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Stand Basal-Area and Tree-Diameter Growth in Red Spruce-Fir Forests in Maine, 1960–80

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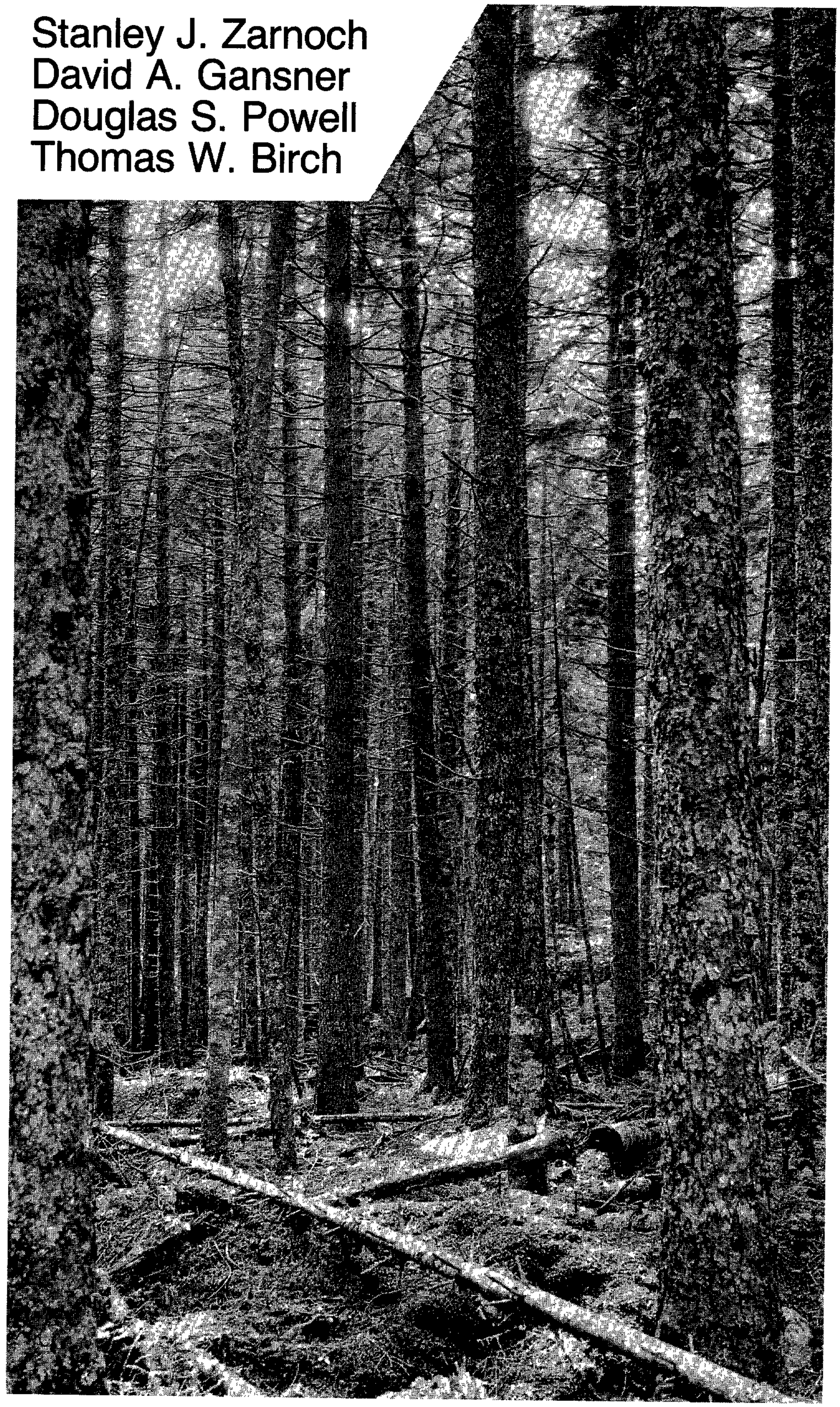

Abstract

Stand basal-area change and individual surviving red spruce d.b.h. growth from 1960 to 1980 were analyzed for red spruce-fir stands in Maine. Regression modeling was used to relate these measures of growth to stand and tree conditions and to compare growth throughout the period. Results indicate a decline in growth. The regression models helped identify trends and relationships but were not useful for predicting growth due to the tremendous amount of variability in the growth of red spruce-fir stands.

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Introduction

Recent interest in the effect of pollution, particularly acid rain, on the growth of forests around the world and specifically on red spruce decline in the northeastern United States (Siccama et. al 1982, Scott et. al 1984, Vogelmann et. al 1985) has been emphasized by the initiation of the National Acid Precipitation Assessment Program (NAPAP). The Forest Response Program (FRP), a jointly funded and co-administered initiative by the Environmental Protection Agency and USDA Forest Service, is part of NAPAP and is responsible for addressing the following three policy questions:

1. Is there a significant problem of forest damage in North America that could be caused by acidic deposition alone or in combination with other pollutants?

2. If so, what is the causal relationship between acidic deposition alone or in combination with other pollutants, and forest damage in North America?

3. If there is a causal relationship, what is the dose-response relationship between acidic deposition alone or in combination with other pollutants, and forest damage in North America?

This paper is related directly to policy question 1 and indirectly to policy question 3 for the red spruce-fir forests of Maine which are primarily of low elevation and used for commercial timber products.

For policy question 1, we assessed growth in two periods, the 1960's and the 1970's. First, we defined what is meant by "growth". Since red spruce-fir forests consist of all-age, multi-species communities of trees, we had to decide what to measure. One can measure growth at the tree level and stand level. At the tree level, growth may be analyzed as diameter growth, basal-area growth, volume growth, or height growth on a species basis. At the stand level, one may use basal-area growth, quadratic-mean stand diameter growth or volume growth for the entire stand, or any one of these measures for a specific species. In this research, we analyzed surviving red spruce-tree diameter breast height (d.b.h.) growth and net change in total stand basal area. No attempt was made to relate growth changes to pollution, but the analysis does give an indication of the temporal and spatial variability that may be expected under the stand conditions and natural factors operating at the time. The analysis which included individual tree d.b.h. growth was only for red spruce trees that survived. It did not consider other species in the stand, or ingrowth, or trees that died. It was hoped that this measure would be related usefully to the numerous tree-core analyses that have been conducted recently (Hornbeck and Smith 1985, Van Deusen 1987).

For policy question 3, the potential of modeling tree d.b.h. growth and net change in total stand basal-area was analyzed as a function of stand attributes. Typical regression techniques were used, and simplicity of models was an important criterion. The objective was to define structural correlation patterns between growth and stand variables, and to evaluate the potential for predicting growth in these very heterogeneous stands. If successful, it could help lay the groundwork for the development of dose-response models for the effect of acidic deposition on red spruce-fir forests.

Thus, three specific objectives were to:

1. Estimate stand basal-area change and variability during the 1960's and 1970's by geographic units of Maine (Fig. 1).

2. Estimate individual surviving-tree d.b.h. growth and variability of red spruce by geographic units of Maine during the 1960's and 1970's.

3. Develop empirical models by using correlation and regression methodology to isolate important variables and formulate pertinent models for stand basal-area change and individual surviving-tree d.b.h. growth.

