AN ABSTRACT OF THE THESIS OF

GARY WAYNE CLENDENEN for the MASTER OF SCIENCE
(Name of Student) (Degree)

in Forest Management (Mensuration) presented on Sept. 2, 1971
(Major) (Date)

Title: GROWTH AND YIELD OF UNMANAGED STANDS OF QUAKING ASPEN ON THE UPPER NAVAJO RIVER IN THE ROCKY MOUNTAINS OF SOUTHWEST COLORADO

Abstract approved: Signature redacted for privacy.
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An average stand diameter yield table and a diameter growth per decade table are presented for unmanaged stands of quaking aspen in southwest Colorado. The yield table presents yields per tree for the following utilization standards: 1. total cubic-foot volume minus the stump, 2. cubic-foot volume to a 4-inch top, a 6-inch top, and an 8-inch top, 3. Scribner board-foot volume to a 6-inch top and an 8-inch top, and 4. International 1/4-inch kerf board-foot volume to a 6-inch top and an 8-inch top. Also, tables are presented for the following: 1. empirical number of trees per acre, 2. empirical average total stand height, 3. ten-year-survival percentages, 4. empirical basal area per acre, and 5. empirical yields per acre. The diameter growth per decade table is based on average stand diameter and present stand age at DBH.

The tables were developed by using stepwise multiple regression techniques. The procedures for predicting future yields per acre are discussed.

Growth and Yield of Unmanaged Stands of Quaking Aspen on the Upper Navajo River in the Rocky Mountains of Southwest Colorado

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of the requirements for the degree of

Master of Science

June 1972

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Date thesis is presented Sept. 2, 1971

Typed by Ilene Anderton for Gary Wayne Clendenen

ACKNOWLEDGEMENTS

The author is grateful to the many people who have helped to make this study possible.

My deepest thanks goes to my former employer, Mr. Gail M. Thomas. Without his assistance in acquiring the basic data this project could never have been started, let alone completed.

My appreciation goes to my graduate committee for the guidance and counseling that I have received -- Dr. John F. Bell my major professor of the O. S. U. School of Forestry, Dr. Roger G. Petersen my minor professor of the O. S. U. Statistics Department, and Dr. David P. Paine of the O. S. U. School of Forestry.

My appreciation is also extended to:

Dave and Shae Dobbins for their moral support when it was needed most.

Stephen McGuire and all my other friends too numerous to mention that have encouraged me and have been my friends, even during the toughest times.

The O. S. U. School of Forestry for financial assistance during my graduate program.

My grandparents and parents, without who's encouragement and understanding this project would never have been attempted.

THANK YOU EVERYONE!

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I. INTRODUCTION

The Problem

The upper Navajo River of southwest Colorado supports vast stands of quaking aspen (*Populus tremuloides* Michx.). These are some of the best developed stands of aspen within Colorado and perhaps anywhere in the United States. Trees were observed with breast height diameters of 22.0 inches and total heights of 117 feet.

Currently there is very little market for aspen in the Colorado area. With the increasing demand for wood fiber, it will only be a matter of time before it is a desired species. To date very little information is available on the growth and yield of aspen in Colorado. Therefore, the forest manager will need a basis for his management decisions.

Scope and Objectives

This study will provide the forest manager with a basis for his decisions. Since other areas of southwest Colorado have similar aspen stands, it may be possible for forest managers in these areas to use the tables developed until such time that a more comprehensive study is made -- either for the region or the species as a whole.

The objective of this study is to develop average stand diameter yield tables and a diameter growth per decade table based on average stand diameter and age for the unmanaged stands of quaking aspen on the upper Navajo River in southwest Colorado.

The Forest Region

Geography

The upper Navajo River Valley lies in the rugged San Juan Mountains of southwest Colorado. It is the first valley west of the continental divide, and it is in the Colorado River drainage. The valley has a broad, flat floor and steep side-walls rising to 12, 000 feet elevation on the east and west sides. The elevation of the study area is between 8, 000 feet and 11, 500 feet. The average valley floor elevation is 8, 800 feet.

Climate

The average annual precipitation in the upper Navajo Valley area is approximately 30 inches. The highest monthly precipitation occurs during the winter months in the form of snow. June is usually the driest month of the year, and July and August are the rainy season. Thunderstorms are frequent during July and August with heavy showers almost every afternoon. Summer daily maximum temperatures are uusually between 70° F. and 80° F. with daily minimums about 40° F. January is typically the coldest month of the year with daily minimum temperatures occasionally dropping to 50° F. below zero. The normal frost free period is quite erratic; it is typically about 60 to 100 days in length.(4).

Forests

The area is forested primarily with even-aged stands of quaking aspen, Engelmann spruce (*Picea engelmannii* Parry), Colorado blue spruce (*Picea pungens* Engelm.), corkbark fir (*Abies lasiocarpa* var. *arizonica* Nutt.), white fir (*Abies concolor* Lindl.), ponderosa pine (*Pinus ponderosa* Laws.), and Douglas-fir (*Pseudotsuga menziezii* var. *glauca* Franco). Many of the aspen stands are relatively pure with very little timber understory. Frequently however, there is an understory of Engelmann spruce or white fir depending upon the elevation. There is generally a heavy forage cover under the aspen stands.

II. LITERATURE REVIEW

Characteristics of Quaking Aspen

Quaking aspen is found primarily in even-aged stands with clean, straight stems. Aspen is a very intolerant species with a pronounced ability to express dominance early in the stand life. Because of its ability to express dominance, aspen rarely stagnates.

The growth of young stands is very rapid for approximately the first 20 years. Rapid natural thinning is characteristic of the young stands. After about 20 years, the growth rate tends to decrease. In sapling and mature timber the growth rate is typically slower in the western part of its range than in the eastern part, but the rate of decay is also slower. The pathological rotation length is usually between 80 and 90 years in the western region (7).

Growth and Yield Studies in Quaking Aspen

In 1925 Baker (1) published a detailed study of aspen for the Central Rocky Mountain Region based on data collected in what is currently known as the Manti - La Sal National Forest in central Utah. He reports findings on the climatic requirements, soil and moisture requirements, tolerance, susceptibility to injurious factors, reproduction characteristics, growth and yield, wood properties, uses, lumbering and logging, and management and silvicultural systems for aspen. There has been no direct work with growth and yield predictions for aspen in Colorado. There has been a study done in Alaska (8) and the Lake States (16).

Techniques of Yield Table Construction

For conifers, Barnes (2) suggests basing future yield predictions on average stand diameter yield tables instead of the conventional site index and age yield tables. He predicted yields at maturity for the Yahk Forest in British Columbia with average stand diameter yield tables. The predictions were approximately equal to the yield of mature stands in the area. Some of the advantages of average stand diameter yield tables are as follows:

1. They should be more applicable to sub-normal, as well as normal, stands than the conventional site index and age yield tables (9, p. 64).
2. Average stand diameter yield tables provide better accuracy of prediction of probable future yields than do site index and age yield tables (11, p.44).
3. The independent variables used for average stand diameter yield tables are more easily and accurately measured than those for the site index and age yield tables (9, p. 64).

4. The one table based on average stand diameter is easier to use than the many tables based on site index and age (11, p. 45).

The construction of an average stand diameter yield table can be accomplished with the following steps:

1. Sort the basic data into diameter (DBH) classes.
2. Relate yield to DBH.
3. For growth predictions, sort the basic data into DBH and age classes, and relate growth to DBH and age (3, 9).
4. Analyze the field data by plots through multiple regression techniques (5, 6, 10, 15).

Volume Tables

Comprehensive Tree-Volume Tarif Tables (13) presents a series of preconstructed local volume tables based on balanced regression equations. The tarif table system has several major advantages over standard volume tables:

1. The need for fitting curves for local volume table derivation is eliminated.
2. For growth measurements the error associated with fitting independent curves for repeated stand measurements is uniformly controlled because of the standardized curves.

3. Volume measurements are listed for nine utilization standards in each table which provides for simple, accurate volume conversion.

4. For volume growth estimates based on increment cores, growth multipliers are provided in each table.

Each table has a tarif number. The tarif number is the cubic-foot volume to a 4-inch minimum top that each square foot of basal area (at DBH) represents (volume basal area ratio). For west coast species a system of tarif access tables have been developed which provide the tarif number associated with the stand under consideration. For aspen, however, no tarif access table was available. Using the methods outlined by Turnbull and Hoyer (14) and a cubic foot volume table to a 4-inch minimum top (12) a tarif access table was constructed for aspen in Colorado. For more detail on the development of the aspen access table see the computer program described in APPENDIX II.

III. GROWTH AND YIELD TABLES

Terms and Measures

Age

Age refers to the average breast height age of the stand. It is the number of years since the trees in the stand attained a total height of 4.5 feet.

Assumed Utilization Standards

The utilization standards were derived from Comprehensive Tree-Volume Tarif Tables (13), and a one-and-a-half-foot stump is assumed. The volume measures presented in the yield tables are as follows:

1. CVT -- total cubic-foot volume excluding the stump
2. CV4 -- cubic-foot volume to a 4-inch minimum top
3. CV6 -- cubic-foot volume to a 6-inch minimum top
4. CV8 -- cubic-foot volume to an 8-inch minimum top
5. S6 -- Scribner board-foot volume to a 6-inch minimum top
6. S8 -- Scribner board-foot volume to an 8-inch minimum top

7. I6 -- International 1/4-inch kerf board-foot volume to a 6-inch minimum top
8. I8 -- International 1/4-inch kerf board-foot volume to an 8-inch minimum top.

Average Stand Diameter

The average stand diameter (DBH) is the average of all trees 5.0 inches DBH and larger represented in the stand, weighted by the number of trees per acre for each DBH class.

