University of Michigan

An Investigation into the Possibility of Developing Straight Line Time Trends Based on Basal Area To Aid in Determining Costs in the Logging Industry

Prepared by

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Introduction

In this writing, basal area of diameter breast high has been used as the basis of determining the time necessary to complete the various operations in converting standing timber to rough lumber. It is hoped that the basal area concept as a means of determining costs will prove satisfactory. Since a certain amount of work is necessary to sever the wood fibers of any specified cross-sectional area of any particular species, it is conceivable that some unit of this area, i.e. basal area in square feet would be a logical approach to cost analysis. This theory was originally advanced by the late Professor D. M. Matthews and in response to his request these additional investigations have been made.

It is a well known fact that basal area as a measurement of timber is relatively new and is not in use by the logging industry. This paper shall endeavor to present an acceptable method of converting basal area to volume in terms of the Scribner and Doyle log rules for mature northern hardwoods in Iron County, Michigan, or any similar area. A volume table for this forest type and area is also developed and presented here.

Quadratic equations and curves act as barriers in attempting to get new ideas accepted, therefore, here an attempt is made to develop straight line trends.

Naturally this gives linear equations which are more easily presented. It follows that constant variation from size class to size class could be given with the time required at some specific diameter. This rule of thumb, if you will, would be usable by the layman in the woods; therefore, if such trends can be developed for various species and areas, a new operator in an area would have some basis for estimating probable costs on a contemplated operation.

I would like to acknowledge the aid given me in the preparation of this paper. The late Professor D. M. Matthews stimulated my original interest and provided me with the original time studies used in this report. Data collected by the students of the Forestry school on northern hardwood species was used to make the form class volume table. Cruise data from Gogebic County, Michigan, by Mr. Frank Murray was used to make the stand tables. Many stimulating discussions and suggestions were received from Mr. George Banzhaf, Mr. Thomas Hellings and Mr. John Carow.

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Ann Arbor, Michigan

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Chapter 1

To conduct any time or cost study, suitable volume and stand tables must be available. After doing some searching for applicable tables, it was decided to construct originals for use in this investigation. The accuracy of these tables can be no better than the original data; therefore, it was necessary to locate reliable data.

Volume Table Construction

The volume table was constructed from data collected by the students of the School of Forestry and Conservation at summer camp in 1947. The original measurements were made on felled hardwood trees in the vicinity of Camp Filibert Roth, Iron County, Michigan. Diameter outside bark at 4.5 feet from the ground was taken as diameter breast height. The scaling diameter of each 16 foot log of each tree was recorded. All diameters were measured to the nearest 0.1 inch on each of the 70 trees used. This data was then sorted into 3 broad diameter groups. The breakdown was by 12 to 16 inch diameter class inclusive, 18 to 22 inch inclusive, and 24 to 28 inch inclusive.

After sorting this data, the taper of each log was determined and these tapers, to the nearest 0.1 inch were averaged for each log, i.e. first log, 2nd. log, etc. by group breakdown. The form class of any tree is found by multiplying the quotient of the top diameter inside bark divided by the diameter breast height outside bark by 100. To ascertain the form class for each group the form class of each individual tree was calculated and the average for each group determined. These figures were entered into Table 1 and were used to determine the top diameters inside bark and volumes in both the Scribner and Doyle log rules. The volumes in Scribner were read from the volume table page 408 in Forest Mensuration by Bruce and Schumacher, and those in the Doyle rule were calculated by the formula for that rule.

These volumes were then plotted over tree lengths in 16 foot logs. From the curves fitted to these points the volumes could be read by 0.5 log lengths and plotted over the diameters breast height. The results of this plotting is shown in Figures 1,2,3 and 4. It was from the graphs in Figures 3 and 4 that the volumes for the volume tables were read. Upon checking the aggregate difference of these tables it was found that the Scribner volume table was 2.9% higher than that of the actual volumes and 1.28% low in the Doyle table. Appendix A includes these volume tables.

Development of the Stand Tables

Mr. Frank Murray provided the basic data for the construction of the stand tables. Cruise sheets from Gogebic County, Michigan, were used in the development of the stand and stock tables in appendix B. These tables include not only the diameter breast height, number of trees per acre, basal area per acre and volumes in both Scribner and Doyle, but the board feet per square foot of basal area.

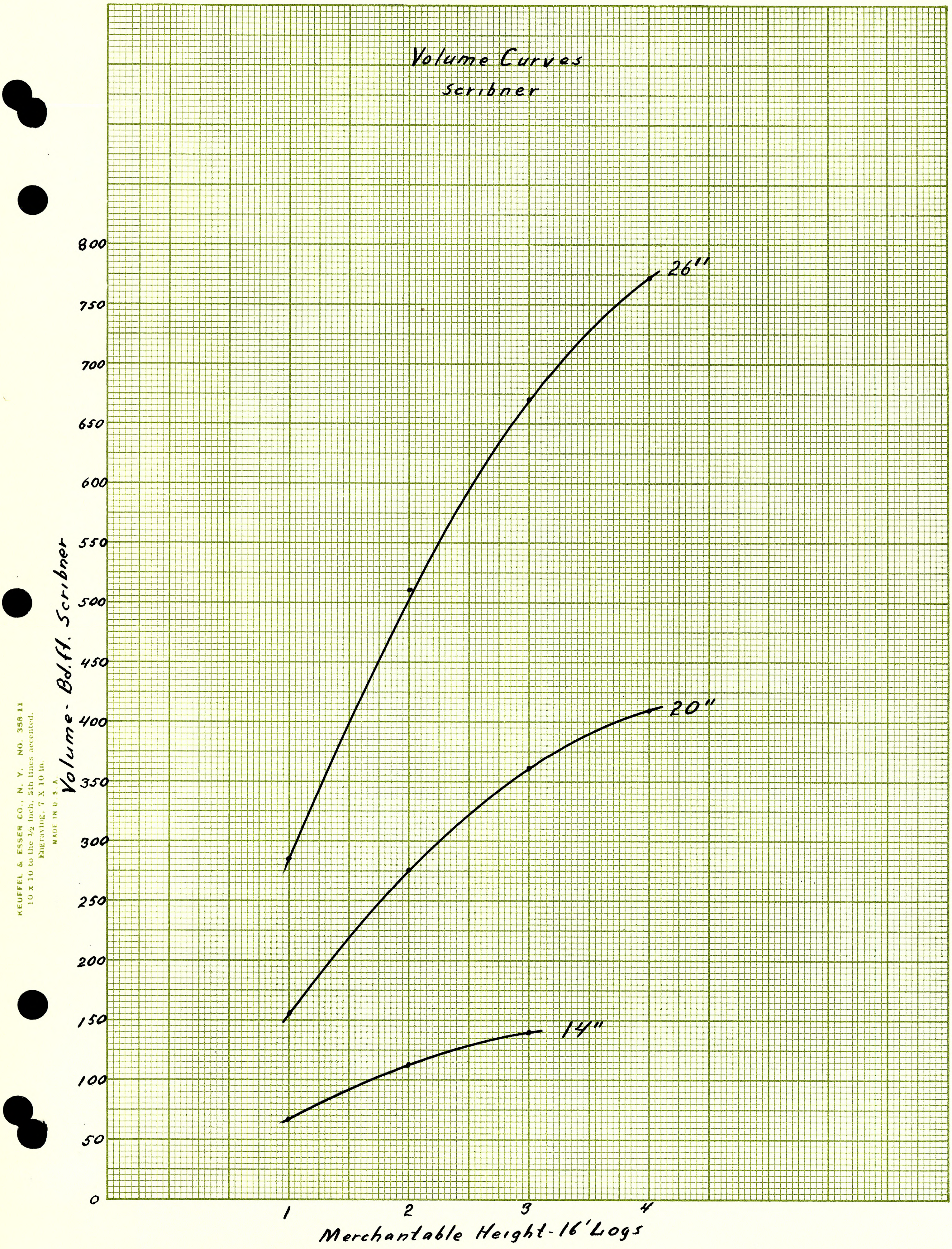
The total number of trees tallied were of two classes, some were in the form of a cruise of about 10% of the residual stand and the others were a 100% cruise of the trees which had been marked for cutting. The various totals by diameter classes and log lengths were multiplied by the appropriate factor and these figures in turn added to the totals of the trees marked for cutting. These totals divided by the number of acres in the area concerned provided the figures in the column--Number of trees per acre. The number of trees per acre times the basal area per tree gave the basal area per acre and the number of trees multiplied by the average volume per tree, which was determined by using the previously prepared volume table, gave the volume per acre.

