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Polymorphic site index curves for noble fir from stem analysis data were compiled from 54 plot locations. On each plot location, the tallest dominant noble fir was felled and sectioned. Site index was based on total height and age at breast height, with index age at 100 years. A graphical test to determine if the curves are polymorphic indicated that polymorphism exists.

Polymorphic Site Index Curves for Noble Fir from Stem Analysis Data

by

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POLYMORPHIC SITE INDEX CURVES FOR NOBLE FIR FROM STEM ANALYSIS DATA

INTRODUCTION

The upper-slope coniferous species of Oregon and Washington have become commercially important in the past decade (Franklin, 1964). Low elevation Douglas-fir still is the primary source of timber for the lumber industry, but the increasing demand for wood and the diminishing supply of old growth Douglas-fir has placed greater importance on the upper-slope coniferous type.

In order to obtain information for managing the upper-slope forest complex, a cooperative study was undertaken by the U.S. Forest Service and Oregon State University in June of 1965. The study consisted of making a stem analysis of all species that are considered commercially important in the upper slope type. At present, 260 trees have been felled and sectioned, 72 of which are noble fir from 54 plot locations.

When the study was undertaken it was thought that at least three noble fir trees per plot were necessary. After the first year, the study was re-evaluated and the decision to take only the tallest dominant noble fir tree on a plot was reached. The main reason for the decision was that the noble fir range could not be covered if three trees per plot were sectioned. Obtaining a sample from the entire noble fir range is more important than a multiple sample from one location. Supporting the decision was evidence from the first year that showed the tallest dominant cut was usually the tallest or nearly the tallest tree in the past. Noble fir is less tolerant than its associates, its light requirements being nearly the same as Douglas-fir, therefore, the dominants stay dominant throughout their lives (Hanzlik, 1925). Figure 1 indicates the individual noble fir plot location from which the data for the following analysis came.

Anamorphic versus Polymorphic Site Index Curves

Site quality, as used in forestry, is defined as the capacity of a given area of land to produce wood fiber (Spurr, 1952). Site quality cannot be measured in absolute terms since environmental factors vary in an uncontrolled pattern (Spurr, 1952; Minor, 1964). Various methods of classifying sites have been used such as indicator plants, volume, and soil condition, but the most common measure of site quality is site index, the height of a stand at a given age in its development (Spurr, 1952). This index of site has been used in North America since 1917 (Vincent, 1961). One must realize that height is not a refined measure of site quality, but height is the best available indicator of site quality in stands past middle age (McLintock and Bickford, 1957).

In the past most site index curves have been anamorphic, that is, proportional curves drawn from one master curve (Bull, 1931).

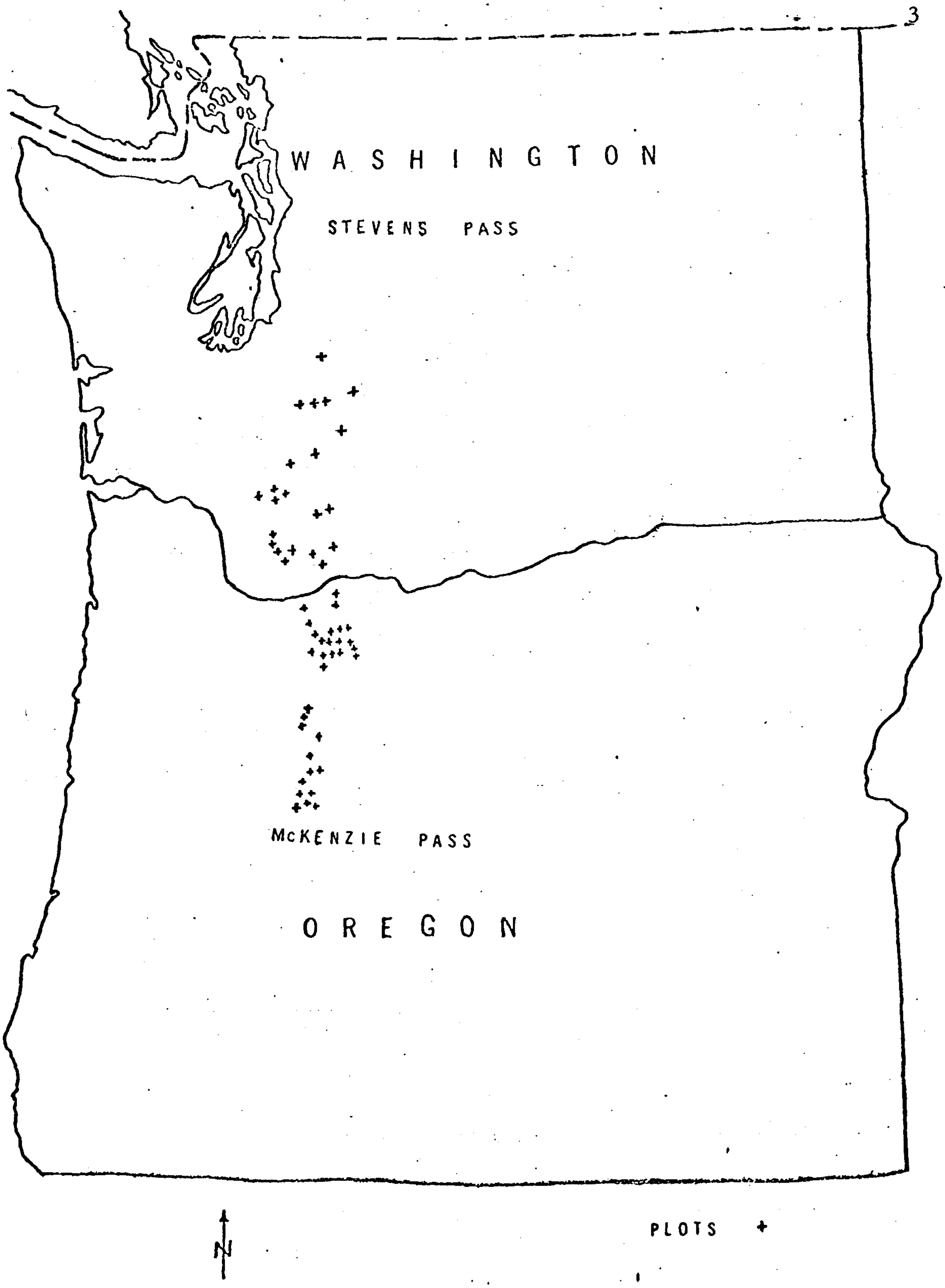

Figure 1. Noble fir plot locations

A problem with anamorphic curves is that they have the same shape for good and poor sites (Smith, Ker, and Heger, 1960). Bull (1931) found in red pine that the period of maximum height growth varied with site class. Low sites exhibited their period of maximum height growth at an older age than the high sites did. Using anamorphic curves in such a situation would probably give an incorrect estimate of site especially when estimating high and low sites. Carmean (1956) found that shapes of site curves could vary within a given site group as soil conditions changed.