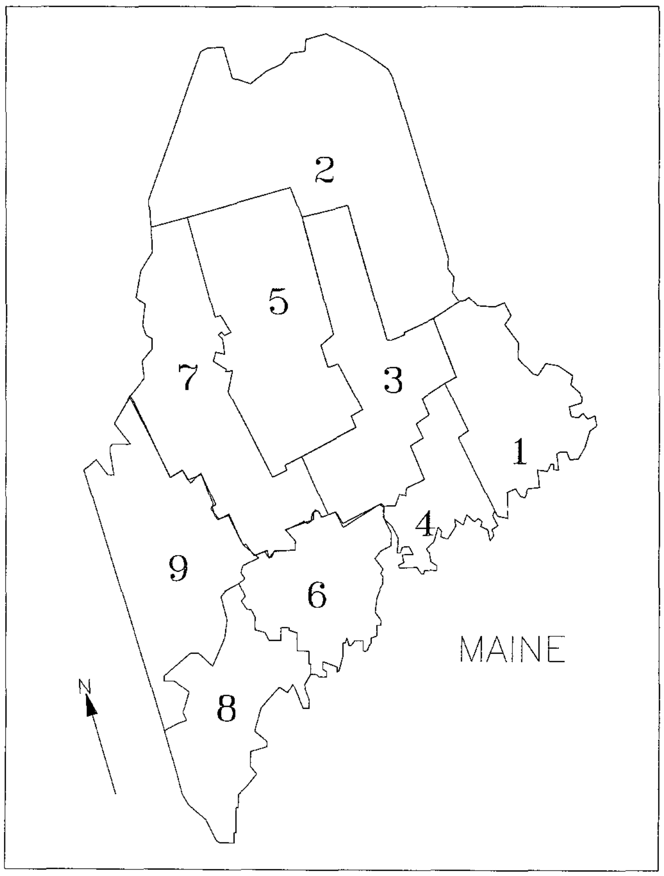


Figure 1.—Geographic units used in the Maine FIA inventory.

Data

The data consist of a subset of a larger data base developed by the Forest Inventory and Analysis (FIA) work unit of the Northeastern Forest Experiment Station for inventories of Maine's forest resources for 1960 (Ferguson and Longwood 1960), 1970 (Ferguson and Kingsley 1972), and 1980 (Powell and Dickson 1984). The exact dates of the field measurements span several years for inventory 1 (1954-58), inventory 2 (1968-70), and inventory 3 (1980-82). Hence, for analysis, two growth periods were available with interval lengths averaging 11.3 and 11.6 years, respectively. The data base originally consisted of 835 plots that contained 0.10 and 0.20 acres and, based on cubic-foot volume classes, represented a stratified random sample of Maine.

The focus of the present study was specifically on typical red spruce-fir stands unthinned during this period; thus, restrictions similar to those of Solomon and others (in preparation) were used as criteria in selecting plots for study. First, the percentage of softwood species' basal area at inventory 1 would be at least 65 percent (note that no restriction was imposed for the other inventories). Second, the plot had to show no human disturbances throughout both growth periods. Also, plots that were thinned with only a few trees left standing were deleted from the analysis if at inventory 1 their basal area was less than 75 square feet per acre and their quadratic-mean stand diameter was greater than 8.0 inches or their basal area was less than 75 square feet per acre and the number of trees was less than 75 per acre. Last, the percentage of the red spruce basal area on a plot at inventory 1 had to be at least 10 percent. The results of these restrictions yielded 87 plots that were measured at all three inventories. The distribution of the plots by basal area, quadratic-mean stand diameter, proportion of softwood per basal area, trees per acre, and elevation is shown in Table 1.

Analysis of Stand Basal-Area Change

Annual plot basal-area change (square feet/acre) was analyzed based on 87 unthinned red spruce-fir plots measured over two growth periods. The results shown in Table 2 indicate that mean plot basal-area change decreased from 2.29 square feet/acre during growth period 1 to 1.29 square feet/acre in growth period 2, reflecting a 44 percent reduction. Basal-area change rates, by geographic unit, reveal for growth period 1 means ranging from 1.26 (Unit 6) to 3.62 (Unit 7) and for growth period 2, 0.26 (Unit 6) to 2.12 (Unit 7). Despite the spatial variability and temporal change which are confounded by varying stand conditions, it is important to note that all units declined in average plot basal-area change during growth period 2. Further insight is shown by the empirical cumulative distribution function of basal-area change for the growth periods (Fig. 2). For example, only 3 percent of the plots showed a negative growth in period 1 while 20 percent had negative growth for period 2. These empirical cumulative distribution functions are useful for indicating maximum potential change; for example, only 5 percent of the stands grew more than 4.5 square feet/acre per year during growth period 1.

Analysis of Surviving-Tree Diameter Growth

Annual tree d.b.h. growth (inches) was analyzed by extracting from the 87 unthinned plots all red spruce trees that had survived through at least one entire growth period. Hence, because of ingrowth and mortality, the same trees were not used in the analysis for both periods. The results (Table 3) show that annual d.b.h. growth decreased from 0.091 to 0.076 inches between the periods, a 16 percent decline. Seegrist and Arner (1982) found similar annual d.b.h. growth during growth period 1 in their analysis of the FIA data, though their data base was somewhat different from the FIA data base due to the restrictions imposed. By geographical unit, the means ranged from 0.059 (Unit 3) to 0.158 (Unit 6) for growth period 1 and 0.051 (Unit 3) to 0.133 (Unit 6) for growth period 2. Diameter growth declined during growth period 2 in all units except 2 where it remained virtually constant. The empirical cumulative distribution function (Fig. 3) illustrates clearly that although the diameter growth distribution is basically identical for the growth periods at its lower tail, it is extremely skewed to the upper tail during growth period 1; that is, there is a greater proportion of faster growing trees.

Modeling

Stand Basal-Area Change

The objective of our modeling effort was to develop an empirical prediction equation for annual stand basal-area change as a function of stand characteristics. The key variables commonly used to predict growth for most forest types are age, site index, and density. However, for these red spruce-fir forests, age and site index are not valid predictors since the age of most stands was indeterminate and soil was so variable that measures of site index were meaningless. Thus, to develop the basal-area model where

BAC = annual basal-area change (square feet/acre),

we used five stand variables that were measurable:

BA = initial stand basal area (square feet/acre) at the beginning of the growth period,

QM = initial quadratic-mean stand diameter (inches) at the beginning of the growth period,

PSW = initial proportion of the plot basal area which is in softwood species at the beginning of the growth period,

NT = initial number of trees per acre at the beginning of the growth period, and

ELEV = elevation (feet) of the plot.