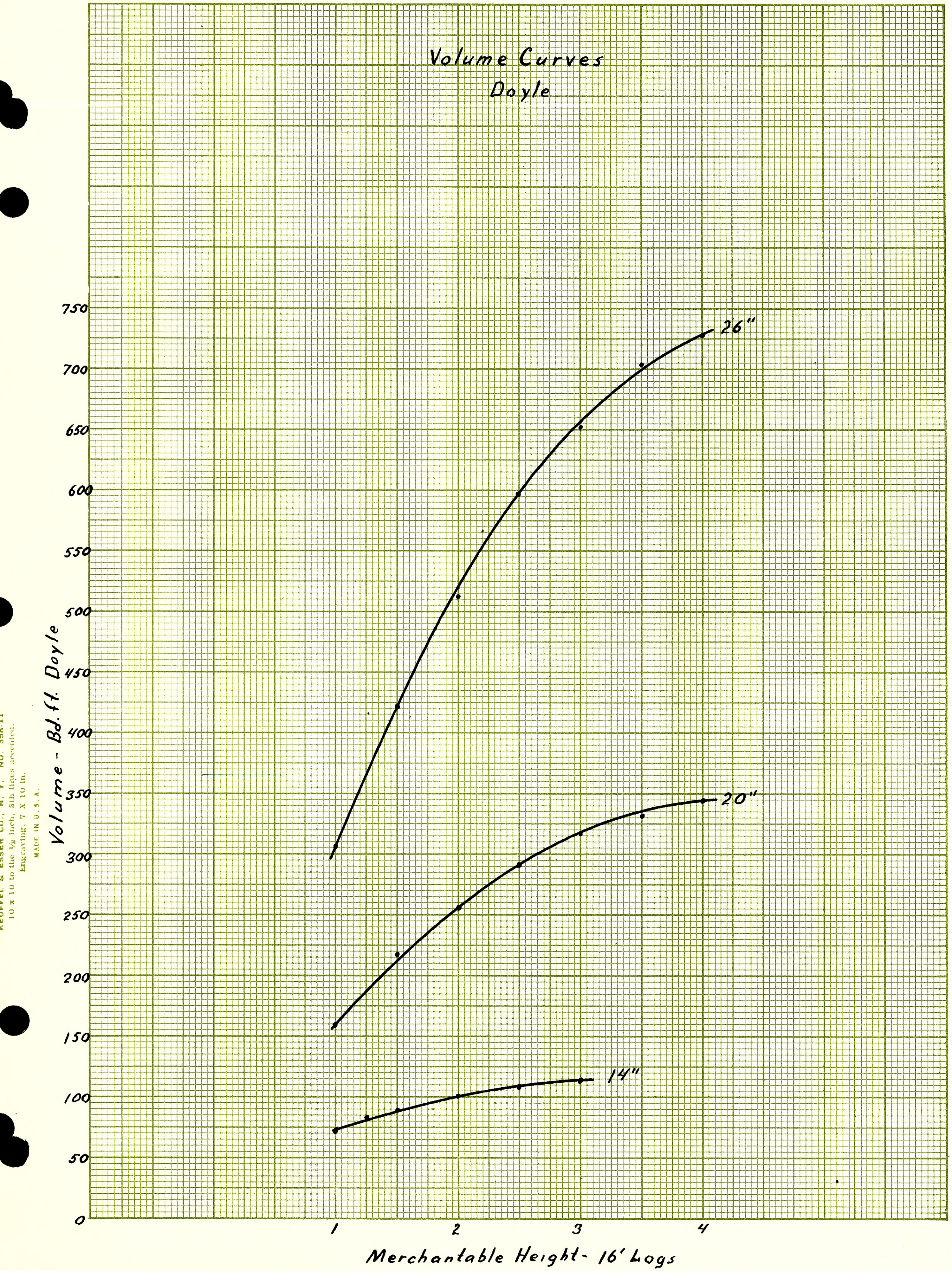
In that the time basis used later in this study is man minutes per square foot of basal area, it is necessary to know the volume per square foot of basal area so that a conversion may be made from basal area to board feet. This figure was obtained by dividing the volume per class by the corresponding basal area.

