92 (Table 3). While all ten factors showed correlation with basal area increment, there were considerable differences in the degree of this correlation. This is shown by the value r^2 (square of correlation coefficient) which indicates the percentage of variation in the dependent variable (basal area increment) accounted for by the independent variable. The value r^2 ranged from .5287 to .0244; thus diameter at breast height in 1953 accounted for 52.87 per cent of the variation in basal area increment, and 1953 inter-crown distance accounted for only 2.44 per cent.

When regression and multiple regression analyses pointed out that initial inter-crown distance was poorly related to subsequent basal area growth, several other measures of competition were formulated. These ranged from the linear distance to the nearest tree to the square of the mean distance to surrounding trees divided by the mean basal area of these trees. The most efficient expression appeared to be the mean distance to the surrounding trees divided by the mean basal area of these trees. This is the competition factor used in this study.

Several of the relationships discussed above are shown in Figure 1.

Other regressions using diameter increment as the dependent variable placed the independent variables in roughly the same order of degree of correlation, but the maximum r^2 was only .3309. In this respect it is interesting to note that linear equations were used in fitting the functions for both diameter and basal area increment. Since basal area is a square function of diameter, it would be expected that if one was linear the other must be curvilinear. Holsoe (1940) found that the relationship of basal area increment to several crown factors was curvilinear, while Stoeckeler and Olsen (1957) found the relation between diameter growth and per cent live crown to be curvilinear. Within the limited range of diameters in this study the graphs indicated straight lines in both cases. The one test of quadratic effect on a basal area increment regression showed curvature to be insignificant.

Since no one factor accounted for much more than half the variation in basal area increment, various combinations of the independent variables were tried in multiple correlations. These combinations and their resultant R^2 values (square of multiple correlation coefficient) are given in Table 4. In every case the probability that the multiple correlation describes a real correlation exceeds .995.

The highest degree of correlation was obtained using four factors: diameter 1953, crown width 1953, competition factor, and crown length 1953; however, crown length added nothing of significance and may be dropped. The equation for predicting basal area increment for five years thus becomes: BA inc. = $-0.0314 + .00720\ \mathrm{DBH} + .00283\ \mathrm{CW} + .000077\ \mathrm{CF} \pm .001$ where DBH is the initial diameter at breast height in inches, CW is initial crown width in feet and CF is the competition factor.

Working in 18-year-old Douglas fir, Warrack (1959) found that initial diameter was the best basis for predicting diameter growth and that measures of crown size added nothing of significance to the estimate.

In analyses of variance of the relationships indicated in Table 4 the total-explained sums of squares for the individual factors were invariably much less than the sum of squares for combined effects. This indicates a possible inter-correlation among the independent variables. This is also evident from the fact that in each case R^2 is less than the sum of the r^2. Clearly the independent variables are accounting in part for the same variation in basal area increment. At the same time 38 per cent of the variation in basal area increment is not explained.

Several of these independent variables were examined for inter-correlations (Table 5). In each case the probability of a linear correlation existing exceeded .995. This is in part the explanation of the failure of the multiple correlations to yield R^2 in excess of .62.