Basal Area Per Acre

Basal area per acre is the total cross-sectional area at DBH in square feet (including bark) of all trees 5.0 inches DBH and larger represented in the stand.

Average Total Stand Height

The average total stand height is the average height measured from the ground to the tip of the crown for all trees 5.0 inches DBH and larger represented in the stand, weighted by the number of trees per acre for each DBH class.

Ten-Year Survival Percentage

The ten-year survival percentage is the percent of the present number of trees per acre that are expected to survive the next ten year period. It is an indirect estimate of future mortality based on the mortality for the past ten year period.

Yield

Yield is the empirical volume for stands of a specified average stand diameter for the eight utilization standards. The yield table includes only living trees 5.0 inches DBH and larger at the time of measurement.

Basic Data

During the summer of 1970 a forest inventory was conducted on the upper Navajo River for the purpose of preparing a timber management plan using temporary sample plots. Two-hundred-twelve trees were measured on 55 plots within the aspen timber type using variable plot sampling techniques. A 20 basal area factor (BAF) angle gauge (Spiegel-Relaskop) was used. The following measurements were taken on every tree on every plot:

1. total height to the nearest one foot by using the Spiegel-Relaskop
2. DBH to the nearest one-tenth inch by using a diameter tape

3. age to the nearest ten years by counting annual rings on increment cores

4. DBH growth for the past ten and 20 years to the nearest one-tenth-inch by measuring the radial growth for the respective periods and doubling. The DBH growth for each period was subtracted from the present DBH to obtain an estimate of the DBH ten and 20 years ago respectively.

Only trees 5.0 inches DBH and larger were measured. Table 1 shows the number of trees and the number of plots sampled by DBH and age classes.

Table 1. Distribution of individual trees and plots..

	Individual Trees								
	Breast Height Age								
DBH Class	30	40	50	60	70	80	90	100+	Total
5.0	1	--	--	--	4	--	--	1	6
6.0	--	2	1	1	2	3	1	--	10
7.0	--	1	--	1	5	4	4	--	15
8.0	--	--	2	1	1	7	4	9	24
9.0	--	--	--	2	--	9	9	7	27
10.0	--	1	--	7	2	5	7	6	28
11.0	--	--	--	2	1	7	4	12	26
12.0	--	--	--	1	1	2	5	8	17
13.0	--	--	--	--	--	1	1	12	14
14.0	--	--	--	--	--	1	1	13	15
15.0	--	--	--	--	--	1	2	8	11
16.0	--	--	--	--	--	--	--	8	8
17.0	--	--	--	--	--	1	--	4	5
18.0	--	--	--	--	--	1	--	1	2
19.0	--	--	--	--	--	--	--	--	0
20.0	--	--	--	--	--	--	--	3	3
21.0	--	--	--	--	--	--	--	--	0
22.0	--	--	--	--	--	--	--	1	1
Total	1	4	3	15	16	42	38	93	212

Table 1. Continued

	Individual Plots								
	Average Breast Height Age								
DBH Class	30	40	50	60	70	80	90	100+	Total
6.0	--	1	--	--	1	2	--	1	5
7.0	--	--	1	--	--	2	--	--	3
8.0	--	--	--	1	1	--	2	1	5
9.0	--	--	--	--	--	1	3	3	7
10.0	--	--	1	1	--	2	1	1	6
11.0	--	--	--	1	--	2	2	2	7
12.0	--	--	--	--	--	--	3	3	6
13.0	--	--	--	--	--	--	1	3	4
14.0	--	--	--	--	--	--	--	4	4
15.0	--	--	--	--	--	--	--	4	4
16.0	--	--	--	--	--	1	--	1	2
17.0	--	--	--	--	--	--	--	1	1
18.0	--	--	--	--	--	--	--	--	0
19.0	--	--	--	--	--	--	--	1	1
Total	0	1	2	3	2	10	12	25	55

Analysis of Data

Regression Models

Stepwise multiple regression techniques and the CDC 3300 computer were used for the analysis of all data. All variables, except the number of trees per acre, were analyzed on an individual tree basis. It was assumed that a tree of a given DBH and height represented the average tree of a stand with the same average DBH and height. The above assumption was verified by the comparison conducted on the growth and yield tables. The number of trees per acre was analyzed by plots, because there is no method of determining the number of trees per acre on an individual tree basis.

The following basic regression model was used for all equations except diameter growth per decade:

$$Y = B_0 + B_1X + B_2X^2 + B_3X^3 + E$$

where: Y = dependent variable to be described

X = independent variable used to describe Y

B_i = regression constants to be determined; rate of change in Y for a unit change in X

E = random error; normally, independently distributed with a mean of zero and a common variance (NID$(0, \sigma^2)$).

The equation for estimating the diameter growth per decade was determined by fitting the following basic model:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_1^2 + B_4X_2^2 + B_5X_1^3 + B_6X_2^3 + B_7X_1X_2 + E$$

where: Y = dependent variable to be described

X_1, X_2 = independent variables used to describe Y

B_i = regression coefficients

E = random error; $NID(0, \sigma^2)$.

Results of Regression Analysis

Volume Per Tree. The following equations were obtained for estimating the volume per tree for the eight utilization standards:

1. $CVT = 23.815 - 8.176(DBH) + 0.987(DBH)^2 - 0.023(DBH)^3$

   $R^2 = 0.893$

2. $CV4 = 21.226 - 7.878(DBH) + 0.972(DBH)^2 - 0.023(DBH)^3$

   $R^2 = 0.900$

3. $CV6 = 19.881 - 8.799(DBH) + 1.084(DBH)^2 - 0.026(DBH)^3$

   $R^2 = 0.914$

4. CV8 $= 58.147 - 19.795(DBH) + 1.938(DBH)^2 - 0.046(DBH)^3$

$$R^2 = 0.930$$

5. S6 $= 191.915 - 69.872(DBH) + 7.398(DBH)^2 - 0.173(DBH)^3$

$$R^2 = 0.877$$

6. S8 $= 326.480 - 109.399(DBH) + 10.544(DBH)^2 - 0.250(DBH)^3$

$$R^2 = 0.896$$

7. I6 $= 202.596 - 78.012(DBH) + 8.712(DBH)^2 - 0.214(DBH)^3$

$$R^2 = 0.879$$

8. I8 $= 381.179 - 131.088(DBH) + 12.998(DBH)^2 - 0.319(DBH)^3$

$$R^2 = 0.899$$

The volume equation for CV8, S8, and I8 show less volume per tree for trees 22.0 inches DBH than for trees 21.0 inches DBH because of the total height distribution found in the trees sampled for this study. If the volume equations for CVT, CV4, CV6, S6, and I6 had been projected beyond 22.0 inches DBH, they too would show a decrease in volume per tree because of the total height distribution. The height adjustment factor discussed on page 25 compensates for what appears to be erroneous volumes per tree.

Trees Per Acre. The following equation was found to provide the best description of trees per acre:

$$\text{LOG(empirical number of trees per acre)}$$
$$= 0.590 + 0.711(\text{DBH}) - 0.072(\text{DBH})^2 + 0.002(\text{DBH})^3$$
$$R^2 = 0.645$$

The number of trees per acre can only be described for average stand diameters less than or equal to 17.0 inches DBH because the curve turns upward at 17.0 inches average stand diameter.

Average Total Stand Height. The following equation was determined for estimating the average total stand height:

$$\text{Average Total Stand Height}$$
$$= 21.192 + 2.180(\text{DBH}) + 0.442(\text{DBH})^2 - 0.020(\text{DBH})^3$$
$$R^2 = 0.532$$

For the specific sample used for this study, the average total stand heights decreased above a DBH of 18.0 inches DBH.

Ten-Year Survival Percentage. Mortality is extremely difficult to predict, especially from temporary sample plots. The estimated number of trees per acre in ten years was computed by subtracting the number of trees per acre that died during the past ten years from the present number of living trees per acre. The sample survival percentages were determined by dividing the estimated number of trees per acre in ten years by the present number of living trees per acre and multiplying by 100. The following equation was found to provide the best estimate of the ten-year survival percentage:

$$\text{Ten-Year Survival Percentage} = 56.77 + 6.20(\text{DBH}) - 0.26(\text{DBH})^2$$

$$R^2 = 0.707$$

This estimate of mortality should be applied with caution. Additional study is needed to provide a more reliable estimate of mortality.

Diameter Growth Per Decade. Two basic approaches were taken for the estimation of diameter growth per decade:

1. Each tree was treated as two observations and recorded with DBH being the DBH ten and 20 years ago, diameter growth being the growth for the next ten years, and age being the present age minus ten and 20 years.
2. Each tree was treated as one observation with DBH being the present DBH, diameter growth being the average diameter growth per decade for the past 20 years, and age being the present age.

With the first approach the highest multiple correlation coefficient that could be found was 0.345. The final predicting equation was found by using the second approach. The following equation was used to estimate the diameter growth per decade:

Diameter Growth Per Decade

$$= 1.5454 + 0.2981(DBH) - 0.0006(DBH)^2 - 0.0492(AGE) + 0.0004(AGE)^2 - 0.0024(DBH)(AGE)$$

$$R^2 = 0.580$$

Average Stand Diameter Yield Tables

Table 2 was derived by solving the previously described regression equations for the specific values of average stand diameter. Yield per tree for the eight utilization standards is presented for trees 5.0 inches DBH and larger in stands of average stand diameters from 5.0 inches DBH through 22.0 inches DBH. No allowance has been made for defect and breakage. To predict net volume per tree, defect and breakage values from the stand under consideration must be applied to the values given in the yield tables. The empirical number of trees per acre, average total stand heights, and ten-year survival percentages are shown in Table 3. Empirical yields per acre, Table 4, were determined by multiplying the empirical number of trees per acre, Table 3, by the volume per tree, Table 2, for each average stand diameter class and utilization standard. Basal area per acre, Table 4, was determined by multiplying the empirical number of trees per acre, Table 3, by the basal area of the average tree in each average stand diameter class. Figures 1 through 3, APPENDIX I, define Table 2 graphically, Figures 4 through 6,

Table 2. Yield of Quaking Aspen stands for trees 5.0 inches and larger DBH.