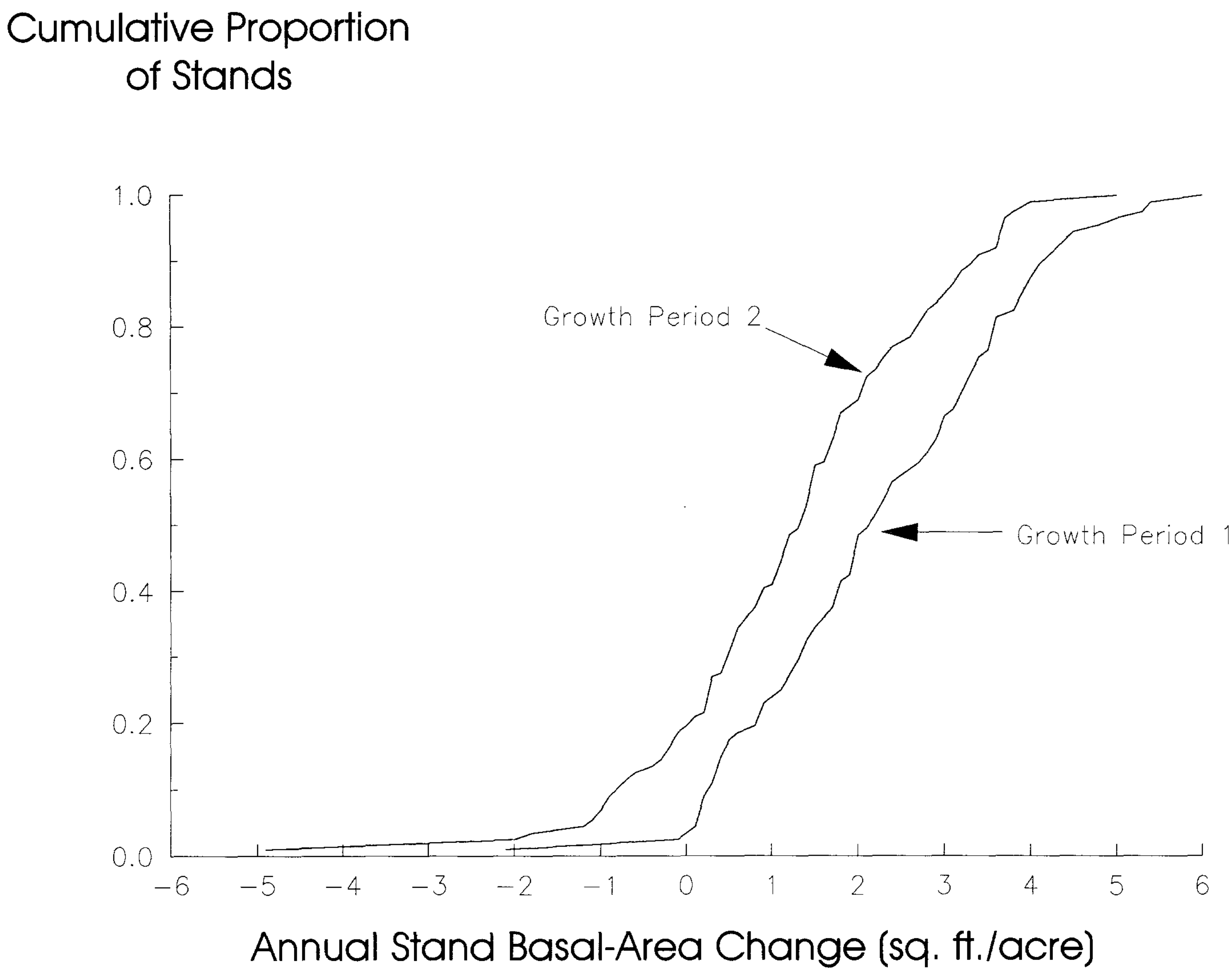


Figure 2.—Empirical cumulative distribution function of annual stand basal-area change (square feet/acre).

This set of variables is similar to that used by Solomon and others (1986, and 1987) for predicting red spruce growth using a matrix projection model. The first step in developing a growth model was to determine the relationship between basal-area change and each of the five stand variables. Graphs are shown in Figure 4 for growth period 1 and in Figure 5 for growth period 2. They indicate very little trend and a considerable amount of variation. Initial basal area and quadratic-mean stand diameter appeared to show significant correlations with basal-area change for both growth periods. Elevation was significantly correlated with basal-area change in growth period 1 but not in growth period 2, though the correlation was positive in both. All other stand variables indicated little promise as potential predictors. Also, no linearizing transformations were identified. However, all possible models of these five basic stand variables were examined to check predictive potential of various combinations of variables. There are a total of 31 models consisting of all combinations of the five variables. Upon examining each of these models and their associated fit statistics, R^2 and mean square error, the basal-area and elevation model appeared to be at least as good as any other for both growth periods and, because of its simplicity, was selected as an appropriate model to predict basal-area change. Thus, the model for growth period 1 was

$$BAC = 2.283 - 0.00887*BA + 0.00100*ELEV$$
with $R^2 = 0.15$ and $MSE = 2.04$

and for growth period 2

$$BAC = 2.292 - 0.01382*BA + 0.00067*ELEV$$
with $R^2 = 0.12$ and $MSE = 2.33$

and all parameters were significant at the 0.05 level.

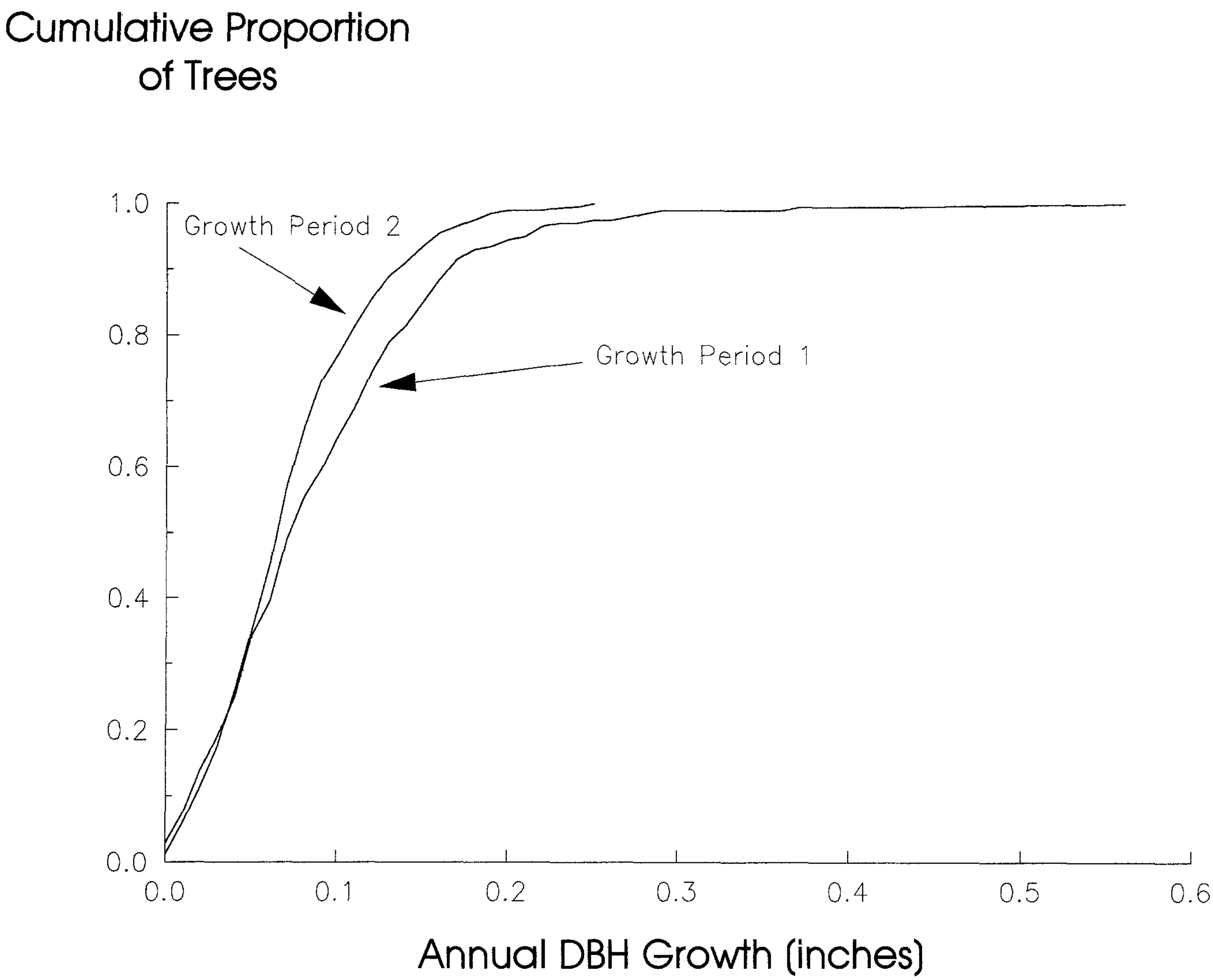


Figure 3.—Empirical cumulative distribution function of annual d.b.h. growth (inches).

Further improvements in the models were attempted by analyzing all two-way interactions of the five basic stand variables. Since the number of potential models for each growth period was then 32,767, it was not feasible to fit all models. Thus, the STEPWISE and RSQUARE procedures were used in SAS (SAS Institute Inc., 1985) to select the best possible models. The fit statistics of the newly created models, though, were similar to the previous two-variable models but were more complex, so these new models were rejected from further consideration.

A graph of the annual basal-area change models is illustrated in Figure 6. Growth decreases the larger the basal area, as expected, but growth increases the higher the elevation, up to 2,000 feet. Growth in period 1 is more influenced by elevation than growth in period 2 which is more affected by basal area. Hence, there appears to be a change in the growth relationship between the two growth periods.