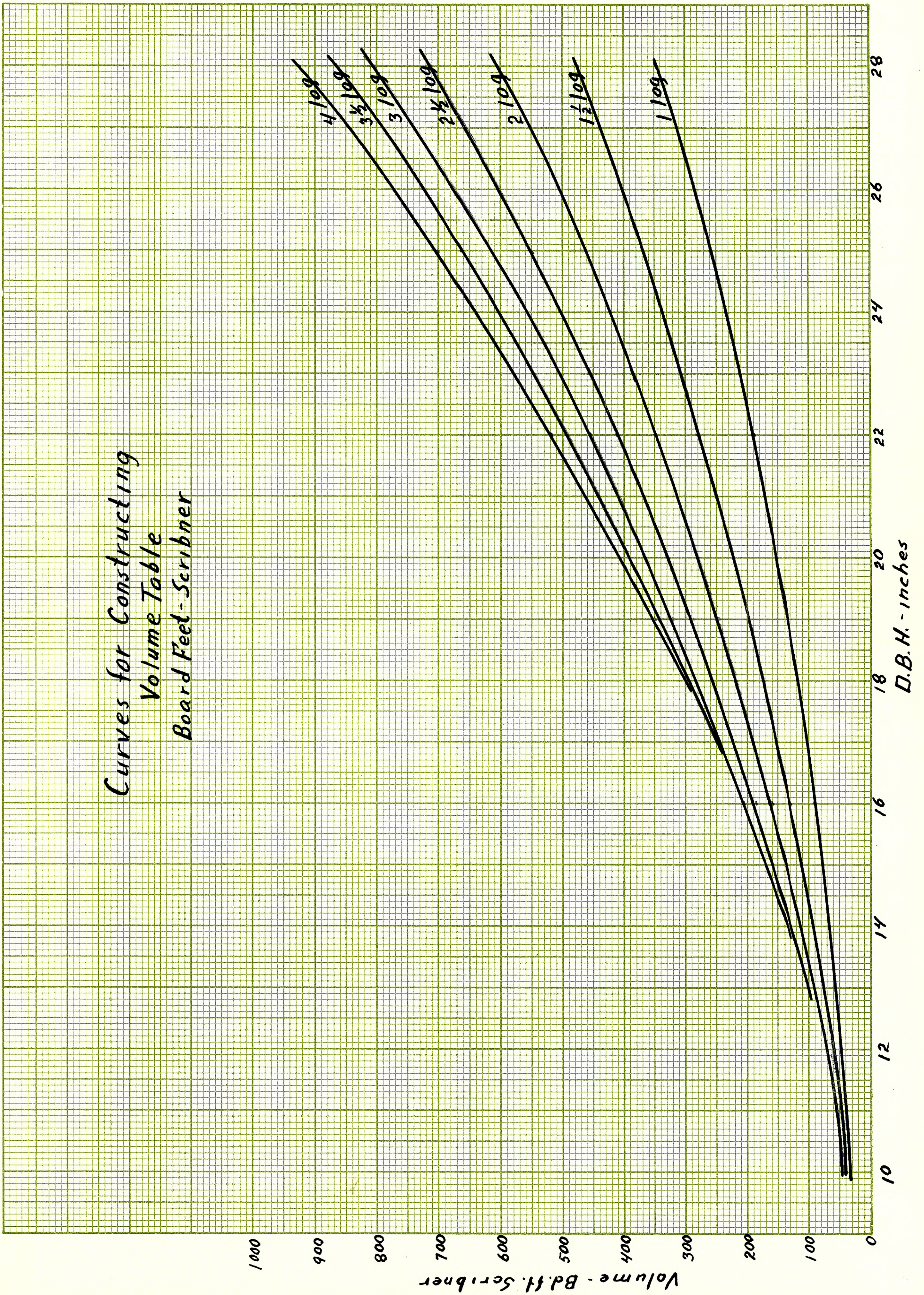
Table 1

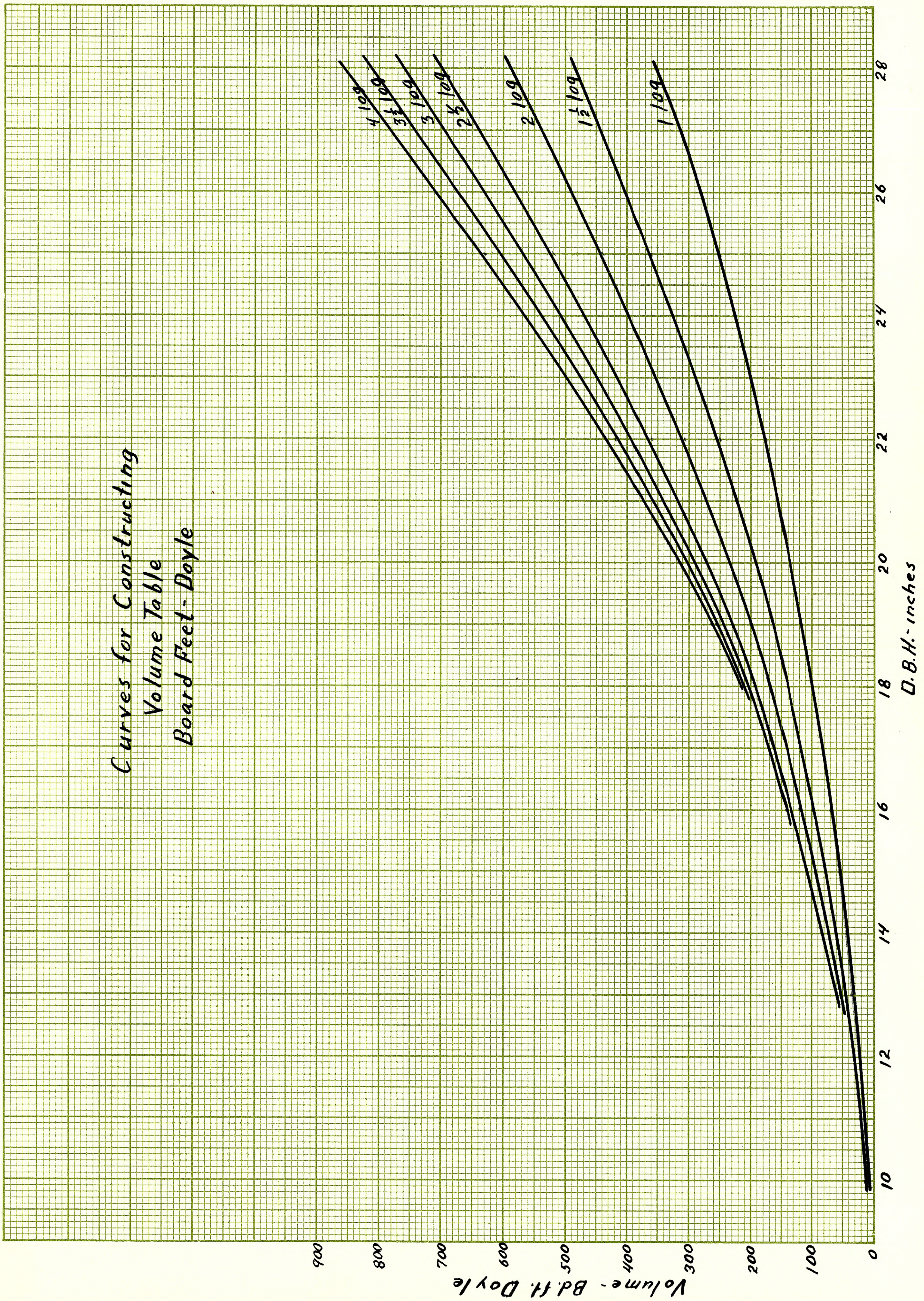
Compilation of Data for Making Northern Hardwood Volume Tables

D.B.H. Class	D.B.H. Used	Av. F.C.		Merchantable Height in 16-foot Logs 1 log	1½ log	2 log	2½ log	3 log	3½ log	4 log
12-16	14	78.0	Taper		0.8	0.8	0.9	0.9		
			Top dib.	10.9	10.1	9.3	8.4	7.5		
			Vol.Scrib.	6.8	93	114	129	139		
			Vol.Doyle	48	67	76	86	88		
18-22	20	78.1	Taper		0.9	0.9	1.0	1.1	1.2	1.2
			Top dib.	15.6	14.7	13.8	12.1	11.7	10.5	9.3
			Vol.Scrib.	157	222	276	325	362	390	409
			Vol.Doyle	135	192	231	264	290	311	318
24-28	26	78.6	Taper		1.0	1.0	1.3	1.4	1.4	1.5
			Top dib.	20.4	19.4	18.4	17.1	15.7	14.3	12.8
			Vol.Scrib.	284	404	511	600	670	727	770
			Vol.Doyle	279	398	487	573	624	677	701


Volume Curves
Scribner
26"
20"
14"
Volume - Bd.ft. Scribner
Merchantable Height - 16' Logs
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
1
2
3
4
KEUFFEL & ESSER CO., N. Y. NO. 358 11
10 x 10 to the 1/2 inch, 5th lines accented.
Engraving, 7 X 10 in.
MADE IN U. S. A.


Volume Curves
Doyle
Volume - Bd. ft. Doyle
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
26"
20"
14"
1
2
3
4
Merchantable Height- 16' Logs
KEUFFEL & ESSER CO., N. Y. NO. 358-11
10 x 10 to the 1/2 inch, 5th lines accented.
Engraving, 7 X 10 in.
MADE IN U. S. A.


Curves for Constructing
Volume Table
Board Feet - Scribner
4 log
3½ log
3 log
2½ log
2 log
1½ log
1 log
D.B.H. - inches
10
12
14
16
18
20
22
24
26
28
Volume - Bd.ft. Scribner
0
100
200
300
400
500
600
700
800
900
1000


Curves for Constructing
Volume Table
Board Feet - Doyle
D.B.H. - inches
Volume - Bd.ft. Doyle
4 log
3½ log
3 log
2½ log
2 log
1½ log
1 log
10
12
14
16
18
20
22
24
26
28
0
100
200
300
400
500
600
700
800
900

Chapter 2

It is well known that basal area as a unit of measurement is not in use in the field. To date so many square feet of basal area is used in the laboratory or research office only. In that in this study the time required to perform the various operations of logging and milling is in terms of man-minutes per square foot of basal area, it is necessary to devise some means of converting basal area to board foot volume. Without a way of making this conversion such a study would be of use only to the technically trained man and of no use to the untrained operator who this is intended to help.