Average Stand Diameter	Yield Per Tree							
	CVT	CV4	CV6	CV8	S6	S8	I6	I8
5.0	4.7	3.3	----	----	---	---	---	---
6.0	5.3	4.0	0.5	----	2	---	2	---
7.0	7.0	5.9	2.5	----	6	---	10	---
8.0	9.8	8.8	5.6	0.2	18	---	27	1
9.0	13.4	12.5	9.5	3.3	36	14	50	22
10.0	17.7	16.9	14.3	7.9	60	38	80	51
11.0	22.6	21.9	19.7	13.5	88	67	114	88
12.0	28.0	27.3	25.5	20.0	119	101	152	129
13.0	33.7	33.0	31.6	27.0	153	139	191	173
14.0	39.6	39.0	37.8	34.3	188	177	232	219
15.0	45.5	44.9	44.1	41.6	224	216	272	263
16.0	51.3	50.7	50.1	48.6	258	254	310	305
17.0	56.8	56.3	55.9	55.1	291	288	344	343
18.0	62.0	61.5	61.1	60.8	321	319	375	374
19.0	66.7	66.2	65.8	65.3	347	343	400	396
20.0	70.7	70.2	69.6	68.5	368	360	418	408
21.0	74.0	73.4	72.4	70.0	384	368	427	408
22.0	76.3	75.8	74.2	69.6	390	366	428	393

Table 3. Empirical number of trees per acre, average total stand height, and ten-year survival percentages of Quaking Aspen stands for trees 5.0 inches and larger DBH.

Present Average Stand Diameter	Empirical Number of Trees Per Acre	Empirical Average Total Stand Height	Ten-Year Survival Percentage
5.0	---	41	81.3
6.0	499	46	84.7
7.0	534	51	87.5
8.0	497	57	89.9
9.0	414	62	91.7
10.0	317	67	93.0
11.0	230	72	93.8
12.0	162	77	94.1
13.0	114	80	93.8
14.0	83	84	93.1
15.0	63	86	91.8
16.0	52	88	90.0
17.0	48	88	87.7
18.0	---	88	84.9
19.0	---	86	81.6
20.0	---	82	77.8
21.0	---	78	73.4
22.0	---	71	68.5

Table 4. Empirical yields per acre of Quaking Aspen stands for trees 5.0 inches and larger DBH.

Average Stand Diameter	Empirical Basal Area Per Acre	Yield Per Acre							
		CVT	CV4	CV6	CV8	S6	S8	I6	I8
5.0	------	1868	1304	----	----	----	----	----	----
6.0	97.95	2650	2016	244	----	900	----	1000	----
7.0	142.74	3759	3156	1324	----	3150	----	5390	----
8.0	173.50	4861	4353	2758	99	8800	----	13270	550
9.0	182.90	5539	5158	3950	1383	14900	6000	20870	9020
10.0	172.89	5617	5351	4530	2495	18920	11980	25360	16260
11.0	151.80	5207	5032	4520	3105	20190	15480	26270	20150
12.0	127.23	4539	4424	4124	3235	19330	16430	24590	20880
13.0	105.09	3843	3768	3600	3078	17460	15800	21810	19760
14.0	88.73	3285	3233	3140	2847	15620	14720	19230	18150
15.0	77.31	2865	2827	2776	2621	14090	13630	17100	16590
16.0	72.61	2667	2637	2607	2529	13420	13200	16090	15880

APPENDIX I, define Table 3 graphically, and Figures 7 through 10, APPENDIX I, define Table 4 graphically.

The curves for volume per acre, Figures 8 through 10, APPENDIX I, take on the same general form as mean annual increment curves. The culmination of mean annual increment is the age at which the stand achieves the maximum physical productivity. The culmination of the volume per acre, Figures 8 through 10, APPENDIX I, can be thought of as the average stand diameter at which the maximum physical productivity is achieved. Using the same logic that is used for the culmination of mean annual increment, it can be said: to achieve the maximum physical productivity, stands should be harvested when their average stand diameter reaches the culmination of volume per acre over average stand diameter.

Diameter Growth Per Decade Table

Table 5 presents diameter growth per decade. By knowing the present average stand diameter and the present stand age at breast height, Table 5 can be used for projecting the present average stand diameter into the future for making growth estimates. An example of projection methods is given in a later section. Figure 11, APPENDIX I, defines Table 5 graphically.

Table 5. Diameter growth per decade of Quaking Aspen stands for trees 5.0 inches and larger DBH.

Present Average Stand Diameter	Present Average Breast Height Stand Age							
	30	40	50	60	70	80	90	100+
5.0	1.5	1.2	0.8	0.6	0.5	0.4	0.4	0.4
6.0	1.7	1.3	1.0	0.8	0.6	0.5	0.5	0.5
7.0	1.9	1.5	1.2	0.9	0.7	0.6	0.6	0.6
8.0	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.6
9.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.7
10.0	---	2.2	1.7	1.4	1.1	0.9	0.8	0.7
11.0	---	2.3	1.9	1.5	1.2	1.0	0.8	0.8
12.0	---	2.5	2.0	1.6	1.3	1.1	0.9	0.8
13.0	---	---	2.2	1.8	1.4	1.2	1.0	0.8
14.0	---	---	2.4	1.9	1.6	1.3	1.0	0.9
15.0	---	---	2.5	2.1	1.7	1.4	1.1	0.9
16.0	---	---	---	2.2	1.8	1.4	1.2	1.0
17.0	---	---	---	2.3	1.9	1.5	1.2	1.0
18.0	---	---	---	2.5	2.0	1.6	1.3	1.0
19.0	---	---	---	---	2.1	1.7	1.4	1.1
20.0	---	---	---	---	2.2	1.8	1.4	1.1
21.0	---	---	---	---	---	1.9	1.5	1.2
22.0	---	---	---	---	---	2.0	1.5	1.2

Table Use

Height Adjustments

In any given stand, the height will probably differ from the average total stand height given in Table 3. The yields presented in Table 2 will need to be adjusted to account for this difference. The following relationship used by Barnes and Bruce (3, 9) can be used for the yield adjustment:

1. Height Adjustment Factor =

$$\frac{\text{(present average total stand height)}}{\text{(average total stand height from Table 3)}}$$

2. Adjusted Volume Per Tree =

   (height adjustment factor) X (volume per tree from Table 2)

Bruce (9, p. 71) searched all available permanent sample plot information for height adjustment factor trends. He did not find any definite tendency for the factor to increase or decrease. Therefore, it can be assumed that the height adjustment factor will remain relatively constant through time for any given stand.

Stocking Adjustments

The present number of trees per acre can be projected ten years into the future by multiplying the present number of trees per acre by the survival percentage, Table 3, for the present average stand diameter and dividing by 100.

Example of Projection Methods

The following example will illustrate the use of Tables 2, 3, and 4 for growth predictions. The following measurements are made in the field:

1. present number of trees per acre = 330 trees/acre
2. present average stand diameter = 9.0 inches DBH
3. present average total stand height = 70 feet
4. present average stand age at DBH = 80 years

The following estimates are wanted:

1. present CV4 per acre
2. CV4 per acre in ten years
3. CV4 growth per acre per year

The following computations are required:

1. present CV4 per tree from Table 2 = 12.5 cubic feet
2. average total stand height from Table 3 = 62 feet
3. height adjustment factor = 70 feet / 62 feet = 1.13
4. adjusted present CV4 per tree = (1.13) X (12.5) =

   14.1 cubic feet

5. present CV4 per acre = (14.1) X (330) = 4653 cubic feet per acre

6. projected diameter growth for next ten years from Table 5 = 1.0 inches

7. projected average stand diameter in ten years = 9.0 inches + 1.0 inches = 10.0 inches DBH

8. future CV4 per tree from Table 2 = 16.9 cubic feet

9. adjusted CV4 per tree = (16.9) X (1.13) = 19.1 cubic feet

10. ten-year survival percentage from Table 3 = 91.7%

11. projected number of trees per acre in ten years = (330) X (0.917) = 303 trees per acre

12. projected CV4 per acre = (19.1)X (303) = 5787 cubic feet per acre

13. CV4 growth per acre for ten years = (5787) - (4653) = 1134 cubic feet per acre per decade

14. CV4 growth per acre per year = (1134) / (10 years) = 113.4 cubic feet per acre per year

A Comparison of the Growth and Yield Table Predictions

Present yields per acre, future yields per acre, and expected growth per acre per year were predicted using the growth and yield tables developed for this thesis. These predictions were compared to comparable values found in the timber management plan prepared during the fall of 1970 for the upper Navajo River Valley. The results of this comparison can be found in Table 6. The predictions for the management plan were made by using the growth multipliers given in Comprehensive Tree-Volume Tarif Tables (13). A field test should be conducted on the tables presented in this thesis to determine if they are applicable to other areas.

Table 6. Comparison of growth and yield table predictions.