To further evaluate the predictive ability of the models, several fit statistics were calculated to show how well the model could predict the data from which it was developed (Table 4). As expected, the bias of each model is zero since the bias is a function of the sum of residuals from a regression model. The absolute bias is of more interest because it expresses the amount one may expect the predicted basal-area growth to differ from the true observed value. This error amounted to approximately 1 square foot for both growth periods and represented a 48- and 92-percent error rate for growth periods 1 and 2, respectively. In addition, the percent bias and percent absolute bias are quite large. However, they must be interpreted with caution since they can be inflated by very small observed values. These statistics indicate that the predictability of the models is quite low due to variability inherent in the red spruce-fir data.

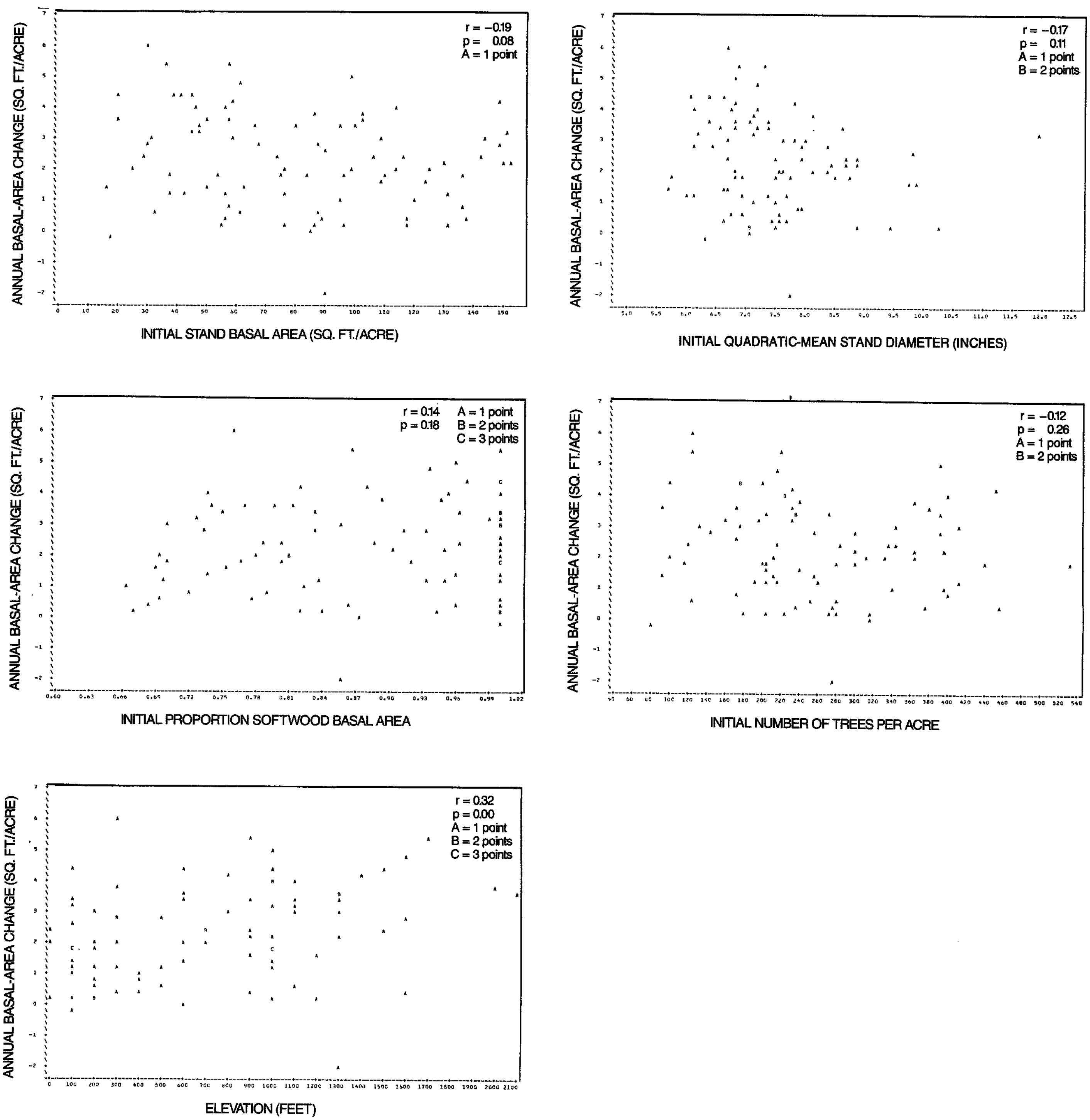


Figure 4.—Relationship of annual basal-area change (square feet/acre) and initial stand conditions in growth period 1. The correlation coefficient, r, and its associated p-value are given.

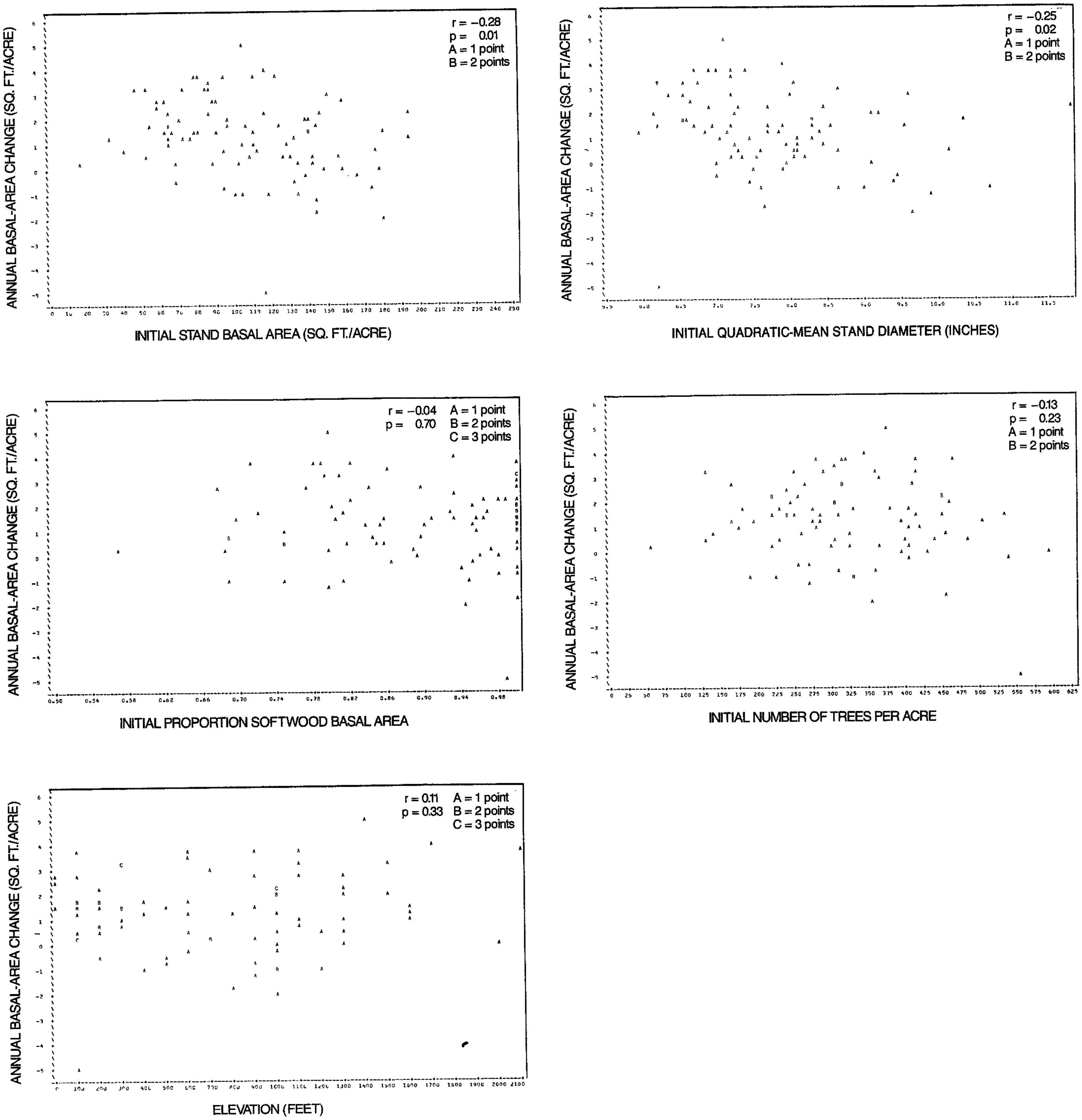


Figure 5.—Relationship of annual basal-area change (square feet/acre) and initial stand conditions in growth period 2. The correlation coefficient, r, and its associated p-value are given.