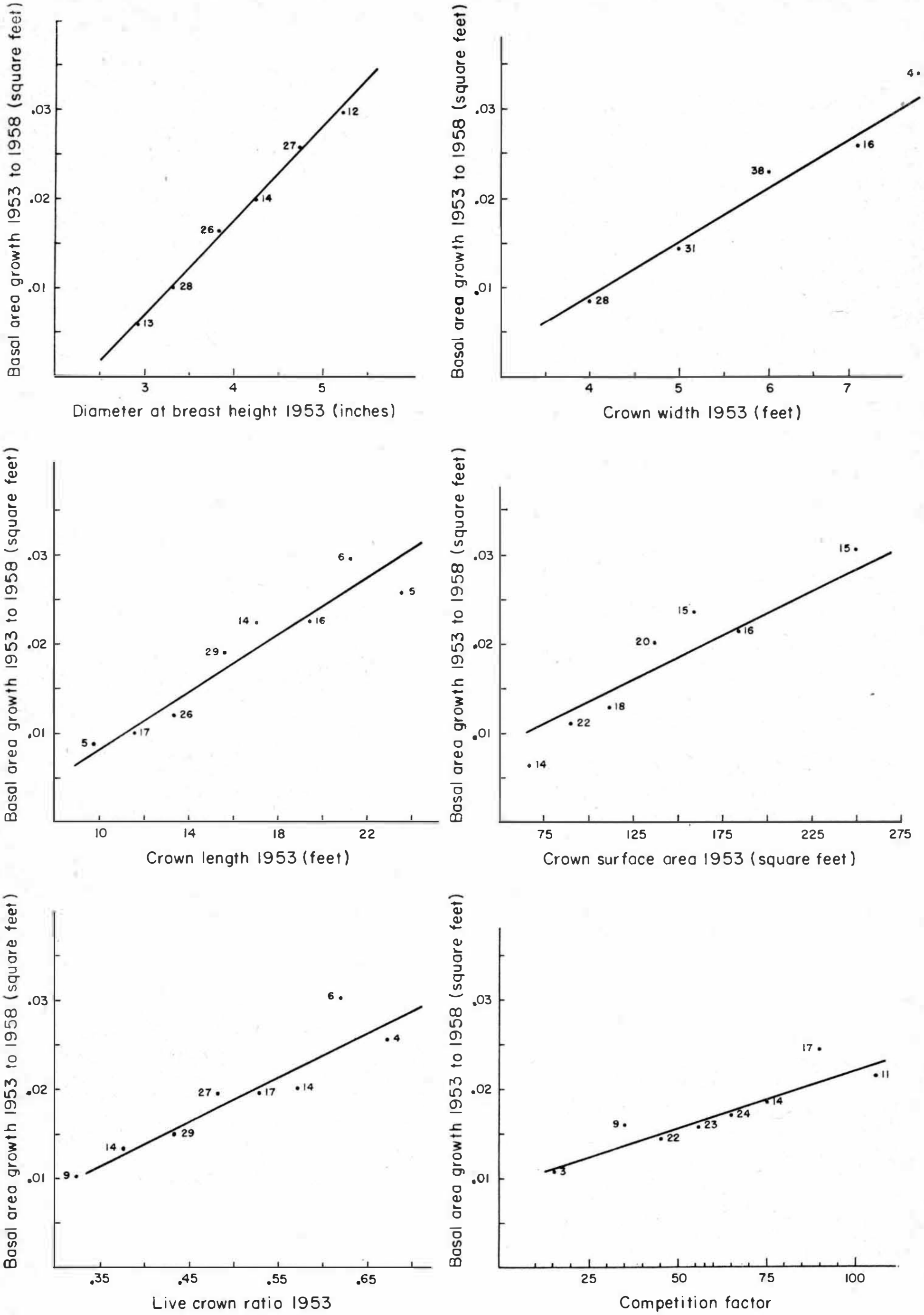

Figure 1. The relationship of basal area increment to several independent variables. The grouping is in terms of the independent variables; the number of trees associated with each point is given on the graph.

TABLE 4. MULTIPLE CORRELATION WITH BASAL AREA INCREMENT FOR A FIVE-YEAR PERIOD RELATED TO SEVERAL INDEPENDENT VARIABLES

	Number of independent variables	P	R^2
Diameter 1953*, Crown width 1953*, Competition factor*, Crown length 1953	4	.995	.6216
Diameter 1953*, Crown width 1953*, Competition factor*	3	.995	.6213
Basal area 1953*, Crown width 1953*, Competition factor*	3	.995	.5864
Diameter 1953*, Inter-crown distance 1953*, Live crown rato 1953*, Crown projection area 1953, Crown surface area 1953, Crown volume 1953	6	.995	.5733
Crown width 1953*, Competition factor*, Crown length 1953*	3	.995	.5215
Crown width 1953*, Competition factor*	2	.995	.4856

*Denotes a factor which contributes significantly to the correlation.
All relationships are in the form: $y = a + bx_1 + cx_2 + dx_3 +$.
P is the probability that the multiple correlation is real.
R^2 is the square of multiple correlation coefficient.

TABLE 5. LINEAR REGRESSIONS CORRELATING SOME OF THE INDEPENDENT VARIABLES USED IN THE MULTIPLE REGRESSIONS

Variables[2]	Regression values[1]				
	a	b	s	P	r^2
DBH 1958/CSA 1958	2.20	0.013	0.17	.995	.7692
BA 1953/CW 1953	0.024	0.021	0.0004	.995	.6053
DBH 1958/CV 1958	3.30	0.0056	0.35	.995	.5172
CPA 1953/DBH 1953	−9.83	8.38	54.4	.995	.4111
DBH 1958/CW 1958	1.96	0.38	0.45	.995	.3802
CL 1953/CW 1953	5.83	1.84	8.67	.995	.3608
BA 1958/CPA 1958	0.05	0.0017	0.0014	.995	.2690

[1]a, b, s^2, P and r^2 as in Table 4.
[2]DBH = diameter at breast height
BA = basal area
CPA = crown projection area
CSA = crown surface area
CV = crown volume
CL = crown length
CW = crown width

Apart from predicting growth it is interesting to examine these multiple correlations from the standpoint of which factors appear to be controlling growth. It must be remembered, however, that proving correlation does not necessarily prove cause and effect.