In order to develop a method of making this conversion it was necessary to construct the stand and stock tables referred to in the preceding chapter. The basal areas and volumes were totaled for all species by diameter classes. This gives weighted totals which in turn gives proper weights to each species. The total basal area was then divided into the total volume which gave a volume per square foot of basal area figure. Upon plotting these volume figures over diameter breast height a definite trend could be seen. Figures 5 and 6.

These trends seemed to be straight lines, therefore an attempt was made to fit straight lines to the data. The data carried sufficient weight from the 10 inch to the 24 inch class. For the Doyle rule one straight line fit the diameter range of 10 to 21 inches well. From the 20 inch class up there seems to be a smaller increase in volume per square foot of basal area which was fitted with one straight line. The data from 30 to 36 inches was very erratic and light so no fact can be drawn from this range.

When the Scribner volumes were plotted it was noted they run relatively higher than the Doyle values with a tendency to come together. ~~about the 30 inch class~~. The initial rate of rather fast increase in volume appears to taper off at about the 18 inch class. At this point the Scribner rule levels off more than does the Doyle rule at the 21 inch class so that they cross at about the 30 inch class.

Even though these graphs are easily readable, it seems advantageous to state the conversion factors in terms of linear equations. To do this it was necessary to determine the slope of the line which is the rise divided by the horizontal run. The volume intercepts of the trend lines were read off and both of these figures substituted in the general formula of a straight line which is $y = ax + c$. In this formula we let $y = V =$ volume, $a =$ the slope of the trend, $x =$ the diameter breast height, and $c =$ the intercept on the volume axis. Rewriting the formula using symbols suitable to forestry, we get the equation $V = (a \times DBH) + c$.

The graphs and formula for the trend lines developed here are given in Appendix D.

To check the soundness of these trend lines a series of calculations are in order. Using the stand table for hard maple in Appendix B as a source for the basal area per acre and the volumes as read from the trend lines just developed the following computations are made. First using the Doyle values for sugar maple we have:

0.90	x	31.2	=	28.08
2.85	x	44.5	=	127.27
4.42	x	57.5	=	254.15
5.66	x	70.5	=	399.03
6.23	x	83.5	=	521.27
4.40	x	96.7	=	425.48
2.86	x	104.7	=	299.44
2.42	x	107.5	=	260.15
0.63	x	110.2	=	69.33
0.38	x	113.0	=	42.94
0.05	x	115.8	=	5.79
				2427.93 bd. ft.

Volume 10-30 inch classes from stand table	2502.54
Volume 10-30 inch classes from above table	2427.93
	74.61

This is 2.98% low.

Now using the Scribner values we have:

0.90	x	62.2	=	55.98
2.86	x	74.0	=	211.64
4.42	x	85.6	=	378.35
5.66	x	97.5	=	551.85
6.23	x	109.2	=	680.32
4.40	x	110.3	=	485.32
2.86	x	111.7	=	319.46
2.42	x	113.1	=	273.70
0.63	x	114.5	=	72.14
0.38	x	115.9	=	44.04
0.05	x	117.3	=	5.87
				3078.67

Volume 10-30 inch classes from stand table	3278.97
Volume 10-30 inch classes from above table	3078.67
	200.30

This is 6.11% low.

Now using the stand table for yellow birch and the volume per square foot basal area values for the Scribner rule we have:

1.04	x	62.2	=	64.69
1.81	x	74.0	=	113.94
3.23	x	85.6	=	276.49
3.74	x	97.5	=	364.65
4.24	x	109.2	=	463.01
4.14	x	110.3	=	456.64
3.02	x	111.7	=	337.33
4.20	x	113.1	=	475.02
1.37	x	114.5	=	156.87
1.11	x	115.9	=	128.65
1.08	x	117.3	=	126.68
				2983.97

Volume 10-30 inch classes from stand table	2724.80
Volume 10-30 inch classes from above table	2983.97
	259.17

This is 9.51% high.

Now using thesstand table for yellow birch and the volume per square foot basal are values for the Doyle rule we have:

1.04	x	31.2	=	32.45
1.81	x	44.5	=	82.55
3.23	x	57.5	=	185.73
3.74	x	70.5	=	263.67
4.24	x	83.5	=	354.04
4.14	x	96.7	=	400.34
3.02	x	104.7	=	316.19
4.20	x	107.5	=	451.50
1.37	x	110.2	=	150.97
1.11	x	113.0	=	125.43
1.08	x	115.8	=	125.06
				2487.93

Volume 10-30 inch classes from stand table	2295.00
Volume 10-30 inch classes from above table	2487.93

This is 8.38% high.

If the basswood stand table is used, the volume by the Doyle rule will be:

0.10	x	31.2	=	3.12
0.31	x	44.5	=	13.80
0.21	x	57.5	=	12.08
0.42	x	70.5	=	29.61
0.55	x	83.5	=	46.93
0.11	x	96.7	=	10.64
0.31	x	104.7	=	32.46
0.53	x	107.5	=	56.98
0.07	x	110.2	=	7.71
0.04	x	113.0	=	4.52
0.05	x	115.8	=	5.79
				224.64

Volume 10-30 inch classes from stand table	273.50
Volume 10-30 inch classes from above table	224.64
	48.86

This is 17.9% low.

Now using the Scribner rule we have:

0.10	x	62.2	=	6.22
0.31	x	74.0	=	23.94
0.21	x	85.6	=	17.98
0.42	x	97.5	=	40.95
0.55	x	109.2	=	60.06
0.11	x	110.3	=	12.13
0.31	x	111.7	=	34.63
0.53	x	113.1	=	59.94
0.07	x	114.5	=	8.02
0.04	x	115.9	=	4.64
0.05	x	117.3	=	5.87
				274.48

Volume 10-30 inch classes from stand table	335.10
Volume 10-30 inch classes from above table	274.48
	60.62

This is 18.1% low.

As will be noticed in the foregoing calculations there is considerable error in any one species In that the original conversion of these should have been done as one calculation. Therefore if we consolidate the previous work we will get the following result.

Species	Scribner Stand Table	Scribner Conversion	Doyle Stand Table	Doyle Conversion
Hard Maple	3278.97	3078.67	2502.54	2427.93
Yellow Birch	2724.80	2983.97	2295.00	2487.93
Basswood	335.10	274.48	273.50	224.64
	6338.87	6287.12	5071.04	5140 .50

Which gives us a 0.82% lower figure by using the conversion formula in conjunction with the Scribner rule. With the Doyle rule the conversion is 1.37% higher. These percentages certainly indicate that it is entirely possible to develop reliable conversion formula. These could be worked out for any number of species in all areas, or could be worked out for different forest types in the different areas. For the purpose of this study the formula developed so far will serve to prove the point.

Chapter 3

The principle objective of this investigation is to determine the possibility of using straight line trends based on basal area as a means of estimating the probable time or cost of a logging or milling operation. Since the wood fibers are uniform in any particular species it is quite conceivable that a certain amount of energy is required to break the fibers of any specified cross sectional area. In that basal area breast height would be relatively easy to determine and has been used in research and taught in the technical training given potential foresters, it will be the basic unit upom which the time required will be calculated.

The original data was provided by the late Professor D. M. Matthews. These data were unpublished time studies made by the U. S. Forest Service. Of the time studies available, seven were chosen to be worked up in this investigation.

There were three studies conducted in the states of New York, New Hampshire and Vermont in 1936-37. The study made in Vermont occupied a median position so it was used. In addition to the three predominant species used in this investigation, the stands included white ash, red spruce, hemlock, balsam fir and basswood in small quantities.