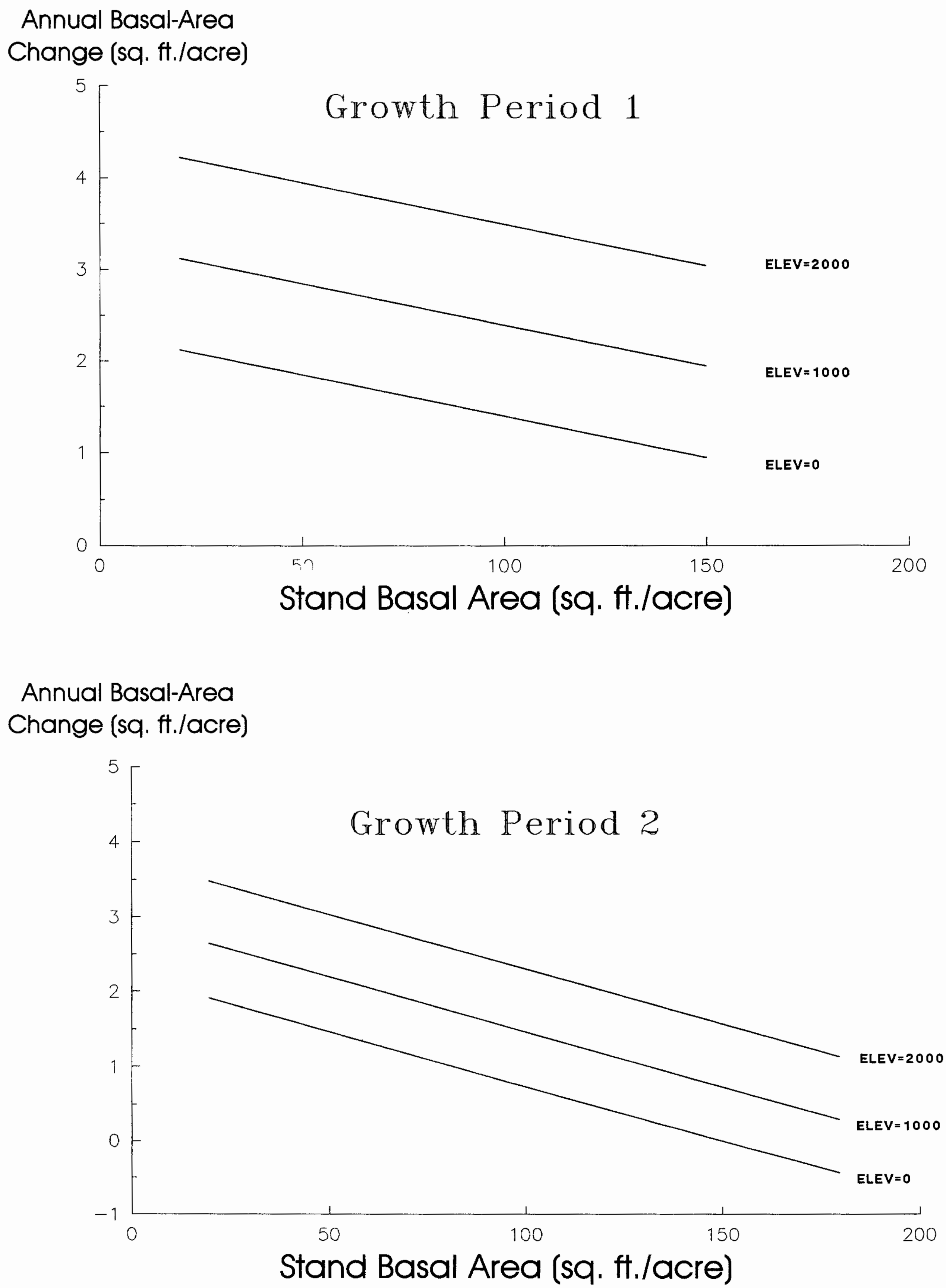
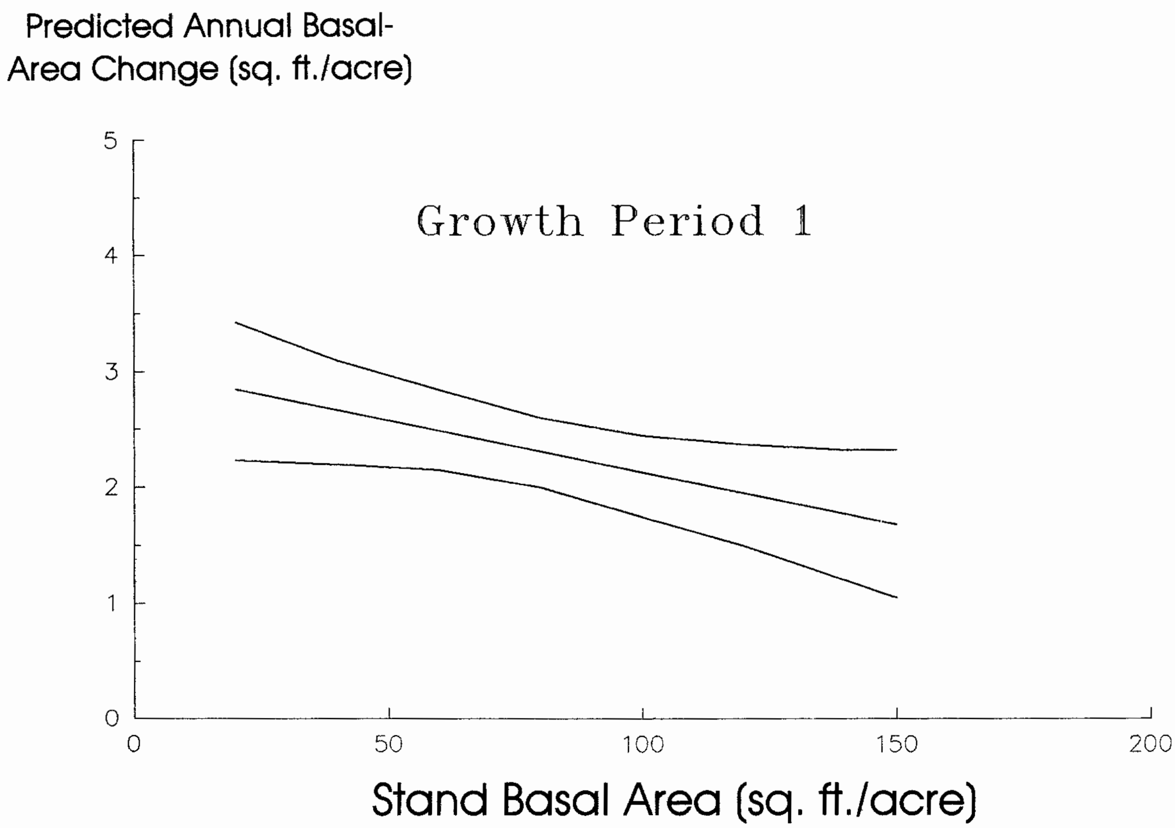


Figure 6.—Plot of the basal area growth-prediction equation relationships.