Bull (1931) developed polymorphic site curves for young red pine. Polymorphic curves are curves that are not proportional to each other, i.e., they are not drawn from the same master curve (Brickell, 1966). Since polymorphic site curves do not have the same shape or trend for each site classification (Spurr, 1964), it might happen that a high site has a curvilinear relationship while a low site has a linear relationship.

In developing his curves, Bull (1931) used seven major site curves each one being based on a definite portion of the total site range. A small group of anamorphic curves was made from each major site curve and the groups were combined into one complete family of curves. The above method is similar to the one used in the following analysis.

ANALYSIS OF THE DATA

Tree Conversion

The first step in the analysis consisted of converting stem analysis data into a useable form. The initial data for site curves was total height of the section above the stump and the ring count of the section (Table I., columns a & b).

Columns "c" and "d" are results obtained by converting columns "a" and "b" into a more useable form. The method was as follows:

1. Stump height (1.3 feet) and stump ring count (358) were deleted.
2. The D. B. H. section, which is 3.2 feet above the stump section, was used as the basis for further calculations.
3. Cumulative height above D. B. H. was calculated by subtracting the 3.2 feet from the height of the section above the stump.
4. Cumulative age above breast height was calculated by taking the ring count at D.B. H. and subtracting the ring count of the section of interest. For an example, suppose one wanted to find the cumulative age at 108.1 feet above breast height.

TABLE I. Tree Data Conversion

Plot 64 — Tree Number One

a Height above stump	b Ring Count	c Cumulative Height	d Cumulative Age
1.3 (stump height)	358	---	---
3.2	349	0.0	0
21.3	331	18.1	18
39.5	321	36.3	28
57.7	313	54.5	36
75.7	304	72.5	45
92.9	292	89.7	57
111.3	275	108.1	74
129.1	252	125.9	97
147.9	219	144.7	130
165.5	176	162.3	173
182.6	122	179.4	227
194.6	81	191.4	268
201.8	50	198.6	299
208.1	30	204.9	319
211.7	16	208.5	333
213.9	7	210.7	342
215.8	0	212.6	349

Taking 349 (ring count at breast height) minus 275 (ring count at 108.1 foot section) equals 74 years.

After the conversion of the data for each tree was accomplished, a graph of each tree was made (Figure 2).

Cumulative height was plotted over cumulated age, and the points were connected by a smooth curve. Heights were then read from the curve at ten year intervals up to total cumulative age. These heights and ages that were read from the graphs are the ones used in the following analysis. The above method was used by Jones (1967) on site index curves for Aspen in the Rocky Mountains.

Index Age at 100 Years

Choosing an index age was an important decision. Three ages were considered -- 50, 100, and 150 years. One hundred fifty years was considered since it is felt after examining the stem analysis data for volume growth that 150 years would probably be closer to the upper slope species rotation age.

Fifty years was considered since the trend is toward shorter rotations and smaller trees (King, 1966).

One hundred years was chosen as the index age for three reasons:

1. It has been the conventional site index age for

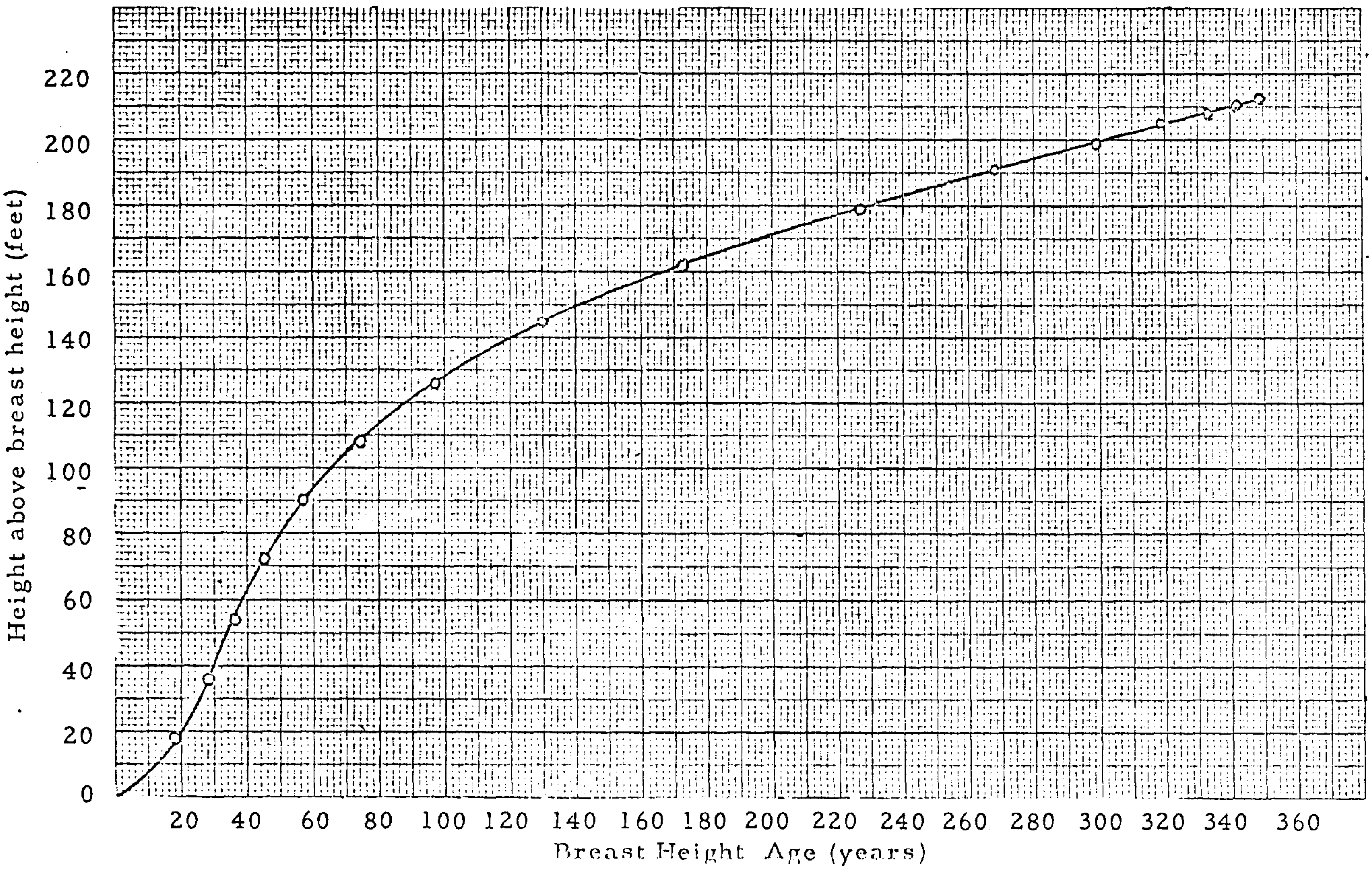

Figure 2. Individual tree curve from plot 64.

western coniferous species (Husch, 1956).