Present Yield Per Acre								
	CVT	CV4	CV6	CV8	S6	S8	I6	I8
Timber Management Plan	4728	4439	3608	2447	16380	12410	20950	15590
Yield Table	4728	4241	3429	2304	15810	11830	20590	14900
Difference	0	-198	-179	-143	-570	-580	-360	-690
Percent Difference	0%	-4.5%	-5.0%	-5.8%	-3.5%	-4.7%	-1.7%	-4.4%

Projected (Ten Years) Yield Per Acre Including Mortality Loss								
	CVT	CV4	CV6	CV8	S6	S8	I6	I8
Timber Management Plan	5500	5220	4465	3161	20550	15950	25870	20210
Growth and Yield Tables	5271	5034	4334	3068	19650	15520	25180	19650
Difference	-229	-186	-131	-93	-900	-430	-690	-560
Percent Difference	-4.2%	-3.6%	-2.9%	-2.9%	-4.4%	-2.7%	-2.7%	-2.8%

Table 6. Continued

Predicted Growth Per Acre Per Year Including Mortality Loss								
	CVT	CV4	CV6	CV8	S6	S8	I6	I8
Timber Management Plan	77.2	78.1	85.7	71.4	417	354	492	462
Growth and Yield Tables	54.3	79.3	90.5	76.4	384	369	459	475
Difference	-22.9	1.2	4.8	5.0	-33	15	-33	13
Percent Difference	-29.7%	1.5%	5.6%	7.0%	-7.9%	4.2%	-6.7%	2.8%

IV. SUMMARY AND CONCLUSIONS

Summary

During the summer of 1970 a timber inventory was conducted on the upper Navajo River for the purpose of preparing a timber management plan. The data collected within the quaking aspen timber type were used to develop growth and yield tables based on average stand diameter for trees 5.0 inches DBH and larger. The tables were developed using stepwise multiple regression techniques, and the resulting regression equations are presented with their corresponding multiple correlation coefficients. Each equation is also presented graphically in APPENDIX I. Empirical volumes per acre are presented in tabular and graphic form. Height and stocking adjustments are discussed. A sample growth projection problem is presented to illustrate the techniques of using the growth and yield tables. A comparison of the growth and yield table predictions was conducted with the timber management plan being used as the basis for comparison. The results of the comparison are presented in tabular form.

Conclusions

The growth and yield tables developed for this thesis are useful in making predictions of future yields and growth for stands of quaking aspen on the upper Navajo River. The survival percentages presented should be used with caution until mortality and ingrowth can be studied on remeasured permanent sample plots. If local estimates of mortality are used, the tables should be generally applicable for the aspen timber type through-out southwest Colorado until a more comprehensive study is made either for the species or the region as a whole. It appears that the culmination of volume per acre over average stand diameter can be thought of as the average stand diameter at which maximum physical productivity is achieved. The assumption -- a tree of a given DBH and total height represents the average tree of a stand with the same average DBH and height -- is valid. Before the tables presented in this thesis are applied to areas other than the upper Navajo River, a field check should be conducted.

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APPENDICES

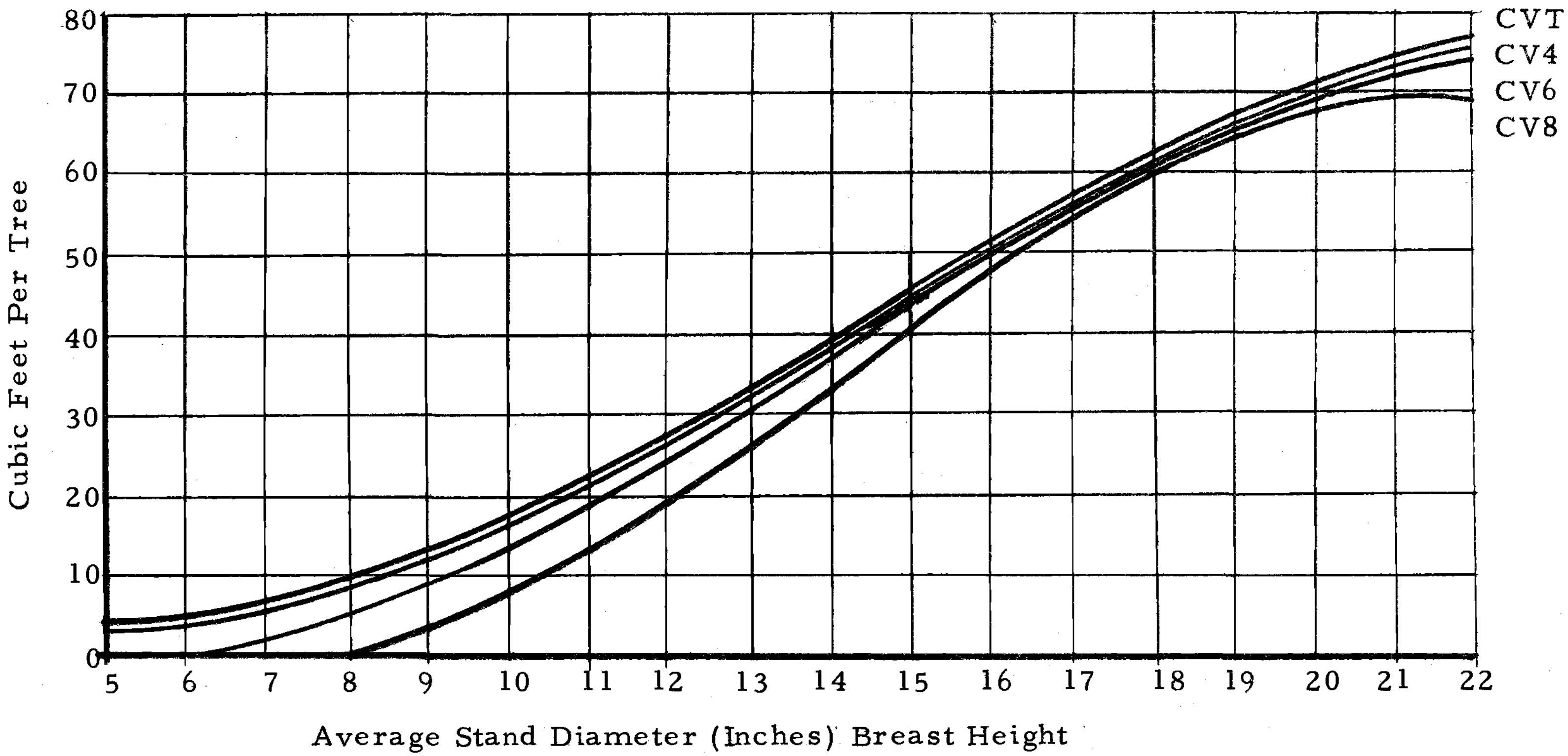

Figure 1. Cubic-Foot Volume Per Tree of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

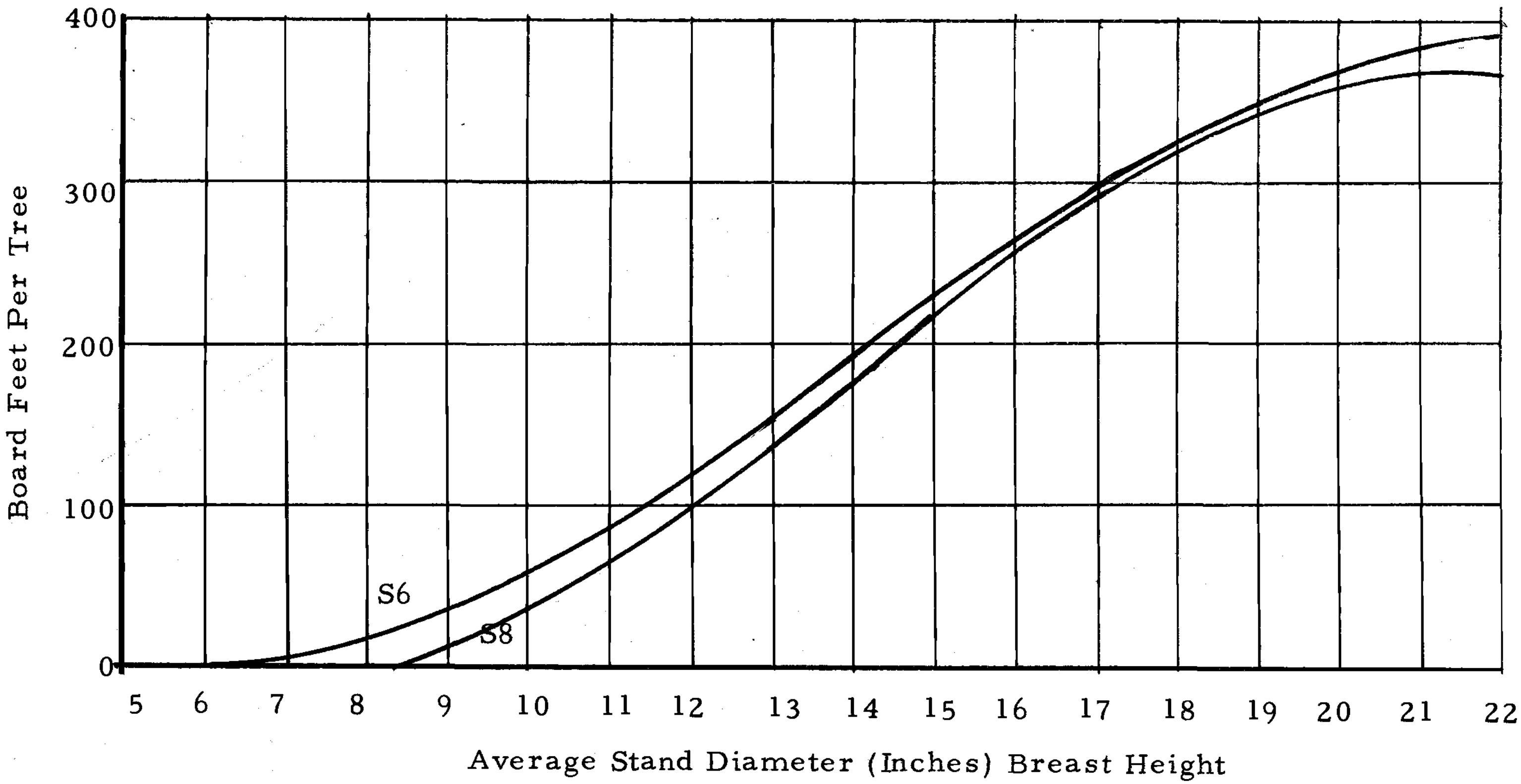

Figure 2. Scribner Board-Foot Volume Per Tree of Quaking Aspen 5.0 Inches and Larger DBH.