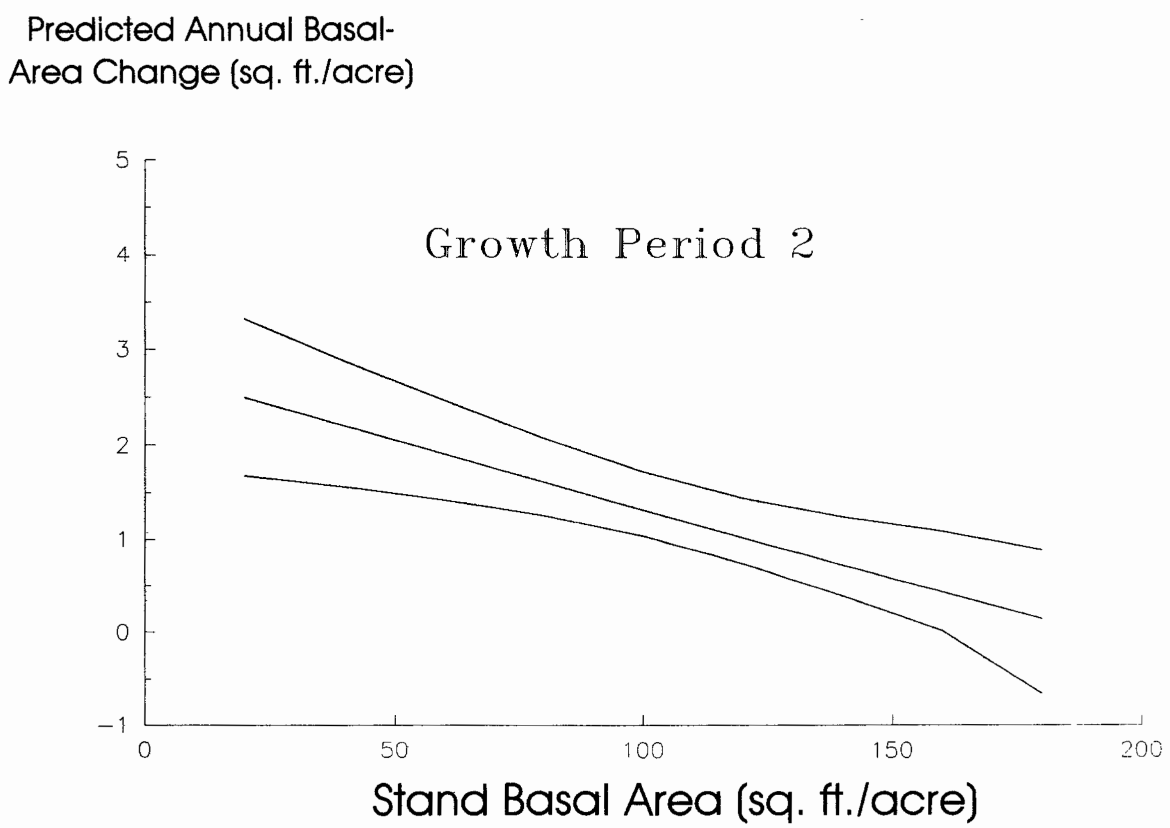


Figure 7.—Confidence intervals (95 percent) on the mean predicted annual basal-area change (square feet/acre) when elevation is kept constant at the mean of 724 feet.

The R^2, mean square error, and fit statistics provide criteria for model evaluation, but it is still important to analyze the variablility in prediction. To further address the issue, confidence intervals on the predicted mean response at various points in the sample space of the independent variables were developed (Fig. 7). The intervals, too, reveal that the models are not useful for predicting growth since the intervals are quite wide. They may, however, be useful in relative trend comparisons.

Surviving-Tree Diameter Growth

The approach in selecting a model for annual surviving-tree d.b.h. growth was similar to that used for annual basal-area change; that is, the relationships between diameter growth and the five stand variables were determined. Individual tree d.b.h. was included as a potential predictor. Graphic plots of d.b.h. growth and the six variables indicated little linear relationship and a considerable amount of variation. However, all variables except ELEV revealed a highly significant correlation (Table 5). No linearizing transformations were identified. Again, all possible models of the six basic variables were examined, yielding a total of 63 models. STEPWISE and RSQUARE procedures also were performed on the six basic stand variables and their two-way interactions. Results indicated that the variables NT and PSW were important since they were continuously selected as candidates in the best models formulated by the variable selection procedures. Conceptually, it seemed reasonable to include d.b.h. as a predictor; it was a highly significant candidate in the variable selection procedure for growth period 2. The final model selected for growth period 1 was

$$DBHG = 0.197 - 0.0948*PSW - 0.000122*NT + 0.00237*DBH$$

with $R^2 = 0.09$ and $MSE = 0.034$

and for growth period 2

$$DBHG = 0.129 - 0.0550*PSW - 0.000097*NT + 0.00436*DBH$$

with $R^2 = 0.15$ and $MSE = 0.015$

and all parameters were significant at the 0.01 level. The magnitude and sign of all parameters are consistent for both growth periods and are biologically sensible and interpretable.

Trends of the annual tree d.b.h. growth models are shown in Figure 8 where 70 and 100 percent softwood stands are illustrated over three density ranges (NT = 100, 300, 500). D.b.h. growth increases the larger the diameter of the tree, and the slope of this relationship is greater for growth period 2. Diameter growth decreases with increasing tree density which is an expected trend in stand development. Growth also declines as softwood percentage in the stand increases. This may be attributable to the tendency of softwood species to dominate the poorer sites; so, as the softwood proportion increases, site quality and, consequently, growth decline.

The fit statistics for the model indicate that once again, it is relatively poor for predicting growth (Table 6). As expected, the bias is zero but the absolute bias represents an error rate of approximately 50 percent when compared to the mean observed value in each growth period.

Temporal Growth Change

Stand Basal-Area Growth

Stand basal-area growth change was assessed by comparing growth during growth periods 1 and 2. Actual basal area growth was 2.29 square feet/acre and 1.29 square feet/acre for periods 1 and 2, respectively, representing a 1.00 square foot/acre decrease. This decrease may be due to changing stand conditions, the spruce budworm infestation during the second period, or pollution. Because stand conditions, such as density, are known to affect growth rates, any temporal comparison should adjust growth for these conditions. Such growth relationships are described with the previously formulated regression growth models and it is postulated that they describe growth during these two growth periods. Hence, to adjust the growth rates for varying stand conditions, growth, during growth period 2, was projected by using the initial stand conditions at period 2 and the basal-area change equation that describes growth in period 1. Here it is assumed that if the growth relationship has not changed in growth period 2, then the model from growth period 1 should be unbiased in describing the observed growth in period 2. The results were that growth was 2.06 square feet/acre during period 2 when the growth relationship for period 1 was used while the observed was 1.29 square feet/acre. This is a difference of 0.77 square foot/acre with a 95 percent confidence interval of 0.70 to 0.83 square foot/acre, indicating a significant difference in net change after adjusting for stand conditions based on the relationships in growth period 1.

Surviving-Tree Diameter Growth

Similar analyses were performed for tree d.b.h. growth. Originally the growth was 0.0911 inches and 0.0759 inches for periods 1 and 2, resulting in a change of 0.0152 inches. Recall that the models for diameter growth were functions of stand and tree characteristics through PSW, NT, and d.b.h. After adjusting the growth in period 2 by the growth model in period 1, the d.b.h. growth was 0.0820 which resulted in a difference of only 0.0061 inches compared with 0.0759 inches in period 2. The 95 percent confidence interval is 0.0051 and 0.0071, indicating a significant difference in d.b.h. growth after adjusting for stand and tree conditions.