2. Since rotation length for noble fir is not known at present, an age between 50 and 150 years seemed reasonable.

3. When a tree reaches 100 years, site quality based on height is fairly indicative of the productive capacity of the land.

Composite Trees

Taking one, two, or three trees per plot caused some difficulty in the analysis of the data. The majority of the plots had only one noble fir cut and sectioned. Nine plots had two or three trees sectioned for reasons explained earlier. The question was how to analyze these nine plots so they would not receive more weight than the other plots. If all the trees on one plot were used in the analysis as separate observations, the final polymorphic index curves would be more of a reflection of the one site locality rather than the range of sites.

To solve this problem, a composite tree was made for each plot that had two or more trees. The composite tree was formed in the following manner:

1. The individual trees were compared to find the least common age, which is the age of the youngest tree.

2. For the individual trees, the arithmetic average of height was calculated for each ten year interval up to the least common age. These arithmetic averages of height determined the shape of the growth curve for the composite tree.

Another method of resolving the unequal number of trees per plot could have been to choose the tallest tree on the plot and use that as the plot tree. It was felt, however, that the composite tree was more representative of the plot site than an individual tree. A composite tree tended to have a smoother sigmoid growth curve than individual trees on the plot. Irregularities, such as snow break, false rings, and height growth variations tended to average out on composite trees.

Grouping Trees into Site Classes

The heights at site index age were classed into ten foot site classes. A frequency chart and a bar diagram (Figure 3) were made and inspected to determine whether the sample represented the range of sites.

As can be seen from the diagram the sample trees represented the range of sites but they were not normally distributed. There appears to be two ranges of heights where clustering occurs. The 80 and 90 foot classes form one cluster of observation and the 110

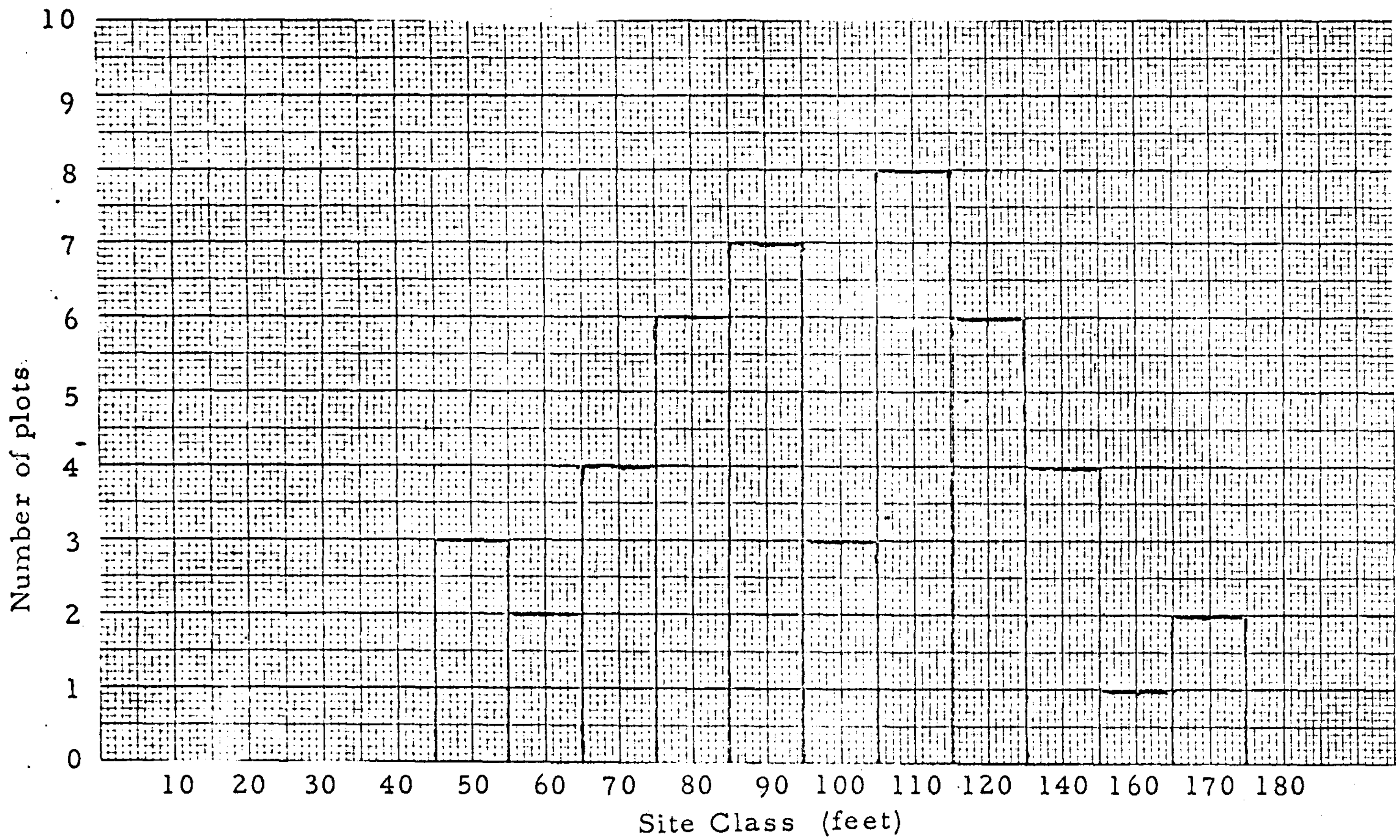

Figure 3. Site distribution at 100 years of age.

and 120 foot classes forms the other cluster of observations. The sample had few observations at the mid-range of site classes, and the observations tapered off near the high and low site classes.

With clustering of observation, a site grouping was made to take advantage of this natural grouping. Four major site classes are as follows:

1. Above 121 feet is Site I.
2. One hundred to 120 feet is Site II.
3. Seventy-nine to 99 feet is Site III.
4. Below 78 feet is Site IV.

The site groupings were not equally spaced as far as height ranges were concerned, but this was done to take advantage of the natural groupings. Also, this permitted at least nine plots in any one site.

STEPWISE REGRESSION

Equations

A stepwise regression program was used to analyze the four groups of data. The general models used are as follows:

1. $\text{Log} \quad H = a + b\,(A^{-x})$

2. $A^2/H \; = \; a + b\,(A) + c\,(A^2)$

Where:

H = Height of tree above d. b. h.

A = Age

a = Constant

b and c = Regression coefficients

x = various selected values which are

.25, .33, .50, .75, 1.0, 1.5, 2.0.

The stepwise regression indicated the best value for "x" from this group is 0.25 and this value was used in comparing the two general models. Both equations were fitted to each group of data.