The felling and bucking was performed by two crews of two men each. There were two units skidding each composed of one man and one horse. The hauling was done by one 20 H.P. caterpillar tractor and scoot over an average estimated distance of 2500 feet. Included in this operation was part of the road work, loading and hauling. In the milling phase of the operation a portable mill was operated by a crew consisting of a head sawyer, one deckman, one offbearer, one marker and one fireman.

The original study in northern Wisconsin was made by Raymond H. Miller and associates in 1935-36. The stand here studied also included hemlock as well as the yellow birch, sugar maple, elm and basswood which are incorporated in this report.

The operations of skidding, loading and hauling overlapped. These operations were performed by a crew composed of one and a half truck drivers, two teamsters and two swampers. There is no statement available as to the manner of organization for the felling and bucking. On this operation the sawmilling was done by a single band mill with shotgun feed. The 38 men employed, operated this mill and its equipment which included a pond, edger, trimmer, green chain and lumber yard space.

There are sixteen columns in the work sheets, Appendix C, Tables 4 - 10 inclusive, of time per unit for the various operations, etc. A general discussion at this point on the derivation of the various columns will give an insight into the following discussion. Column 2 was taken from basal area tables. Columns 1, 3, 5, 8, 11 and 14 were taken from the original time study sheets. To determine the basal area per M, column 4, the volume per tree was divided unto the basal area per tree and this quotient multiplied by 1000. The man hours per square foot of basal area columns under each of the major operations was calculated by dividing the basal area per M into the man hours per M in each of the operations. These last figures multiplied by 60 minutes gave the last column under each operation heading.

The first step in attempting to develop these straight line trends after acquiring the original data was determining the man-minutes per square foot of basal area. These values were then plotted over d.b.h. in the graphs in Appendix C. Smooth curves were adjusted by halves so that each end ofthe curve is better fitted and therefore more accurately placed on the data. After plotting the curves as well as possible straight lines were then fitted to the data. These straight lines are the potential trend lines, if you will, that we are looking for.

When the curves had been plotted many things were noted, among which was the similarity of curves for one operation in each of the two areas under consideration. The curves for the Vermont studies were not as uniform as those from Northern Wisconsin. The maximum diameter range used in the Vermont study was from 11 inches to 23 inches inclusive. The original data covered a wider range but the relative weights of the end points which were dropped were of little importance. This is evidenced by the small weights shown on the end points of the graphs.

Upon examining the curves plotted for felling and bucking, Figures 7, 11 and 15, we find the sugar maple shows the same relative hump at about the 14 inch class. The yellow birch and beech on the other hand show a rather steady downward trend throughout the diameter ranges under consideration. In both of the later cases this drop is about 0.44 minute per diameter class, for the yellow birch it is 0.45 minutes and for the beech it is 0.43 minutes. The actual time ranges are for the yellow birch 18.1 minutes to 23.5 minutes, for the beech 19.1 minutes to 23 minutes over a range of 9 inches which is well within the 12 inch range of the yellow birch. The variation in the sugar maple curve is about 0.27 minutes per diameter class from the 14 inch class up. These figures on variation per size class are fairly close to one another and further investigation may show a more definite trend. It will be noted though that the time for sugar maple is consistently a little higher than the other species. This may be due to the higher specific gravity or density of this species.

The skidding curves, Figures 8, 12 and 16, show very similar characteristics in that they all drop steadily over most of the diameter ranges being studied. They also show a tendency to level off in the larger sizes. The drop per inch of increase in diameter class of the sugar maple is 0.56 man-minutes. For the yellow birch we find a decrease of 0.58 man-minutes for each inch of diameter increase. In this respect the beech is slightly lower. It's decrease for each inch of increase of diameter class is 0.53 man-minutes per square foot of basal area. Should the curves of skidding in northern Wisconsin show close similarities to these curves it may be concluded that the skidding time per square foot of basal area has a definite trend. It will be noted that the straight lines as fitted to these data fit remarkably well and easy on the graphs.

All three of the hauling curves, Figures 9, 13 and 17, have different trends. Both the yellow birch and sugar maple curves show an increase in the lower diameter with a decrease in the upper diameter. The increase in the sugar maple data is more rapid than in the yellow birch where as the decrease is gentler. From 14 inches to 23 inches inclusive on the sugar maple graph, the time plotted starts at 19.1 man-minutes rises to 19.7 man-minutes at 17 inches and then drops back to 19.0 man-minutes. That is a 0.15 man-minute increase and a 0.10 man-minute drop. For most purposes this might be interpreted as a horizontal line. The yellow birch starts at 17.9 man-minutes in the 11 inch class then rises to 18.6 man-minutes at the 14 inch class or 0.18 man-minutes per one inch increase in diameter and drops off to 17.5 man-minutes in the 22 inch class, 0.12 man-minutes per inch. In contrast to the rising then falling curve of the two above mentioned species the beech curve steadily rises from 16.0 man-minutes at the 12 inch diameter to 17.3 man-minutes at the 20 inch diameter, which is 0.13 man minutes per inch increase in diameter. This increase tends to counter balance the drops in the other curves and if the weighted average were calculated it would be found to be 18.43 man minutes per square foot of basal area.

The milling curves, Figures 10, 14, 18, show a downward trend from about the 13 inch class up on the hard maple and yellow birch studies. The general lay of the data seems to indicate a rise in time to this point or at least in the lower diameter classes. This might indicate that the milling practice was to saw the smaller trees with increasing care as to quality outurn up to the point where the time starts to come down. These indications are not found in the curve for milling of the beech. In this curve we see a fairly steady increase in time per square foot of basal area with the larger sizes. It might be found if these studies were carried farther that a horizontal or slightly descending trend would be developed. The maximum differential in the plotted data is only 2.8 man-minutes per square foot of basal area for a 11 inch range in the yellow birch. This would show only about a 0.25 minute differential from size class to size class. Upon considering the three specbs together there is a maximum differential of 4.6 man-minutes over a range of 12 inches even this gives about a drop of 0.40 minute from one diameter to the next larger.

Northern Wisconsin Study

It will be noted that the felling and bucking curves Figures 19, 23, 27, 31, for this operation show decided inclinations toward a decrease in time with an increase of diameter breast high. In one case this decline is shown only in the 10 to 28 inch diameter. This curve for the elm shows an increase of about 1 man-minute from 14 inches to 20 inches inclusive. The decrease is about 2 man-minutes for the diameter range from 20 inches to 28 inches. These figures show a general decrease for the entire range being studied, which correlates with the curves for the other species. The curve for the felling and bucking of yellow birch shows an increase in the lower three diameters but from 14 inches up to the 24 inches class there is a decrease of 4.5 man-minutes per square foot of basal area. This gives a net fall of about 0.45 man-minutes per inch increase in diameter. The felling and bucking curve for sugar maple drops from 22.3 man-minutes to 17.4 man-minutes over a range of 15 inches or a decrease of 0.35 man-minutes per square foot of basal area for each inch of increased diameter. These decreases are upheld by the basswood curve. It drops from 19.4 man-minutes at 13 inches to 14 man-minutes at 27 inches. This is a drop of 0.39 man-minutes per inch of increase in diameter. It is interesting to note that this particular curve is encouraging as an indication that the straight line trend may prove applicable. A slight S curve could have been fitted to the data of the basswood felling and bucking time but the curvature would have been practically negligible.

Three of the skidding curves, Figures 20, 24, 28, 32, have two separate slopes. The basswood curve for instance drops from 27.2 man-minutes at the 13 inch class to 17.7 man-minutes at the 20 inch class for an average drop per diameter class of 1.36 man-minutes. The diameter range of 20 inches to 27 inches has a decrease from size class to size class of 0.83 man-minutes. Sugar maple most closely resembles the basswood in respect to time. The average drop over the 12 to 20 inch classes is 1.19 man-minutes per inch of increase in diameter. For the upper diameter range of 20 inches to 26 inches, the average decrease in time is 0.67 man-minutes per square foot of basal area for eahh inch increase in diameter breast high. The other curve showing two separate slopes is the one for elms. Here too the break in slope is at 20 inches.