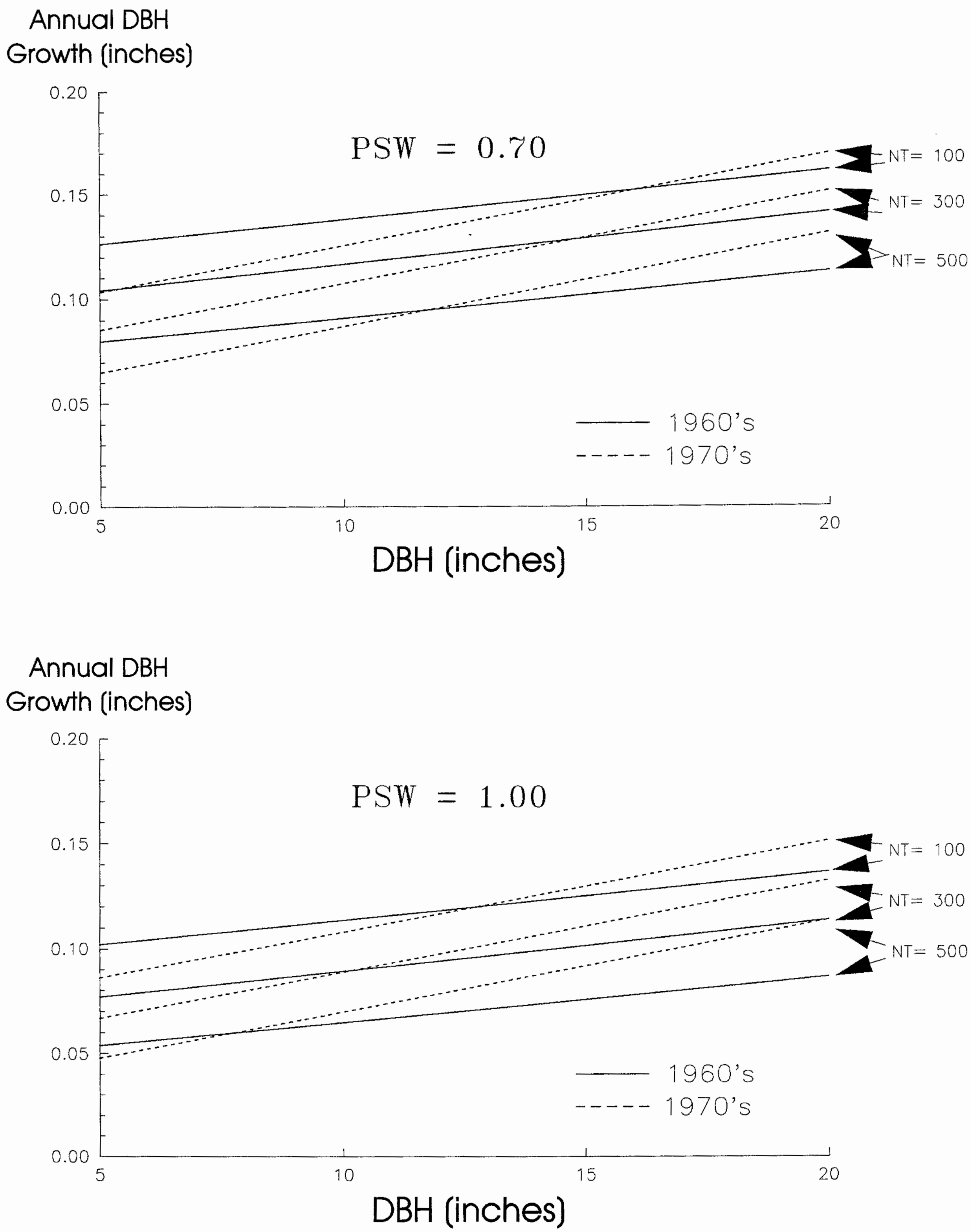


Figure 8.—Plot of tree diameter growth-prediction equation relationships.

Conclusions

- Stand basal-area change has declined from the 1960's to the 1970's, and the change is significant after adjusting for stand conditions.
- Surviving-tree d.b.h. growth has declined from the 1960's to the 1970's, and the change is significant after adjusting for stand and tree conditions.
- Although there are significant correlations between net change in stand basal area and stand characteristics, it is doubtful that conventional regression modeling techniques could yield equations useful in predicting growth because of variability in the growth of red spruce-fir stands.
- Also, despite significant correlations between tree d.b.h. growth and stand and tree conditions, regression modeling for predictive purposes yielded poor results. Possibly, an individual-tree, distant-dependent modeling approach would prove to be a more useful technique for predicting growth. This approach uses more precise information on the micro-environment of a tree and one does not have to rely on stand averages that may not be representative for an individual tree. However, the disadvantage of this approach would be the requirement of a very demanding data set and increased computer costs for model execution.

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Table 1.—Distribution of 87 remeasured red spruce-fir plots by stand characteristics at inventory 1

Stand basal area (ft^2/a)	Quadratic-mean stand diameter (inches)							
	5	6	7	8	9	10	11	Total
0–40	2	10	2					14
40–80		18	10	1				29
80–120	1	2	16	6	2	1		28
120–160			6	7	2		1	16
Total	3	30	34	14	4	1	1	87

Stand basal area (ft^2/a)	Proportion softwood per stand basal-area				
	0.65–0.70	0.70–0.80	0.80–0.90	0.90–1.00	Total
0–40		4	4	6	14
40–80	2	7	5	15	29
80–120	5	5	6	12	28
120–160	1	1	5	9	16
Total	8	17	20	42	87

Stand basal area (ft^2/a)	Number of trees per acre						
	0–100	100–200	200–300	300–400	400–500	500–600	Total
0–40	3	11					14
40–80		6	21	2			29
80–120		1	13	12	1	1	28
120–160		1	2	7	6		16
Total	3	19	36	21	7	1	87

Stand basal area (ft^2/a)	Elevation (feet)						
	0–400	400–800	800–1200	1200–1600	1600–2000	2000–2400	Total
0–40	7	2	1	3	1		14
40–80	11	6	6	2	3	1	29
80–120	8	6	8	5		1	28
120–160	4	1	10	1			16
Total	30	15	25	11	4	2	87

Table 1 (continued)

Quadratic-mean stand diameter (inches)	Proportion softwood per stand basal-area 0.65–0.70	0.70–0.80	0.80–0.90	0.90–1.00	Total
5				3	3
6	2	8	5	15	30
7	5	6	10	13	34
8		2	4	8	14
9	1	1		2	4
10			1		1
11				1	1
Total	8	17	20	42	87

Quadratic-mean stand diameter (inches)	Number of trees per acre 0–100	100–200	200–300	300–400	400–500	500–600	Total
5	1	1				1	3
6	2	9	15	4			30
7		7	10	11	6		34
8			7	6	1		14
9		1	3				4
10			1				1
11		1					1
Total	3	19	36	21	7	1	87

Quadratic-mean stand diameter inches	Elevation (feet) 0–400	400–800	800–1200	1200–1600	1600–2000	2000–2400	Total
5	2	1					3
6	12	3	8	5	2		30
7	10	10	9	1	2	2	34
8	4	1	5	4			14
9	2		1	1			4
10			1				1
11			1				1
Total	30	15	25	11	4	2	87

Table 1 (continued)

Proportion softwood per stand basal area	Number of trees per acre						
	0–100	100–200	200–300	300–400	400–500	500–600	Total
0.65–0.70			4	4			8
0.70–0.80	1	5	9	1	1		17
0.80–0.90		5	7	5	3		20
0.90–1.00	2	9	16	11	3	1	42
Total	3	19	36	21	7	1	87

Proportion softwood per stand basal area	Elevation (feet)						
	0–400	400–800	800–1200	1200–1600	1600–2000	2000–2400	Total
0.65–0.70	5	1	2				8
0.70–0.80	6	3	2	5		1	17
0.80–0.90	10	3	4	2	1		20
0.90–1.00	9	8	17	4	3	1	42
Total	30	15	25	11	4	2	87