Comparison of fitted values to arithmetic means of observation (Table II) provides a simple but valid method of choosing the better model. It is clear from this analysis that Model Two provides a smaller standard error of fit, with a marked advantage for all site classes. It should be noted, however, that the exponent, .25,

TABLE II. Deviations of the trial curves from the mean curves.

	Deviations (feet) $\hat{Y} - \overline{Y}$							
Age	Equation 1				Equation 2			
Years	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
10	-2.0	-0.7	-0.8	-1.2	-4.9	-2.8	-2.7	-2.7
20	1.3	1.6	0.2	-0.3	-2.6	-0.3	-2.4	-2.4
30	1.2	-0.9	-0.3	0.1	-1.1	-0.5	-1.9	-1.7
40	0.8	-3.8	-1.8	-1.2	-0.1	-0.6	-1.2	-2.5
50	-3.4	-6.7	-1.9	-2.6	0.2	-1.3	-0.6	-3.3
60	-7.3	-9.9	-2.2	-3.6	-1.6	-2.4	0.0	-3.9
70	-9.8	-9.0	-2.7	-4.0	-3.0	-2.3	0.1	-4.0
80	-9.5	-7.1	-3.8	-3.3	-3.0	-1.3	-1.1	-3.2
90	-9.1	-5.1	-3.5	-2.6	-3.7	-1.0	-1.3	-2.5
100	-6.6	-2.5	-2.1	-2.3	-3.3	-0.5	-0.9	-2.5
110	-2.7	1.4	-0.4	-1.9	-2.3	0.0	-0.8	-2.4
120	1.2	4.8	1.8	-1.3	-1.4	0.2	0.0	-2.2
130	7.2	8.5	3.8	-0.1	-0.2	0.1	0.0	-1.7
140	11.5	12.4	5.8	1.3	0.1	0.0	-0.2	-1.0
150	16.9	15.9	8.3	2.4	0.3	-0.8	-0.1	-0.8
$\sum d^2$								
	908.23	828.69	171.22	74.40	84.56	24.91	22.59	102.16
Mean deviation								
	-0.68	-0.07	0.03	1.37	-1.77	-0.90	-0.86	-2.45
Error of Fit (s_d^2)								
	64.367	59.186	12.229	3.296	5.660	1.014	0.821	0.849

used in Model One, is not optimum, so that there exists the possibility that another exponent would change the results.

It is noted in Table II and in Table V that the mean deviation of observation means from the fitted curve is non-zero for each model on each site, and that these mean deviation differ from Table II to Table V. Since the mean deviation may be interpreted as average bias over the range of ages considered, it is clear that better fits can be obtained in all cases by addition of a constant to the fitted curve which constant is equal to the mean deviation for each case. Thus it is appropriate, that model comparisons be made in terms of standard deviation of the deviation of fit.

Formula Refinement

With the final formula model chosen, the next step was the solving and refinement of the individual site equations. The criteria for grouping the data into major site classes are the same as those used in choosing the formula model except two additional ones were established. They are the following:

1. All trees under 150 years were discarded.
2. All points up to 250 years on the remaining trees were included in the analysis. Any points with ages over 250 years were eliminated.

Limiting the data to the 250 year range and discarding the young trees avoided the problems that might occur when the data does not represent a true sample for all ages. As pointed out by Curtis

(1964) site curves can be distorted if the older trees happen to have a lower average site index than the younger trees. Curves based on such data would overestimate site at the older ages. Estimates of site at younger ages would probably be valid but estimates of site at the older ages would be unreliable.

One disadvantage these restrictions have is that the curves are automatically limited to 250 years unless extrapolation is used. Another disadvantage is that the final curves are based on a limited number of trees.

The stepwise regression was used again to solve the individual site equations for the "a", "b", and "c" coefficients. Solving the equations for heights at various ages and plotting the curves showed that the major site curves for groups I and II crossed around 20 years of age. This was not critical for the curves are designed to rate sites when the trees are 30 years or greater, but the cross-over is unrealistic in site prediction. Therefore, the equations were inspected to see what coefficient had the most influence at the younger ages. In the equation $A^2/H = a + b\,(Age) + c\,(Age)^2$ it was noticed that the constant "a" had the most influence at ages under 20 years. If the value of the constant in the group equations varied greatly and in no predictable pattern, the crossing of the site I and site II curves or any other curves could occur at the lower ages. This is exactly what happened with the cross-over in question. The site I group had and appreciably larger constant than the site II group. In solving the equations for height, this difference in the constants caused the site I group to have a lower height value than site II.

To straighten out the curves for the lower ages the formula was changed into the following form:

$$3. \quad A^2/H - 14.94 = b(Age) = c\ (Age)^2$$

The 14.94 value is the wieghted mean average of the constants from the four site group equations. Using equation three in a step-wise regression and forcing the equation to have an intercept of zero changed the "b" and "c" coefficients very little. Solving the new equations for heights at various ages and comparing them with the heights from the previous equations showed that the only real change in height values were at the lower ages. The height values from 30 to 250 years did not change more than three-tenths of a foot.

Final Equations

The final equations for the four major site groupings are as follows:

Site Group I

$$A^2/H - 14.94 = .20781\ (A) + .00412\ (A)^2$$

Site Group II

$$A^2/H - 14.94 = .34745\ (A) + .00436\ (A)^2$$

Site Group III

$$A^2/H - 14.94 = .56086\ (A) + .00476\ (A)^2$$

Site Group IV

$$A^2/H - 14.94 = 1.0209\ (A) + .00507\ (A)^2$$

In the above equation A = age and H = height above stump. A table of the root residual mean square follows.

TABLE III. Statistical values for site equations.

Site Group	The root residual mean square ("a" = 14.94)	The root residual mean square ("a" is variable)
I	12.4682	12.4783
II	11.3878	11.3187
III	20.0700	20.0665
IV	41.7765	41.8739

The four equations were solved for heights to the nearest one-hundredth foot at ten year intervals of age. Four and one-half feet was added to each value of height to get the total height of the tree. The total heights are plotted over d. b. h. age in Figure 4.