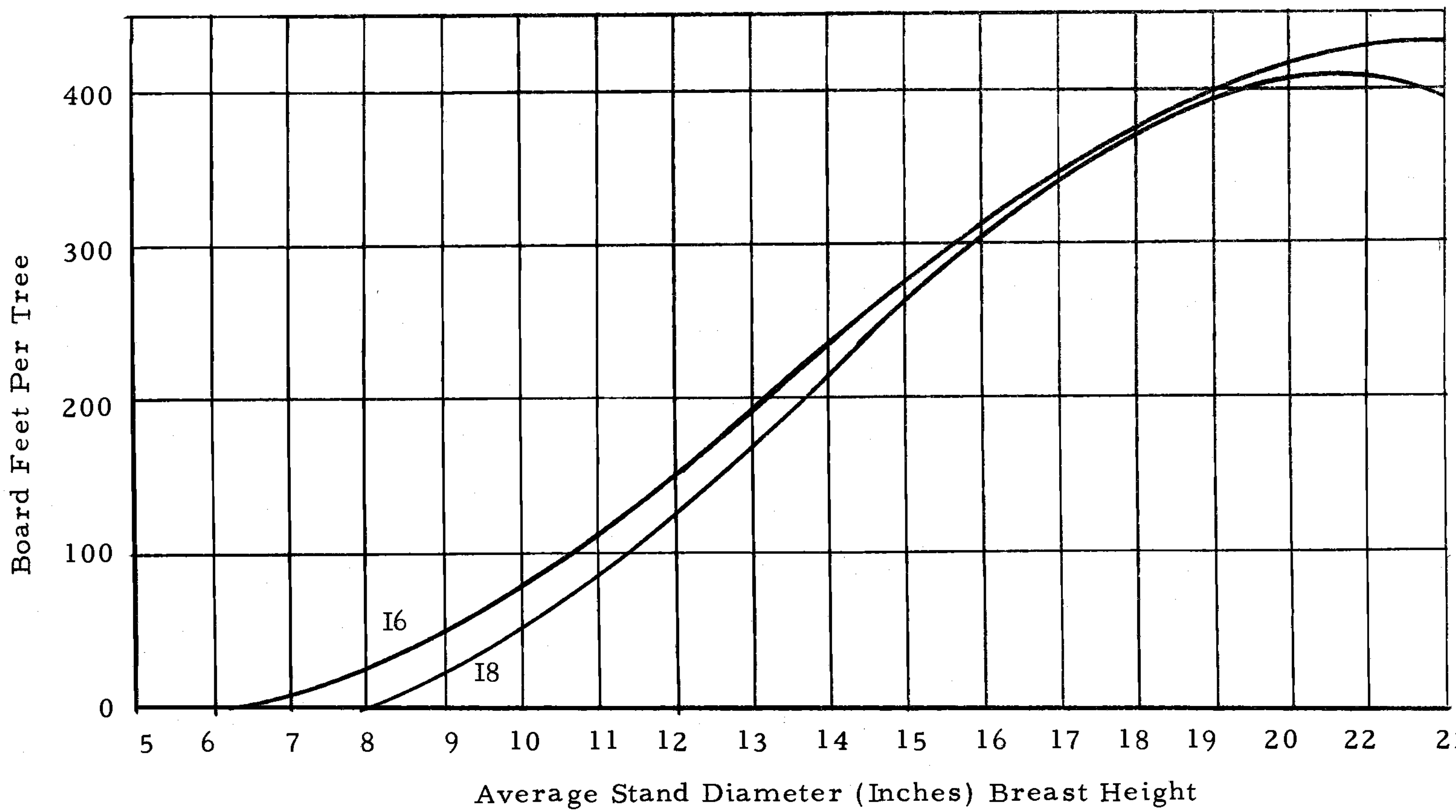

Figure 3. International 1/4-Inch Kerf Board-Foot Volume Per Tree of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

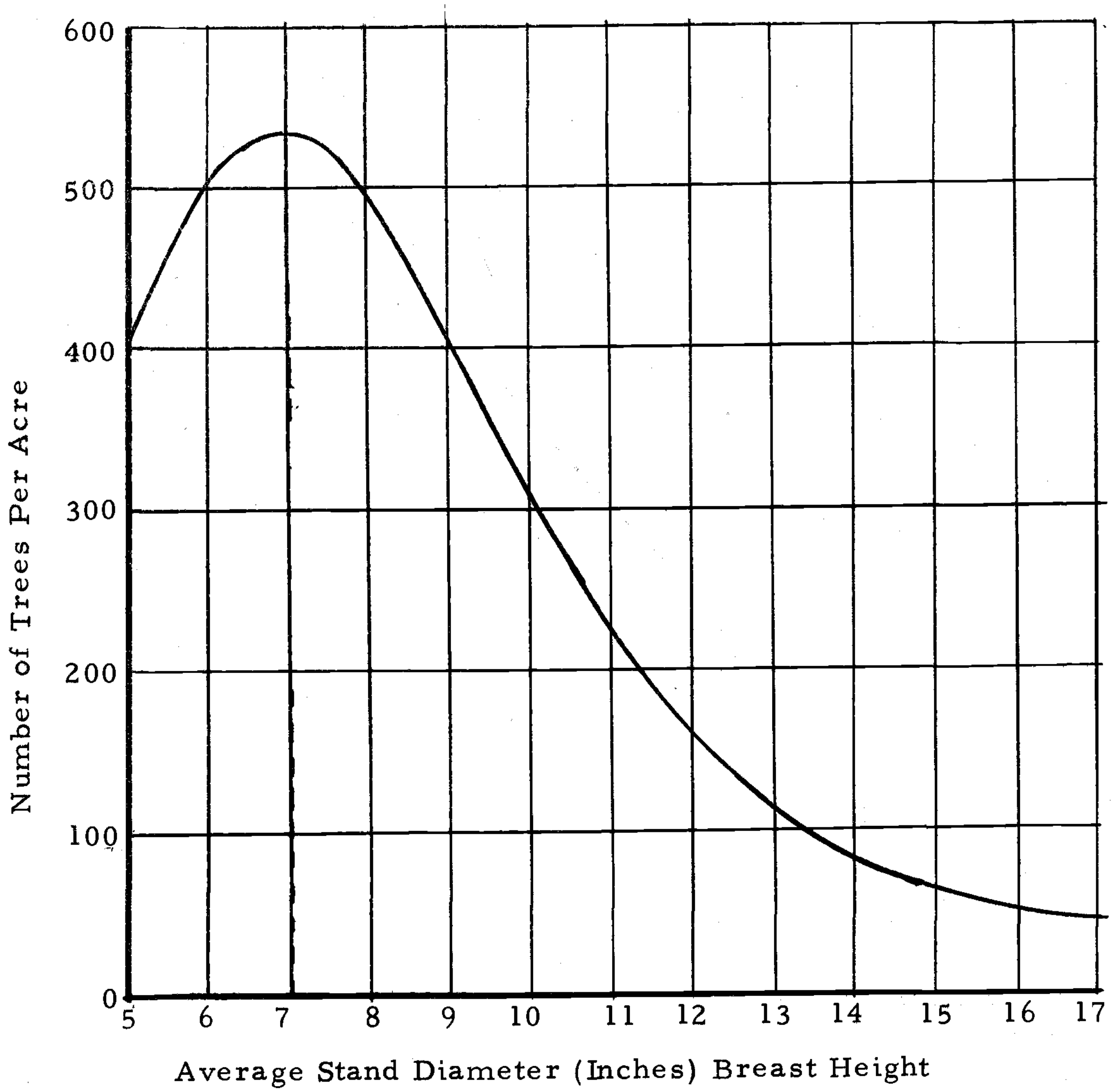

Figure 4. Empirical Number of Trees Per Acre of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