For diameter below this point, we have an average decrease in man-minutes of 0.63 for every inch of diameter. The diameter larger than 20 inches have about 0.21 man-minutes fall in time per inch of diameter increase. In this series we find the yellow birch curve assumes a definite S pattern. Because of the location of the data here we find that one straight line or rather one continuous slope is best suited for discussion. Considering this as a one slope line we have a drop of 0.78 man-minutes per square foot of basal area for the diameter range of 12 to 24 inches inclusive.

It is very interesting to see that part of the loading and hauling curve for the basswood, Figure 29, also plots as a straight line. The part of the curve from 13 inches to 18 inches inclusive rises then falls with the high point being at 15 inches. The rise is only 0.40 man-minutes and the drop over the above range is 0.50 man-minutes per inch. Under examination we find that the drop per inch of diameter breast high for the straight line range of this curve is 0.43 man-minutes. The loading and hauling curve for elm Figure 33 and the other two has the same general shape as the basswood in that it rises through the lower diameter classes and then falls off to the end of the range. The rise in this case is from 14 inches to 19 inches inclusive. The net change over this range is plus 2.3 man-minutes or about 0.46 man-minutes per inch of increased diameter. From 19 inches to 28 inches the data drops 2.5 man-minutes per class. The sugar maple curve, Figure 21, rises from the 12 inch class to the 14 inch one inclusive. Over these diameters the rise 0.80 man-minutes or 0.40 man-minutes per inch increase in diameter. From 15 inches to 26 inches the trend is down with a drop of 4.6 man-minutes. This gives us a decrease in time of 0.42 man-minutes for each inch of diameter increase. All of these trends are very similar as is also the one for yellow birch. The yellow birch curve, Figure 25, rises from 12 inches to 15 inches at the rate of 0.50 man-minutes per inch of diameter increase. The slope down starts with the 16 inch class and continues through the 24 inch diameter. Over this range of diameter there is a drop of 0.35 man-minutes for each inch.

The most strikingly similar curves in this study are those pertaining to milling, Figures 22, 26, 30, 34. They all rise rapidly and reach a high point around the 18 to 20 inch class, from which they rapidly drop off. This high point probably is at the point where the height growth of the tree slows to practically nothing, that is the length in logs comes to a standstill. This would cause a rapid increase in time in that the number of logs increases more rapidly than the basal area. For each of the logs the time necessary for turning would be about constant so this time would vary directly as to the number of logs in a tree.

Since these curves have such a high point in the middle, it is practically impossible to fit two straight lines to the data. Because of this, three lines would be necessary to make a reasonable fit and this would cause much cnnfusion in the use of these trend lines. Perhaps further study of this type of operation would disclose facts which tend to support or disprove this tendency for the curves to rise and then fall rapidly.

For the basswood milling curve it rises from 76.1 man-minutes at 13 inches to 83.7 man-minutes at 18 inches and then drops to 70.0 man-minutes at 27 inches. This gives a net difference of 13.7 man-minutes over a range of 10 inches which is a sizable variation. The rapid change would have a marked effect on the costs of milling various sizes of trees. Upon examination the sugar maple curves starts at 45.5 man-minutes at 12 inches and ends at 46.5 man-minutes at 26 inches with the high point at 17 inches and a value of 54.9 man-minutes. Once again the variation from inch class to inch class is marked and would seriously effect thd milling cost. The elm curve shows the same rapid change in time from one diameter class to the next. A low point of 47.7 man-minutes at 14 inches is at one end of the curve, at 20 inches the high point is reached with a point of about 59.0 man-minutes. When we get to the 28 inch the man-minutes are down to 48.2. The milling curve of the yellow birch shows the same general trend except the decrease from the high point is more gentle. Here we have a value of 39 man-minutes for the 12 inch class which rises to 50.6 man-minutes at the 19 inch diameter. The decline from this point is rather gradual to a point at 24 inches where the time value is 47.7 man-minutes. From the original data it is not possible to determine if the practice of the mill may have had some important influence on these curves. If the head sawyer had instructions to saw more for quality as size increased, the time element would increase to some point where quality was at a premium and then gradually taper off. Such a practice would tend to accentuate the hump in these curves.

Determination of Error Induced

In all of the above discussions of the graphs of man-minutes over diameter breast high, I have used the values as actually plotted. Of course these would change if either of the other two possible sets of values were used but the relations would remain practically constant. The other values could have been those read from the curves themselves or the straight lines.

To see if the straight lines induce much error in the time necessary and hence the cost of logging a stand, the following calculations are in order. For the purpose of these computations the values read from the fitted curves and straight lines will be used. There is little net difference between the values on the curve and the plotted points as the curve was balanced in by weighted values. The following form of calculations will be used for determining the error induced if the Northern Wisconsin time study is used.

Yellow Birch -- Felling and Bucking

D.B.H.	Man-minutes per Square foot of BA		B.A. per Acre	Time per Acre	
	Curve	Trend Line		Curve	Trend Line
12	19.5	19.5	1.81	35.3	35.3
14	20.3	20.5	3.23	65.5	66.2
16	19.8	19.5	3.74	72.9	74.0
18	18.5	18.5	4.24	78.5	78.5
20	17.4	17.6	4.14	72.0	72.9
22	16.6	16.6	3.02	50.1	50.1
24	15.8	15.6	4.20	66.4	65.5
				440.7	442.5

In using the above form for computations we find the totals for the following to be:

Felling and Bucking	Curve	Trend line	% of Error
Yellow Birch	440.7	442.5	+.41
Sugar Maple	593.8	594.5	+.12
Basswood	36.9	36.9	.00
Elm	9.8	9.8	.00
	1081.2	1083.7	+.23
Skidding			
Yellow Birch	360.0	359.0	-.28
Sugar Maple	534.2	536.9	+.51
Basswood	42.2	42.1	-.24
Elm	8.8	8.8	.00
	945.2	946.8	+.17
Loading and Hauling			
Yellow Birch	299.2	298.8	-.13
Sugar Maple	416.1	418.0	+.46
Basswood	33.6	33.7	+.30
Elm	5.6	5.6	.00
	754.5	756.1	+.21

I have not seen fit to try to balance in straight lines to the milling curves due to their extreme curvature. For trendlines to be of use they should be relatively simple. In the case of these curves as has been stated before, it would take at least three straight lines to even faintly follow the trend indicated by the curves. This would complicate matters beyond practicability.

From the above tabulations it will be noted that the percentage error induced by using the trend lines as plotted is very small. The most extreme error for all species is less than a quarter of one percent. An operator could hardly hope to estimate costs of an operation closer than this figure. Should we compute the error on an operation which delivers logs to a mill we find the over all error is about 0.20%. This is negligible in the light that it is an estimation.

Chapter Four

We have determined several things in this investigation, some of which are conclusive and others which are only indicative. The indications are primarily that further study is necessary to definitely fix the location of the trend lines and those used in making the conversions from basal area to board foot volumes.

The conversion formulae set forth in this study definitely show that it is possible to correlate basal area at breast height with board foot volume. The data used herein is definitely limited which tends to cast a shadow as to the precise accuracy of these formulae. To accurately develop the necessary formulae, it would be necessary to run a study such as the one conducted in Chapter 2 of this paper on a much larger number of trees. It would also be necessary to broaden the coverage of such investigations to include other species and timber types, as those produced here deal only with the northern hardwoods in the northern hardwood-hemlock type.