Returning to the growth equation, it could be said that of the major factors related to the basal area growth of a tree, initial diameter, (or initial basal area), is itself the integration of the factors which have affected growth to that point. As such it contains a number of unknowns. It seems reasonable, therefore, to examine growth over a five-year period relative to any number of factors but excluding initial diameter. By this means the factors of which initial diameter is the integration may be sought. Two multiple correlations without initial diameter are listed in Table 4. When diameter was dropped from the equation for predicting growth, the value of R^2 dropped from .6213 to .4856. It is interesting to note that when crown length is placed in this equation it becomes significant in the absence of initial diameter (R^2 = .5215). That is, crown length is accounting for some of the variation previously accounted for by diameter because of an intercorrelation of the two.

Working in pole stands of western white pine, Arnold (1949) found that a crown index (crown length by crown width) accounted for 75 to 90 per cent of the variation in basal area growth. Although this and several other possibilities were tested in the present study, the combination of crown width, competition factor and crown length explained the most variation and this left some 48 per cent of the variation in basal area increment unaccounted for. Several probable reasons for this large residual variation are discussed.

DISCUSSION

Of the various intrinsic and extrinsic factors affecting growth, the former appear to predominate, but there is much unexplained variation.

Crown dimensions are usually considered to be indicative of a tree's capacity to produce wood. In the present study, crown width was found to be the most important factor. Crown length, surface area and volume showed lesser degrees of correlation. Within the range of sizes examined the amount of crown appeared to be a limiting factor to growth, but was certainly not the sole factor. It is possible that growth is less related to crown characters over short periods of release when the crown is enlarging in preparation for later diameter growth. Thus there may be a delayed reaction of growth in response to crown release.

The difficulties of measuring tree crowns must be kept in mind. For instance, most crowns are asymmetrical, yet in computing surface area or volume, symmetry of a definite form is assumed. Such errors could affect the resultant crown estimates and correlations.

The crowns underwent considerable changes during the study period (Table 1). On the average, crown length increased on all but the control trees. Crown width increased on all stems but much less on the controls. The crown release of 3 to 5 feet resulted in the greatest average increases in crown width and crown length and hence in crown surface and volume.

The average inter-crown distance remained near zero for the control trees and for the 1 to 3, 3 to 5, and 5 to 7 foot levels of release the original opening was reduced by 39, 30 and 24 per cent, respectively. Thus the crowns of all released trees still have free-growing space (Figure 2). There was no apparent threshold of inter-crown distance beyond which growth increased rapidly. In fact, inter-crown distance has less influence on growth than several other factors.

Changes in the rate of natural pruning could not be observed over the short remeasurement period. There was no epicormic branching.

Four untreated stems similar to those included in the study were analysed for growth pattern as described by Duff and Nolan (1953). The radial pattern indicated that growth near breast height was past the peak and showed a gentle decline. Presumably all 120 stems would be in the same stage of the pattern in which case the equation for predicting basal area increment could lead to slight over-estimates. Although this pattern would not contribute to the unexplained