Number of trees per acre	Elevation (feet)						
	0–400	400–800	800–1200	1200–1600	1600–2000	2000–2400	Total
0–100	1	1		1			3
100–200	10	2	3	2	1	1	19
200–300	12	5	10	7	2		36
300–400	5	7	6	1	1	1	21
400–500	1		6				7
500–600	1						1
Total	30	15	25	11	4	2	87

Table 2.—Annual stand basal-area change (square feet/acre) and mean stand initial growth-period conditions for red spruce-fir stands

Geographic unit	Growth period	Stand basal-area growth			Mean stand conditions				
		N[a]	Mean	S.D.*	BA[b]	QM[c]	PSW[d]	NT[e]	ELEV[f]
1	1	11	1.89	1.58	67	7.1	0.81	228	182
	2	11	1.31	0.92	82	7.3	0.83	275	182
2	1	20	2.09	1.23	92	7.6	0.90	288	815
	2	20	1.13	1.52	118	7.9	0.91	351	815
3	1	11	1.98	1.09	71	7.0	0.88	261	336
	2	11	0.43	2.24	95	7.3	0.88	319	336
4	1	11	1.70	1.59	73	7.6	0.86	226	173
	2	11	1.52	1.45	85	8.0	0.87	249	173
5	1	22	2.90	1.43	96	7.8	0.89	277	1045
	2	22	1.48	1.80	130	8.2	0.90	365	1045
6	1	1	1.26	—	56	6.9	0.70	215	100
	2	1	0.26	—	69	7.6	0.57	220	100
7	1	6	3.62	1.83	50	6.7	0.95	200	1500
	2	6	2.12	1.21	104	7.1	0.97	377	1500
8	1	1	1.81	—	84	8.8	0.92	200	100
	2	1	1.47	—	109	9.5	0.91	220	100
9	1	4	1.94	2.75	90	7.7	0.83	274	1725
	2	4	1.71	1.55	107	8.1	0.88	298	1725
Total	1	87	2.29	1.53	81	7.5	0.88	258	724
	2	87	1.29	1.61	107	7.8	0.89	324	724

*Standard deviation

[a]N = Number of plots used in analysis.

[b]BA = Initial stand basal-area (ft^2/acre) at beginning of growth period.

[c]QM = Initial quadratic-mean stand diameter (inches) at beginning of growth period.

[d]PSW = Initial proportion of plot basal area in softwood species at beginning of growth period.

[e]NT = Initial number of trees per acre at beginning of the growth period.

[f]ELEV = Elevation (feet) of plot.

Table 3.—Individual annual surviving-tree d.b.h. growth, and mean tree and stand initial growth-period conditions for red spruce

Geographic unit	Growth period	D.b.h. growth			Tree d.b.h.	Mean stand conditions				
		N[a]	Mean	S.D.*	Mean	BA[b]	QM[c]	PSW[d]	NT[e]	ELEV[f]
1	1	55	0.104	0.1324	7.7	71	7.4	0.79	230	197
	2	77	0.084	0.1316	7.5	81	7.3	0.84	276	202
2	1	228	0.072	0.1374	7.1	95	7.3	0.90	322	769
	2	293	0.072	0.1090	7.4	119	7.5	0.92	387	792
3	1	103	0.059	0.1346	6.3	81	6.2	0.96	394	211
	2	78	0.051	0.1464	7.0	101	6.9	0.95	391	275
4	1	118	0.128	0.2263	8.1	87	8.1	0.86	240	167
	2	122	0.118	0.1585	8.7	97	8.2	0.86	270	162
5	1	317	0.096	0.1960	7.7	107	7.8	0.92	322	1009
	2	442	0.073	0.1239	7.8	135	7.9	0.93	403	1031
6	1	3	0.158	0.0905	9.0	56	6.9	0.70	215	100
	2	3	0.133	0.0402	10.9	69	7.6	0.57	220	100
7	1	68	0.102	0.2298	6.7	51	6.7	0.97	204	1429
	2	157	0.066	0.1031	7.0	101	6.9	0.98	390	1405
8	1	7	0.138	0.2331	9.7	84	8.8	0.92	200	100
	2	13	0.097	0.1722	9.5	109	9.5	0.91	220	100
9	1	38	0.112	0.2443	6.9	94	7.8	0.84	286	1781
	2	54	0.093	0.1314	7.4	118	8.0	0.87	334	1852
Total	1	937	0.091	0.1929	7.3	92	7.4	0.91	305	767
	2	1239	0.076	0.1323	7.6	116	7.6	0.92	372	869

*Standard deviation

[a]N = Number of plots used in analysis.

[b]BA = Initial stand basal-area (ft^2/acre) at beginning of growth period.

[c]QM = Initial quadratic-mean stand diameter (inches) at beginning of growth period.

[d]PSW = Initial proportion of plot basal area in softwood species at beginning of growth period.

[e]NT = Initial number of trees per acre at beginning of the growth period.

[f]ELEV = Elevation (feet) of plot.

Table 4.—Mean values of fit statistics for annual basal-area change models based on observed (O_i) and predicted (P_i) values

Growth period	Observed	Predicted	Bias[a]	Absolute bias[b]	Percent bias[c]	Percent absolute bias[d]
1	2.29	2.29	0.00	1.11	169.3	241.8
2	1.29	1.29	0.00	1.19	63.2	232.1

[a]Bias = $(P_i - O_i) / N$

[b]Absolute Bias = $|P_i - O_i| / N$

[c]Percent Bias = $100 (P_i - O_i) / NO_i$

[d]Percent Absolute Bias = $100 |P_i - O_i| / NO_i$

Table 5.—Correlation of annual tree d.b.h. growth (inches) with tree and stand conditions. Figures in parentheses are probability values associated with testing hypothesis: correlation coefficient is zero

Growth period	Tree d.b.h.	Stand				
		BA[a]	QM[b]	PSW[c]	NT[d]	ELEV[e]
1	0.11 (0.00)	−0.07 (0.02)	0.17 (0.00)	−0.18 (0.00)	−0.24 (0.00)	0.05 (0.10)
2	0.28 (0.00)	−0.16 (0.00)	0.12 (0.00)	−0.18 (0.00)	−0.30 (0.00)	−0.06 (0.03)

[a]BA = Initial stand basal area (ft^2/acre) at beginning of growth period.

[b]QM = Initial quadratic-mean stand diameter (inches) at beginning of growth period.

[c]PSW = Initial proportion of plot basal area in softwood species at beginning of growth period.

[d]NT = Initial number of trees per acre at beginning of growth period.

[e]ELEV = Elevation (feet) of plot.

Table 6.—Mean values of fit statistics for annual diameter-growth models based on observed (O_i) and predicted (P_i) values

Growth period	N	Observed	Predicted	Bias[a]	Absolute bias[b]	Percent bias[c]	Percent absolute bias[d]
1	937	0.0911	0.0911	0.0000	0.0478	77.2[e]	105.9[e]
2	1239	0.0759	0.0759	0.0000	0.0330	54.6[f]	81.1[f]

[a]Bias = $(P_i - O_i) / N$

[b]Absolute Bias = $|P_i - O_i| / N$

[c]Percent Bias = $100 (P_i - O_i) / NO_i$

[d]Percent Absolute Bias = $100 |P_i - O_i| / NO_i$

[e]Based on N = 911 observations due to elimination of observations when Observed is zero.

[f]Based on N = 1219 observations due to elimination of observations when Observed is zero.

Zarnoch, S.J.; Gansner, D.A.; Powell, D.S.; Birch, T.A. 1990. **Stand basal-area and tree-diameter growth in red spruce-fir forests in Maine, 1960-80**. Res. Pap. NE-633. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 18 p.

Stand basal-area change and individual surviving red spruce d.b.h. growth from 1960 to 1980 were analyzed for red spruce-fir stands in Maine. Regression modeling was used to relate these measures of growth to stand and tree conditions and to compare growth throughout the period. Results indicate a decline in growth.

Keywords: stand basal-area; tree-diameter growth; red spruce; fir; Maine

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