In respect to the trend line development it may be stated that they can be developed satisfactorily. We have here shown that such trend lines developed with one set of data applied to a stand table which had been constructed from different data, induced very little error. Although these lines have been determined for the species and area covered in this study it is self-evident that such trends are not fixed in respect to their time values. It is quite likely that these trends could be consolidated by species so as to come up with a heavier weighted trend. If this were to be done, more time study data would have to be consulted.

I have not developed the formulae for the various trend lines as plotted, because I feel there is a need for further study to more specifically locate the lines. Such formulae could be written by the method given in Chapter 2. They could then be stated either in symbols or words for use by the layman as well as the trained man.

It is evident that the felling and bucking operation has a declining time trend per square foot of basal area as the diameter increases. The rate of decrease varies from species to species as does the time required at any specific diameter. As was stated previously, the board foot volume per square foot of basal area increases with diameter. If the time per square foot of basal area was converted to time per M the decrease would be more pronounced thereby getting confirmation from the experience of contract loggers. These loggers have found through selective logging that costs decrease per M as you cut larger sized timber.

Of all the operations, skidding shows the most similarity. For this operation all of the curves have a definite decrease in time with the increase in diameter.

This trend would hold as long as the equipment being used was not made to work outside its load limits. In the Vermont study this trend seems to be a single straight line, but in the Northern Wisconsin study there seems to be a sag at about the 20 inch class, causing two separate trend lines to be used. One may definitely say in the face of the evidence shown in this study that trend lines are applicable to skidding operations.

The time required to load and haul logs tends to increase in the lower diameter ranges then taper off as the larger diameters are reached. This could be partially caused by the relation between height and diameter growth. It has been determined that the maximum merchantable height of lake states hardwoods is usually reached at about the 18 inch class. This would cause the relationship between the number of logs and basal area to level off when this diameter was reached, and therefore the fixed time of hooking and unhooking would become constant on a per tree basis. The one exception to the general trend stated above is the tractor hauling curve for beech in Vermont. This hauling curve climbs throughout the diameter range under consideration. Both the yellow birch and sugar maple curves for the Vermont study turns down in the larger diameter classes. I am unable to correlate this variation in that my knowledge of that area is nil.

The milling phase of the operation presents the most variation. The curves for milling in the northern Wisconsin study are very similar in that they all rise rapidly in the lower diameters, level off around the 18 to 20 inch class, and then decline rapidly to the upper diameter limit of the species studied. As stated before, it is impractical to try to develop trend lines for this operation. The curves for the Vermont study presents three distinct types of curves. For yellow birch, there is a relatively steady decrease throughout the diameter range with the increase in diameter. The curve for the beech shows the opposite trend, that is a steady increase in time with the increase in diameter. The sugar maple curve starts as the beech with rising time values with increasing diameter then a reversal of slope to a decreasing time per square foot of basal area which is similar to the yellow birch curve. Because of these erratic curves it is impossible to draw any conclusions from the milling curves except that further study is needed.

It must be noted that the trend lines here-in developed had the human factor in the original data. How efficient the original workers were is debatable. We can probably conclude that the equipment in use then was not nearly as efficient as that in use today. Because of these factors there probably is need for adjustment in the locations of these trend lines. Quite likely with power saws the felling and bucking trend lines would tend to become more horizontal with a general decrease in the man-minutes per square foot of basal area values. Other improvements in equipment will in turn influence the time values for the operations on which they are used.

To summarize briefly, we have found that trend lines of man-minutes per square foot of basal area over diameter breast high can be developed and induce very slight errors in determining the time necessary to accomplish different operations. A satisfactory method of converting basal area at diameter breast height to board foot volume in either the Doyle or Scribner rule has been developed. The two principle problems of this investigation have therefore been accomplished.

Appendix A

Northern Hardwood Volume Tables

Mature Northern Hardwoods

Birch, Maple, Basswood, and Elm

Iron County, Michigan

B. K. Bowman   1949   Merchantable Top.

Board Feet - Scribner.

DBH inches	Merchantable Height in 16-foot logs							Basis # Trees
	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	
10	35	40	43					
12	40	50	57					8
14	68	93	114	129	139			8
16	90	132	162	187	207			9
18	118	176	219	251	281	292	298	11
20	157	222	276	325	362	390	409	6
22	190	278	348	410	456	495	519	8
24	233	340	426	501	559	605	640	8
26	284	404	511	600	670	727	770	9
28	347	477	604	712	801	866	920	3
Basis # Trees	4		10		50		6	70

Prepared by Form class - taper method

Block indicates extent of basic data

Aggregate difference - +2.9%

Mature Northern Hardwoods

Birch, Maple, Basswood, and Elm

Iron County, Michigan

B. K. Bowman 1949 Merchantable Top.

Board Feet - Doyle

DBH inches	Merchantable Height in 16-foot logs							Basis # Trees
	1	1½	2	2½	3	3½	4	
10	12	13						
12	28	34	38					8
14	48	67	76	81	88			8
16	70	100	122	139	142			9
18	99	140	176	198	208	215	219	11
20	135	192	231	264	290	311	318	6
22	174	245	303	357	392	420	435	8
24	211	318	390	460	504	540	563	8
26	279	398	487	573	624	677	701	9
28	359	490	595	705	763	822	860	3
Basis #Trees	4		10		50		6	70

Prepared by Form class - taper method.

Block indicates extent of basic data.

Aggregate difference - -1.28%

Appendix B

Northern Hardwood Stand Tables

Stand and Stock Table, Hard Maple,

Mature Hardwood - Hemlock, Gogebic County

Michigan

Typical Acre

DBH	#Trees/a	B.A./a	Vol.Scrib.	Bd.ft./ Sq.ft.B.A.	Vol. Doyle	Bd.ft/ sq.ft.B.A.
10	1.64	0.90	57.40	63.78	19.68	21.87
12	3.64	2.86	203.48	71.15	112.48	39.33
14	4.11	4.42	383.05	86.44	265.92	60.16
16	4.04	5.66	557.92	98.57	422.58	74.48
18	3.53	6.23	739.89	118.76	596.22	95.70
20	2.00	4.40	534.60	121.50	447.60	101.73
22	1.10	2.86	350.57	122.58	319.44	111.69
24	0.77	2.42	311.46	128.70	288.29	119.12
26	0.17	0.63	85.58	135.84	69.56	110.41
28	0.09	0.38	55.50	145.78	54.90	144.47
30	0.01	0.05	5.52	110.40	58.50	117.00
32	0.01	0.06	5.01	83.50	55.10	91.83
34	0.01	0.06	9.28	154.67	108.50	180.83
	21.12	30.93	3293 .26		2518.9	

Stand and Stock Table, Yellow Birch

Mature Hardwood - Hemlock, Gogebic County

Michigan

Typical acre

DBH	#Tree/a	BA/a	Vol.Scrib.	Bd.ft/ Sq.ft.BA	Vol.Doyle	Bd.ft/ Sq.ft./BA
10	1.90	1.04	65.5	63.0	42.0	40.4
12	2.30	1.81	123.2	68.2	68.1	37.6
14	3.03	3.23	265.0	82.1	186.5	57.8
16	2.67	3.74	313.5	83.8	236.5	63.3
18	2.42	4.24	431.0	101.7	346.0	81.6
20	1.89	4.14	368.1	89.0	313.8	75.8
22	1.16	3.02	324.5	107.4	287.5	95.0
24	1.35	4.20	442.5	105.3	408.0	97.2
26	0.37	1.37	141.7	103.4	137.5	100.4
28	0.26	1.11	121.9	109.8	123.3	111.1
30	0.22	1.08	120.8	111.9	124.5	115.2
32	0.01	0.06	5.0	84.0	5.8	96.7
34	0.01	0.06	6.0	99.6	7.1	118.4
36	0.01	0.07	6.9	99.4	8.4	120.1
	17.60	29.17	2724.8		2295.0	