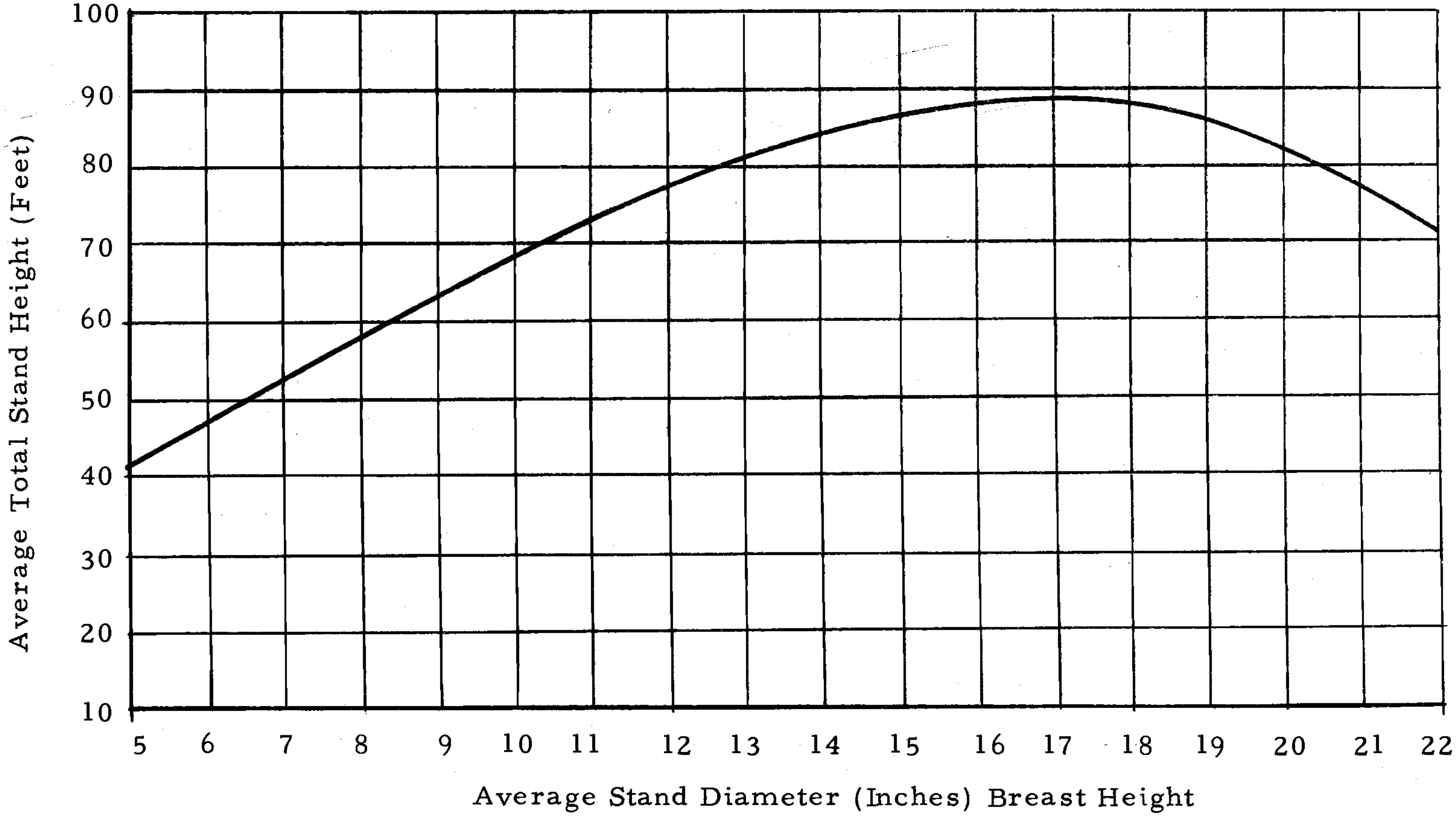

Figure 5. Average Total Stand Height of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

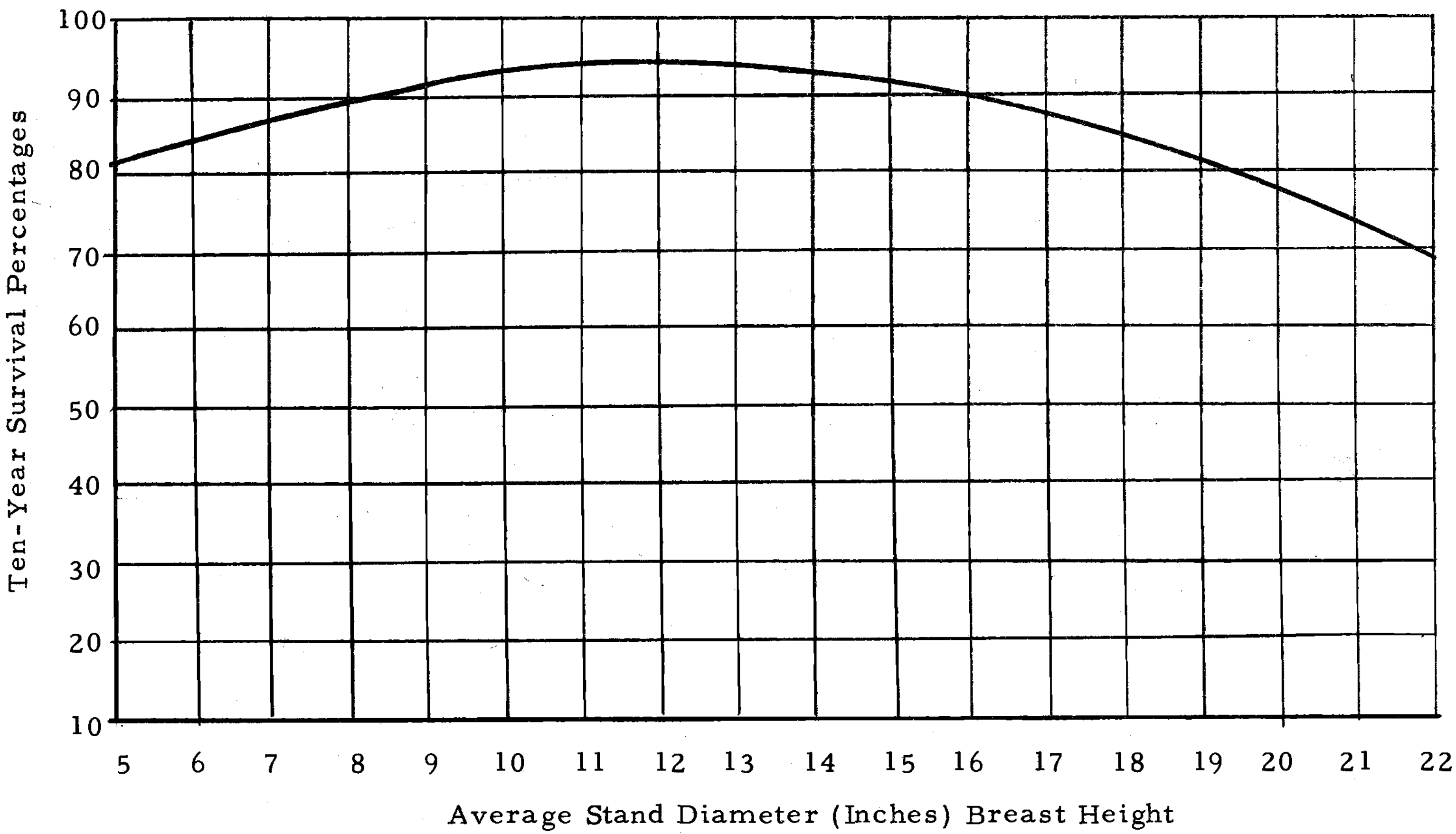

Figure 6. Ten-Year Survival Percentages of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

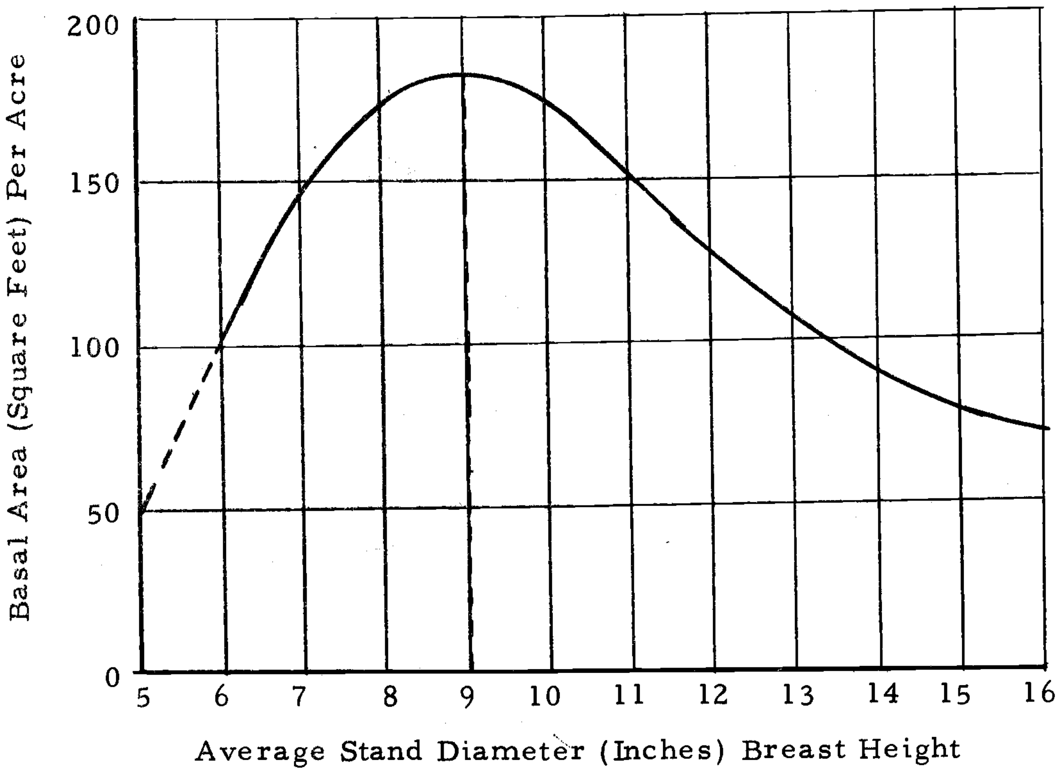

Figure 7. Basal Area Per Acre of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