According to King (1966):

> The use of age at breast height . . . is more convenient and accurate than total age as the independent variable in site measurements. When total age is to be derived from breast-height counts, the years to add varies with site quality and a number of other conditions related to stand history. These conditions are not usually known. The use of preliminary estimates of site to get age subjects site index to needless chance of error. Such difficulties are avoided by using b. h. (p. 8)

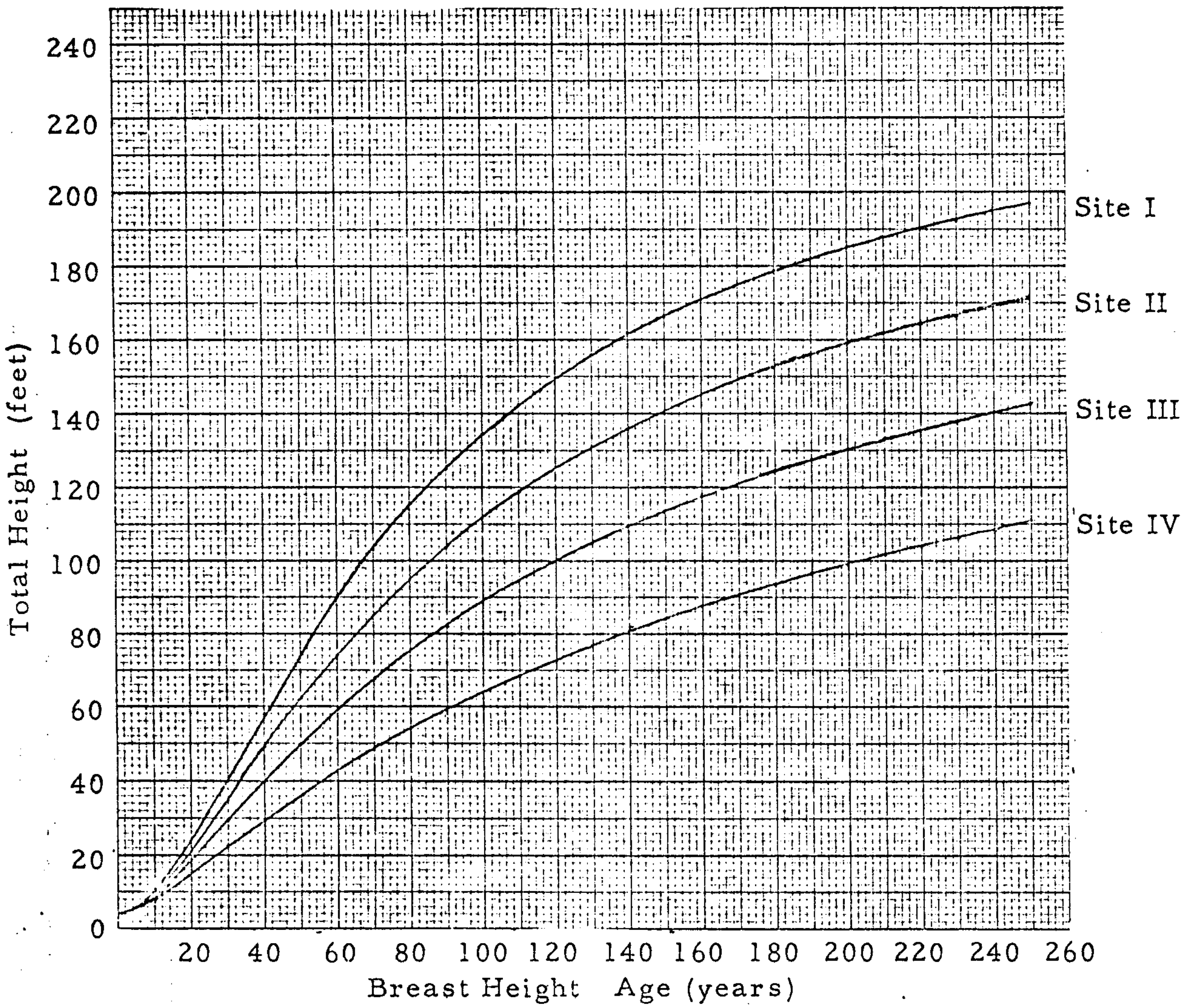

Figure 4. Major site curves.

Husch (1956) was one of the first in America to suggest the use of breast height age in site curves. Gilmore (1968) used breast height age in his site index curves for white pine in Illinois. Others have also used breast height age as their reference point.

Goodness of Fit

The final curves were compared to their respective mean curves to determine the goodness of fit. Table IV gives the standard deviation of the population at specified ages.

TABLE IV. Standard deviation of the population at specific ages.

Age (years)	Site I	Site II	Site III	Site IV
50	13.7	11.0	12.2	12.2
100	12.1	6.4	5.0	11.8
150	15.4	7.8	6.5	11.1
200	13.1	9.1	10.1	11.5
250	16.5	8.6	15.6	11.6

Table V gives the individual deviation of the final curves from the mean curves. Site II has the largest error of fit and Site III has the lowest error.

Figures 5 and 6 are graphical representations of the mean curves and the final curves with the population standard deviations from Table IV originating from the mean curve.

TABLE V. Deviation of the final curves from the mean curves.

	Deviations (feet) $\hat{Y} - \bar{Y}$ Equation 3			
Age Years	Site I	Site II	Site III	Site IV
10	-4.3	-2.8	-1.8	-2.2
20	-1.2	-1.1	-0.8	-1.8
30	0.9	-2.5	-0.5	-1.0
40	1.8	-3.7	-0.3	-2.5
50	1.8	-5.3	-0.4	-3.6
60	-0.7	-6.8	-0.4	-4.5
70	-2.7	-6.7	-0.9	-4.4
80	-3.1	-5.4	-2.4	-4.1
90	-4.3	-4.5	-2.9	-3.4
100	-4.3	-3.3	-2.6	-3.4
110	-3.7	-2.0	-2.3	-3.2
120	-2.9	-0.8	-1.5	-2.9
130	-1.9	0.0	-1.4	-2.3
140	-1.7	0.8	-1.2	-1.3
150	-1.6	1.0	-0.9	-0.9
160	-1.6	1.8	-0.8	-0.9
170	-1.9	1.7	-0.8	-0.7
180	0.9	1.9	-0.2	-1.0
190	1.1	1.9	-0.1	0.7
200	0.1	1.3	-0.6	0.4
210	0.8	1.0	-0.4	0.2
220	0.4	0.3	-0.5	-0.6
230	-0.6	-2.8	-1.6	-1.4
240	-2.0	-3.2	-0.2	-2.4
250	-3.0	-3.7	-0.9	-2.9
$\sum d^2$	135.11	262.69	43.74	153.26
Mean deviation	-1.348	-1.716	-1.063	-2.003
Error of fit (s_d^2)	3.737	7.879	0.645	2.208