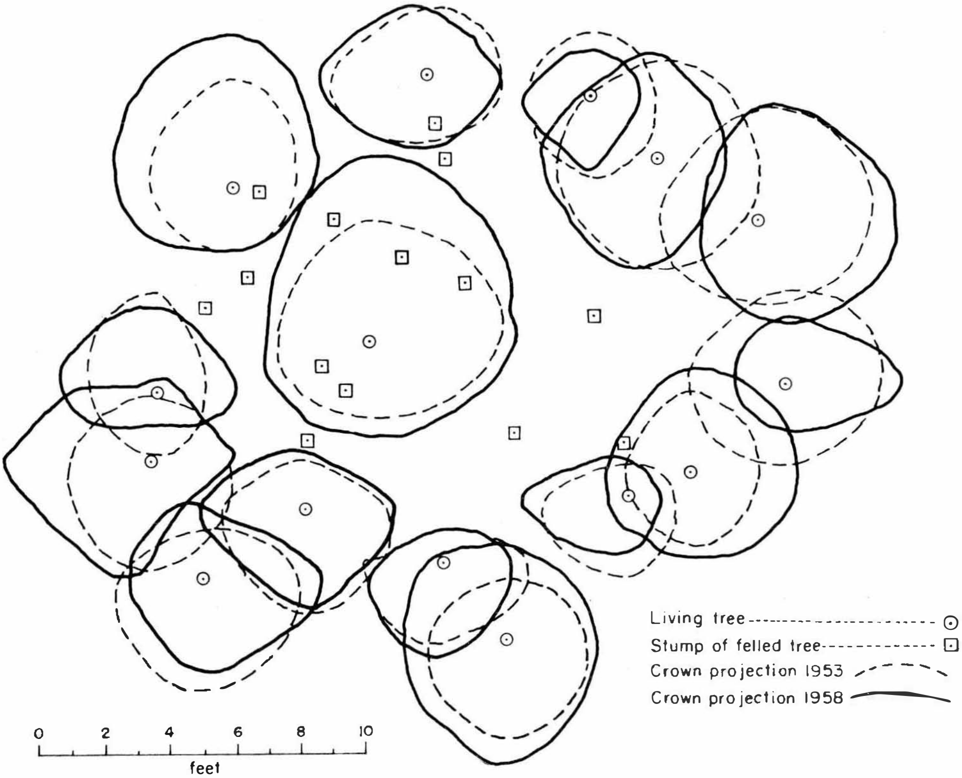

Figure 2. An example crown projection map. The treated tree was 5.0 inches in diameter n 1953 and was given a crown release of 3 to 5 feet.

variation in basal area increment, a study of it could suggest a different measure of growth, one which takes account of the three-dimensional changes that could take place. That is, it is possible that equivalent changes in basal area at breast height would be encountered under different treatments, and that the real effects of the treatments occurred at another level in the stem.

Although the site appeared uniform, pits were dug at each tree and the site was evaluated from physical features. No correlation was found between site and basal area increment.

Differences in root competition, which could not be assessed, may be the cause of much of the unexplained variation. The possibility of natural grafting of roots of the released tree to the roots of some of the removed trees was considered especially in the four instances of exceptionally rapid growth. A partial examination was made of the roots of these trees, but no evidence of grafting could be found.

There is, of course, genetic variation among the 120 trees in the study. However, the trees are growing in a uniform stand, appear of uniform character and are the descendants of an equally uniform forest. Under such conditions it seems unreasonable to expect genetics to be responsible for 48 per cent of the variation in basal area increment.

The possibility that some crowns would be inherently more efficient than others was considered by Wile (1957) who concluded that this would be rare.

Probably most important among the possible causes of the large residual variation is the failure to measure either the incident energy on the crown, or alternatively the effective receiving area of the crown. The energy incident on a crown would be affected not only by the crown's gross position in slope and aspect, but also by its position with respect to its competitors. For instance, an especially tall neighbour to the south would greatly reduce the amount of energy incident on a tree, or the crown area or crown volume, which is available to receive this energy. Attempts to approximate this effect by using the distance to the nearest neighbour to the south were unsuccessful in the present study.

Although an equation has been developed which will predict basal area increment with reasonable precision, unexplained variation remains. Better results will probably be obtained with data for a ten-year period. However, it is apparent that no one factor can be accepted as controlling the rate of basal area growth in immature balsam fir. As to the combination of factors which control growth, crown width, crown length and competition are important, but the conclusion is reached that not all the critical factors have been measured. To increase the understanding of tree growth and appreciate how it may be best controlled silviculturally requires more knowledge of the effects of root competition and better methods for determining crown size particularly in the third dimension.

SUMMARY

A study of the response of 40- to 50-year-old balsam fir to four levels of crown release, 1 to 3, 3 to 5, 5 to 7 feet, and a control, was carried out at Green River, New Brunswick, between 1953 and 1958. The treatment led to increased basal area growth, but the degree of release had relatively little influence on the rate. The relationship of increment to various intrinsic and extrinsic factors was examined and basal area increment was found to be related to initial breast height diameter, crown width and a derived competition factor, but much variation is unexplained. An equation for predicting basal area growth is presented and a discussion of the possible factors contributing to the unexplained variation is given.

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