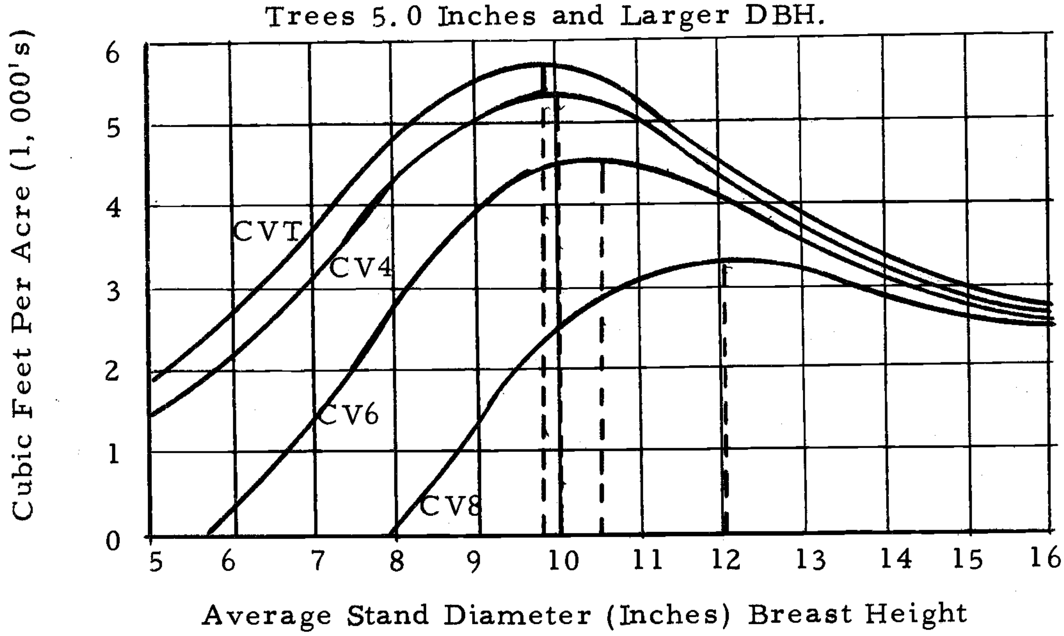

Figure 8. Cubic-Foot Volume Per Acre of Quaking Aspen 5.0 Inches and Larger DBH.

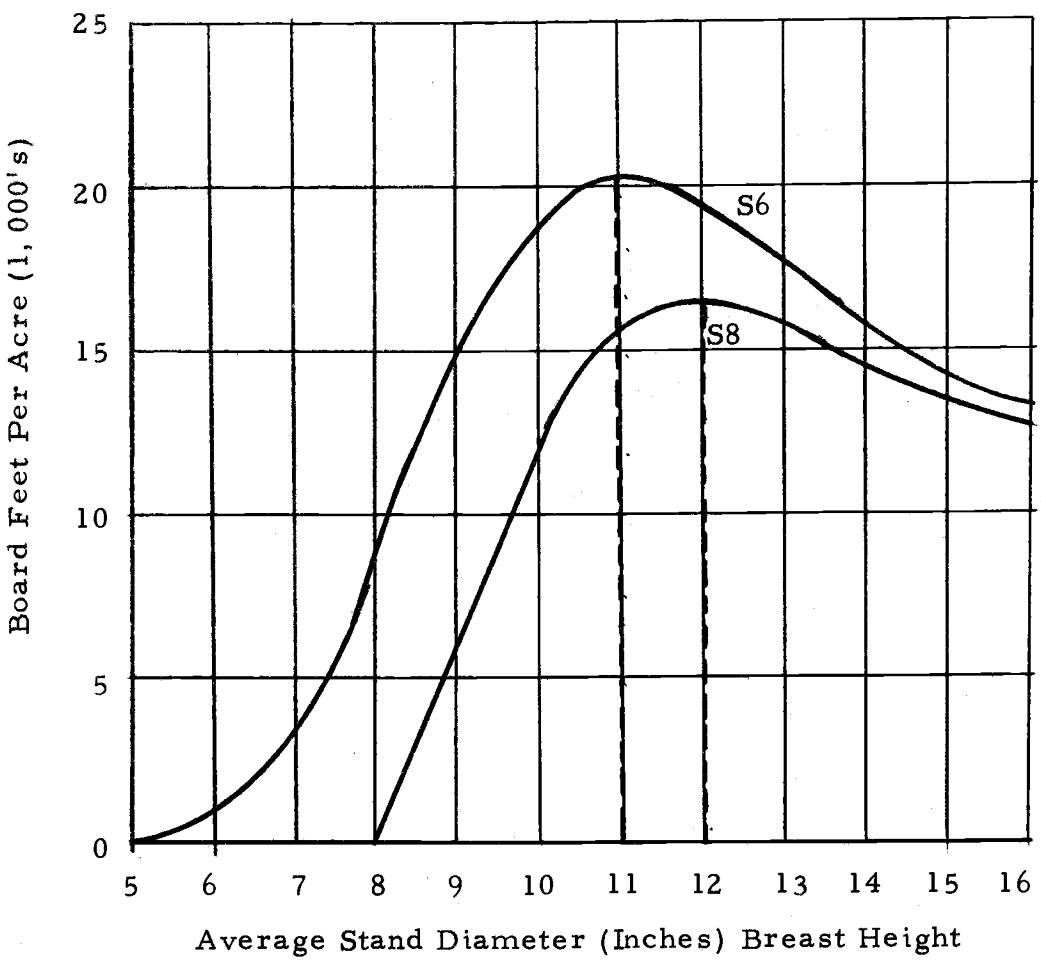

Figure 9. Scribner Board-Foot Volume Per Acre of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

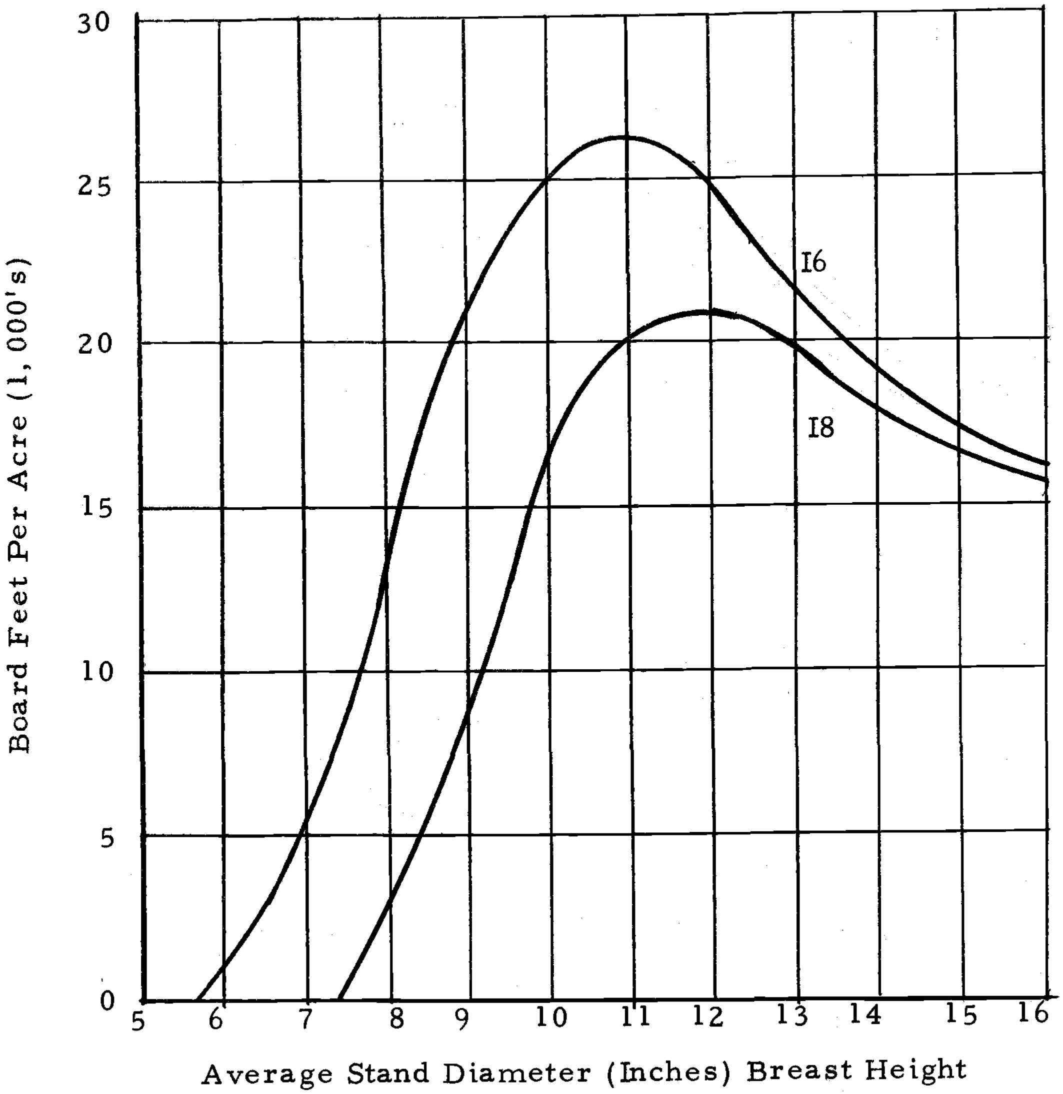

Figure 10. International 1/4-Inch Kerf Board-Foot Volume Per Acre of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