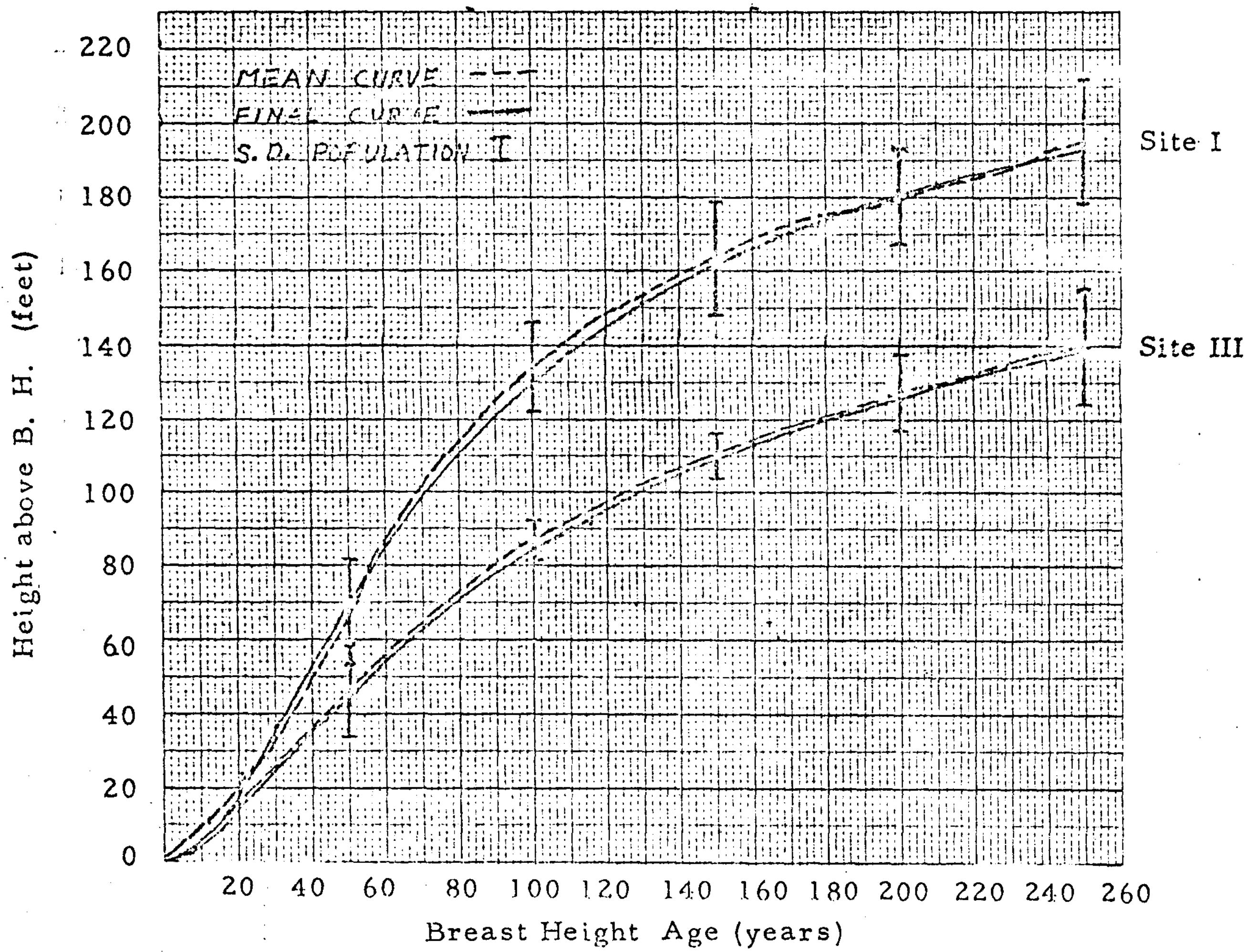

Figure 5. Graphical comparison of final curves with mean curves (Sites I and III).

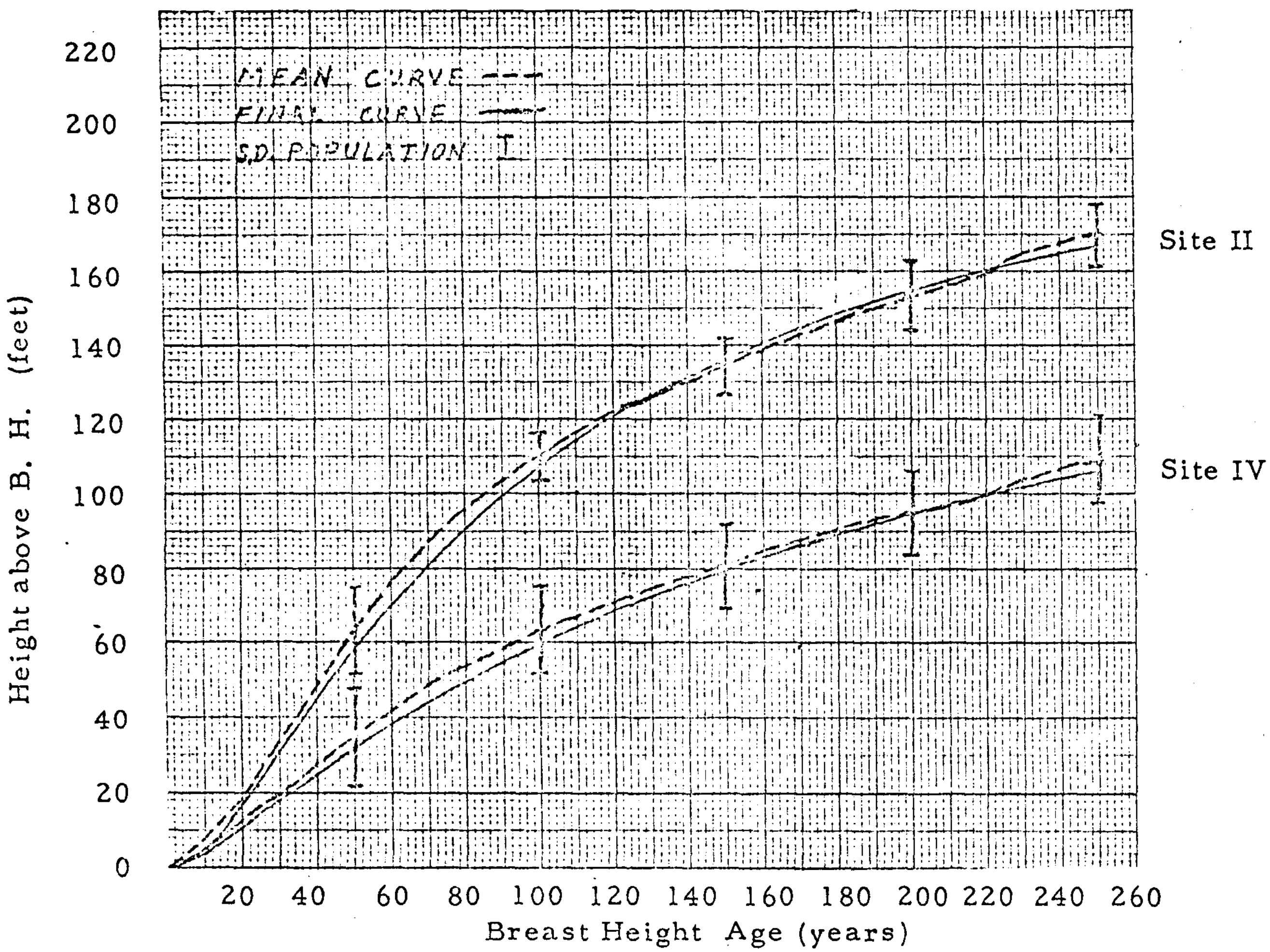

Figure 6. Graphical comparison of final curves with mean curves (Sites II and IV).