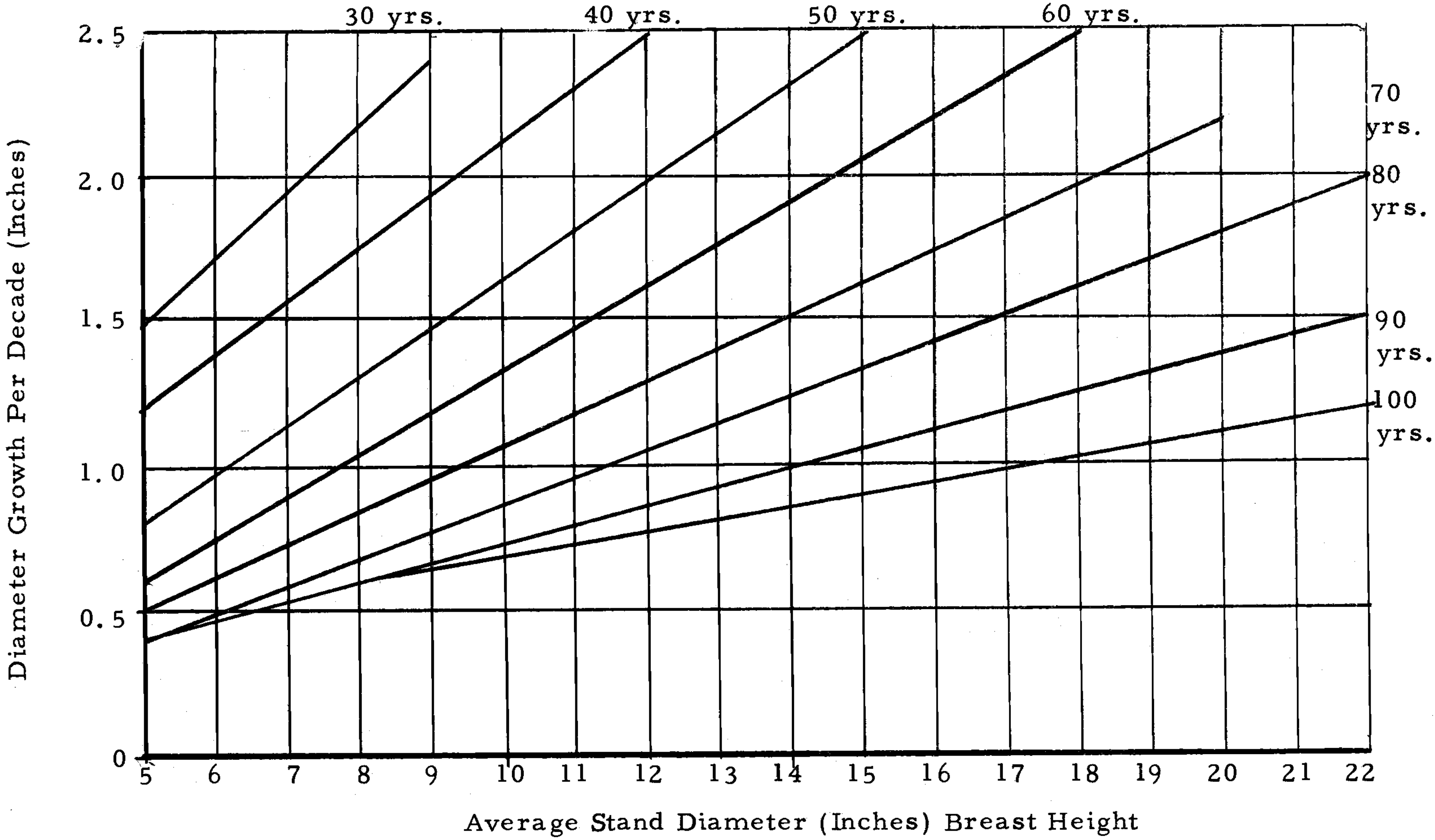

Figure 11. Diameter Growth Per Decade of Quaking Aspen for Trees 5.0 Inches and Larger DBH.

APPENDIX II

TARIFAC

A Computer Program for Tarif Access Table Construction

Introduction

TARIFAC is a FORTRAN IV computer program written for the CDC 3300 computer at Oregon State University to provide tarif access tables for the Comprehensive Tree-Volume Tarif Tables (13). The following relationship was used for computing tarif numbers:

$$\text{Tarif Access Constant} = \frac{0.913}{(B - 0.087)}$$

where:

B = the basal area of a stem for a given diameter (14)

Program Description

TARIFAC performs the calculations required to convert a standard cubic foot volume table into a tarif access table. In simplified form TARIFAC functions as follows:

1. Reads a portion of a standard cubic foot volume table, and interpolates between values to the nearest one-foot

in total height and to the nearest one-tenth-inch in diameter.

2. Reads tarif access constants, and multiplies the above volumes by the tarif access constant.

3. Prints the above computed tarif numbers in table form with headings.

TARIFAC has several limiting factors that must be understood before it can be successfully utilized:

1. It will handle only a portion of the original volume table on each run. Each run will handle two 11 X 6 volume matricies. The first column of the second matrix must be the fifth colume of the first matrix.

2. The volume matricies must be based on ten-foot height and one-inch diameter increments.

3. If a second run is needed, as usually is the case, the first row of the second run matricies must be the same as the last row of the first run matricies.

4. If there is no volume shown on the volume table for a given height and diameter, the volume input must be zero.

<u>Input</u>

1. Variables:

   A. Cubic foot volume is entered in two 11 X 6 matricies on cards one through 11 and 121 through 131. The FORMAT specification for each card is 6F6.2.

   B. Tarif access constants are entered on cards 12 through 112. The FORMAT specification for each card is F6.4.

   C. Matrix index values of the first and last column of the access table to be printed each time through the printing DO LOOP are entered on cards 114, 116, 118, 120, 133, 135, 137, 139, and 141. The FORMAT specification for each card is 2I2.

2. Headings:

   The beginning diameter to be printed each time through the printing DO LOOP is entered on cards 113, 115, 117, 119, 132, 134, 136, 138 and 140. Also, the total heights to be printed across the top of each table are entered on the above cards. The FORMAT specification for each card is F2.0 10I4.

Output

The output is a tarif access table for the desired species. Because of printer limitations the output consists of several segmented tables. Each table covers ten feet of height by one-foot increments and ten inches of diameter by one-tenth-inch diameter increments.

Program Listing

```
          PROGRAM TARIFAC
          DIMENSION CV(101, 51)ACCESS(171, 51), TA(101), MM(10)
    100   FORMAT (6F6.2)
    101   FORMAT (F6.4)
    102   FORMAT (///58H)      TARIF ACCESS TABLE  FOR
IN S. W. COL
          CORADO///)
    103   FORMAT(///4H DBH, 46X, 23HTOTAL  HEIGHT - FEET)
    104   FORMAT(F2.0, 10I4)
    105   FORMAT(1H, 3HOB, 10(7X, I4))
    106   FORMAT(1HO, F5.1, 10(6X, F5.2))
    107   FORMAT(1H,3H OB, 7X, 3H110)
    108   FORMAT(1HO, F5.1, 6X, F5.2)
    109   FORMAT(2I2)
          PRINT 102
          DO 99 N=1, 2
          DO 10 I =1, 101, 10
     10   READ (20, 100)(CV(I, J), J=1, 51, 10)
          DO 15 I=1, 101
          IF(N.EQ.2) GO TO 20
     15   READ (20, 101)TA(I)
     20   DO 20 I=1, 101, 10
          J=1
          DO 30 K=1, 5
          MMN=J+10
          IF(CV(I, MMN).AND.CV(I, J)) 24, 27
     24   DIFF=DV(I, J+10)-CV(I, J)
```

```
      STEP=DIFF/10.
      MMM=J-1
      DO 25 L=1, 9
      M=J+L
      MMM=MMM+1
25    CV(I, M)=CV(I, MMM)+STEP
      GO TO 30
27    MNN = J+9
      MMNN = J+1
      DO 29 JJ=MMNN, MNN
29    CV(I, JJ)=0.0
30    J=J+10
      DO 40 J=1, 51
      I=1
      DO 40 K=1, 10
      MMM=I+10
      IF(CV(MMN, J).AND.CV(I, J)) 34, 37
34    DIFF=CV(I+10, J)-CV(I, J)
      STEP=DIFF/10.
      MMM=I-1
      DO 35 L=1, 9
      M=I+L
      MMM=MMM+1
35    CV(M, J)=CV(MMM, J)+STEP
      GO TO 40
37    MNN=I+9
      MMNN=I+1
      DO 39 II=MMNN, MNN
39    CV(II, J)=0.0
      MN=MMN
      MMN=MN+10
40    I=I+10
      DO 45 I=1, 101
      DO 45 J=1, 51
45    ACCESS(I, J)=TA(I)*CV(I, J)
      IF(N.EQ.2) GO TO 55
      DO 50 LL=1, 4
      PRINT 103
      READ (20, 104)A, (MN(I), I=1, 10)
      READ (20, 109)JJ, NN
      PRINT 105, MM
      DO 50 I=1, 101
      PRINT 106, A, (ACCESS(I, J), J=JJ, NN)
```

```
50      A=A+0.1
        GO TO 99
55      DO 60 LL=1,5
        PRINT 103
        READ(20,104)A,(MM(I),I=1,10)
        READ(20,109)JJ,NN
        PRINT 105,MM
        DO 60 I=1,101
        PRINT 106,A,(ACCESS(I,J),J=JJ,NN)
60      A=A+0.1
        A=A-10.1
        PRINT 103
        PRINT 107
        DO 65 I=1,101
        PRINT 108,A,ACCESS(1,51)
65      A=A+0.1
99      CONTINUE
        STOP
        END
```