Test for Polymorphism

A graphical approach was used to test for polymorphism among the four major curves. The test proceeded as follows:

1. The site one curve was chosen to be the reference curve.
2. The height of each curve (except site one) at the index age was divided into the height of the site one curve at the index age.
3. Each value of height on each individual curve was multiplied by the corresponding ratio that was obtained in step two.
4. The height values obtained in step three were plotted over age which is shown in Figure 7.

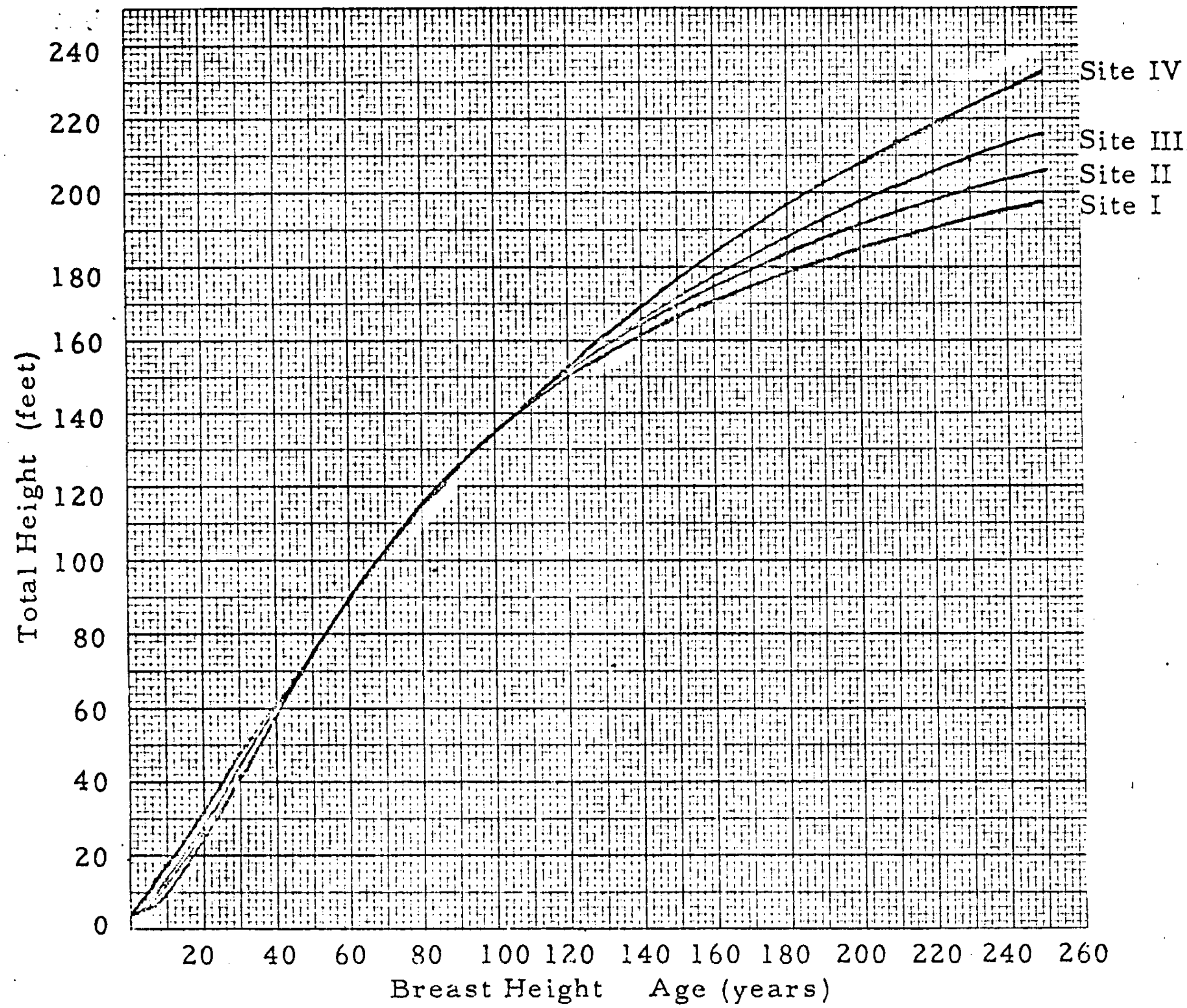

Figure 7. Test for polymorphism.

As can be seen from the graph, the four site curves almost coincide at ages under 110. At ages 110 or higher, there is increasing differences among curves. There is a definite pattern in these differences as can be seen from Figure 7. If the curves were anamorphic (proportional), they would deviate very little from each other when the above graphical test is applied. The curve differences could be sampling error, but this is not likely since they have a distinct pattern in the differences.

Site IV is greater than site III, site III is greater than site II, and site II is greater than site I. This pattern is similar to what Bull (1931) found to be true in red pine, i.e., low sites grow at an almost constant rate over time. The low site curve does not flatten out as much as a high site curve.

Developing Ten Foot Interval Curves

The construction of the final family of curves was similar to Bull's (1931) method for red pine except for a few variations. A ten foot interval at site index age was desired between index curves, where as Bull's (1931) were at one foot intervals. The method of constructing the index curves from the major curves also deviates from Bull (1931).

The index curves range from 50 feet to 160 feet at index age 100. The 50 and 60 foot curves are anamorphic curves obtained from the site IV master curve. Likewise, the 140, 150, and 160 foot curves are anamorphic curves obtained from the site I master curve. Dunning (1942) used the same procedure as outlined above for his site curves for a mixed coniferous forest. The construction of the other curves, 70, 80, 90, 100, 110. 120, and 130, was not as simple. Since each curve in question lies between two major curves, a problem arose as to which major curve should influence the minor curve. A logical approach to the problem is to have both major curves influence the ten foot interval curves that lie between them. The following method allows the two major curves to influence the minor curves that may lie between them.

1. Calculate the height interval between the two major curves of interest at ten year intervals.
2. At the index age, calculate the height interval between the curve that is to be constructed and the lower major site curve.
3. Divide the height interval obtained in step two by the height interval between the two major curves at the index age.
4. Multiply each interval obtained in step one by the value obtained in step three. This gives a value for each ten years of age.

5. Add each ten year age value obtained in step four to the height of the lower major site curve at corresponding ages.

The above method is similar to interpolation and gives a fairly even spacing to the final family of site curves. This method is felt to be more desirable than obtaining anamorphic curves for each site group and combining the anamorphic curves into a family of curves. By using only anamorphic curves uneven spacing occurs in the family of curves and some curves cross at the lower ages.

RESULTS AND CONCLUSIONS

Results

Table VI gives the results of the method previously outlined in detail and Figure 8 is the final noble fir site index curves. The values in Table III are to the nearest foot. Figure 6 is a graphic representation of Table III. Note that since the table is based on breast height age and total height the curves have an intercept of 4.5 feet.

Estimating Site Index

In using the site curves or the site index table it should be noted that it is necessary to use the height of the tallest dominant or dominants. McArdle (1961) and others have used average height of dominants and codominants for their site estimation. According to Dahms (1966), the tallest trees in the stand give the best estimate of sites. Since the curves are based on the tallest dominant noble fir in the stand, the trees used in estimating site index should be of comparable stature.

No attempt is made to suggest the proper number of trees needed to estimate site quality. Some authors (Dahms, 1966; King, 1966) have suggested various numbers to measure in order to have

TABLE VI. Site index table.

	Total Height of Tree (Feet)											
DBH Age	SI 50	SI 60	SI 70	SI 80	SI 90	SI 100	SI 110	SI 120	SI 130	SI 140	SI 150	SI 160
10	7	8	9	9	9	9	10	10	10	11	11	12
20	12	14	16	17	19	20	21	22	23	25	27	28
30	18	21	24	27	30	32	35	37	40	42	45	48
40	23	28	32	36	41	45	48	52	56	60	65	69
50	28	34	40	45	51	56	61	67	72	78	83	89
60	33	40	47	53	60	67	73	80	87	93	100	107
70	38	46	53	61	69	76	84	92	100	107	115	123
80	42	51	59	68	76	85	94	102	111	120	128	137
90	46	55	65	74	84	93	102	112	121	130	140	149
100	50	60	70	80	90	100	110	120	130	140	150	160
110	54	64	75	85	96	106	117	127	138	148	159	170
120	57	68	79	90	101	112	123	134	145	156	167	178
130	60	72	84	95	106	118	129	141	151	162	174	186
140	63	76	88	99	111	122	134	145	157	168	180	192
150	66	79	91	103	115	127	139	151	161	173	186	198
160	68	82	95	107	119	131	143	155	166	178	191	204
170	71	85	98	110	123	135	147	159	170	182	195	208
180	73	88	101	114	126	138	151	162	174	186	199	213
190	75	90	104	117	130	141	154	166	177	190	203	217
200	77	93	107	119	132	144	157	169	180	193	207	220
210	79	95	109	122	135	147	160	171	183	196	210	224
220	81	98	112	125	137	150	162	174	185	198	213	227
230	83	99	114	126	139	152	164	176	187	200	215	229
240	85	102	116	129	142	155	167	179	190	203	218	232
250	87	104	118	131	144	157	169	181	192	205	220	235

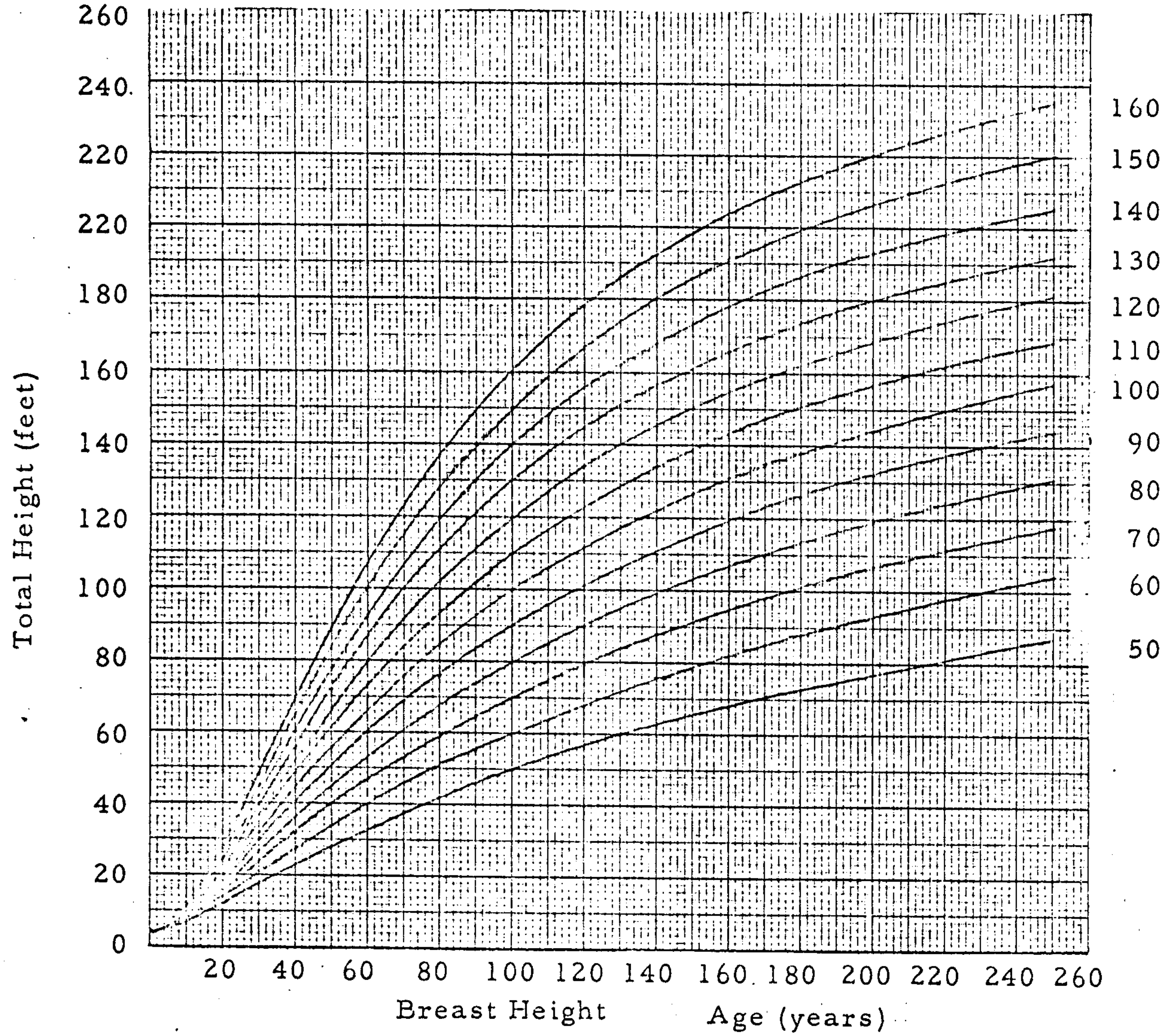

Figure 8. Site curves.

a good estimate of site quality. No set number is given here since in some of the upper-slope mixed stands noble fir may make up a small percentage of the total stand. In some areas it might be difficult to find a predetermined number of trees.

Conclusions

The site index curves are of a polymorphic nature since they were developed from four different major curves. A better method of developing polymorphic curves would be to develop a main curve for each ten foot site index. This is not practical since a great number of sectioned trees would be required to develop reliable curves.

Checking the present site curves was done by comparing them graphically with individual tree curves that were used in the analysis. A better method of checking is to compare trees that were not used in the analysis. This was not done because the data were not available.

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