Stand and Stock Table, Basswood

Mature Hardwood - Hemlock, Gogebic County

Michigan

Typical Acre

DBH	#Trees/a	BA/a	Vol.Scrib.	Bd.ft./ sq.ft.BA	Vol.Doyle	Bd.Ft./ sq.ft.BA
10	0.19	0.10	7.0	70.0	2.3	23.0
12	0.40	0.31	24.6	79.4	13.3	42.9
14	0.19	0.21	21.7	103.3	14.4	68.6
16	0.31	0.42	54.6	130.1	40.0	95.3
18	0.31	0.55	65.1	118.4	55.5	101.0
20	0.05	0.11	12.2	111.0	10.2	92.7
22	0.12	0.31	46.2	149.0	41.1	132.8
24	0.17	0.53	76.2	143.9	69.6	131.3
26	0.02	0.07	12.0	171.4	11.5	164.2
28	0.01	0.04	7.1	177.6	7.1	177.5
30	0.01	0.05	8.4	167.1	8.5	170.0
	1.78	2.70	335.1		273.5	

Stand and Stock Table, Red Maple,

Mature Hardwood - Hemlock, Gogebic County

Michigan

Typical Acre

DBH	#Trees/a	BA/a	Vol.Scrib.	Bd.ft./ sq.ft.BA	Vol.Doyle	Bd.ft./ sq.ft.BA
10	0.31	0.17	11.2	65.9	3.8	22.4
12	0.37	0.29	20.0	69.1	11.1	38.3
14	0.47	0.50	44.7	89.5	30.8	61.6
16	0.27	0.38	39.7	104.7	30.2	79.5
18	0.10	0.18	14.7	81.7	11.9	66.2
20	0.09	0.20	19.7	98.5	16.8	84.0
22	0.04	0.11	11.7	106.5	10.4	94.6
24	0.02	0.06	9.9	165.0	8.9	147.3
26	0.01	0.04	5.1	127.5	4.9	122.5
	1.68	1.93	176.7		128.8	

Stand and Stock Table, Black Ash,

Mature Hardwood - Hemlock, Gogebic County

Michigan

Typical Acre

DBH	#Trees/a	BA/a	Vol.Scrib.	Bd.ft/ sq.ft.BA	Vol.Doyle	Bd.ft./ sq.ft.BA
10	0.25	0.14	8.8	62.9	3.0	21.4
12	0.12	0.09	6.0	66.7	3.3	36.7
14	0.27	0.28	28.6	102.1	19.8	70.7
16	0.04	0.06	6.2	103.3	4.6	76.7
18	0.04	0007	9.6	137.1	7.6	108.6
20	0.01	0.02	3.6	180.0	2.9	145.0
22	0.01	0.03	4.1	136.7	3.6	120.0
	0.74	0.69	66.9		43.8	

Stand and Stock Table, Elm

Mature Hardwood - Hemlock, Gogebic County
Michigan
Typical Acre

DBH	#Trees/a	BA/a	Vol.Scrib.	Bd.ft./ Sq.Ft.BA	Vol.Doyle	Bd.ft./ sq.ft.BA
14	0.05	0.05	5.7	114.0	3.8	76.1
16	0.06	0.08	9.7	120.8	7.3	91.3
18	0.00	0.00				
20	0.06	0.13	16.5	127.0	13.8	106.2
22	0.02	0.05	7.0	140.0	6.1	122.0
24	0.01	0.03	3.4	113.3	3.2	106.7
26	0.06	0.22	30.6	139.0	29.2	132.7
	0.25	0.56	72.9		63.4	

Appendix C

Time Study Tables and Graphs

Table 4, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Sugar Maple, Vermont

(1)	(2)	(3)	(4)	FELLING and BUCKING			SKIDDING			HAULING			MILLING		
D. B. H.	B. A. per Tree	Vol.* per Tree	B. A. per M	(5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	(8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	(11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	(14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
11	0.660	56	11.80	4.31	0.365	21.9	3.24	0.274	16.5	3.16	0.268	16.1	3.96	0.336	20.1
12	0.785	73	10.75	4.13	0.384	23.0	2.92	0.272	16.3	3.11	0.289	17.3	3.76	0.350	21.0
13	0.922	93	9.82	3.97	0.405	24.2	2.65	0.273	16.4	3.06	0.312	18.7	3.57	0.364	21.8
14	1.069	113	9.46	3.81	0.402	24.1	2.41	0.256	15.3	3.02	0.319	19.1	3.42	0.362	21.7
15	1.227	134	9.15	3.69	0.403	24.2	2.23	0.244	14.6	2.98	0.326	19.5	3.32	0.363	21.8
16	1.369	156	8.95	3.56	0.398	23.9	2.05	0.229	13.7	2.94	0.329	19.7	3.22	0.360	21.6
17	1.576	178	8.85	3.47	0.392	23.5	1.90	0.215	12.9	2.91	0.329	19.7	3.13	0.354	21.2
18	1.767	201	8.79	3.38	0.389	23.4	1.78	0.203	12.2	2.88	0.328	19.7	3.06	0.349	20.9
19	1.969	225	8.75	3.31	0.378	22.7	1.68	0.192	11.5	2.85	0.326	19.5	3.01	0.344	20.6
20	2.182	250	8.75	3.25	0.372	22.3	1.59	0.182	10.9	2.84	0.325	19.5	2.97	0.340	20.4
21	2.405	276	8.72	3.21	0.368	22.1	1.50	0.172	10.3	2.82	0.324	19.4	2.94	0.338	20.2
22	2.640	302	8.75	3.18	0.364	21.8	1.42	0.162	9.7	2.80	0.320	19.2	2.92	0.334	20.0
23	2.885	329	8.77	3.14	0.358	21.5	1.35	0.154	9.2	2.78	0.317	19.0	2.90	0.331	19.9

*All volumes in board feet mill tally

Table 5, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Yellow Birch, Vermont

(1)	(2)	(3)	(4)	FELLING and BUCKING			SKIDDING			HAULING			MILLING		
D. B. H.	B. A. per Tree	Vol. * per Tree	B. A. per M	(5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	(8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	(11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	(14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
11	0.660	62	10.65	4.17	0.392	23.5	2.80	0.263	15.8	3.17	0.298	17.9	3.90	0.366	22.0
12	0.785	77	10.20	3.94	0.386	23.2	2.63	0.258	15.5	3.13	0.307	18.4	3.75	0.368	22.0
13	0.922	92	10.00	3.74	0.374	22.4	2.45	0.245	14.7	3.08	0.308	18.5	3.61	0.361	21.6
14	1.069	109	9.80	3.54	0.365	21.9	2.31	0.236	14.1	3.04	0.310	18.6	3.49	0.356	21.4
15	1.227	126	9.73	3.38	0.348	20.8	2.15	0.221	13.3	2.99	0.307	18.4	3.39	0.348	20.9
16	1.396	144	9.69	3.25	0.336	20.2	2.02	0.208	12.5	2.96	0.306	18.3	3.29	0.340	20.4
17	1.576	163	9.66	3.14	0.325	19.5	1.88	0.195	11.7	2.92	0.302	18.1	3.22	0.334	20.0
18	1.767	183	9.65	3.06	0.317	19.0	1.76	0.182	10.9	2.88	0.299	17.9	3.17	0.328	19.7
19	1.969	205	9.60	3.00	0.312	18.8	1.66	0.173	10.4	2.85	0.297	17.8	3.13	0.326	19.6
20	2.180	227	9.60	2.95	0.308	18.4	1.55	0.163	9.75	2.82	0.294	17.6	3.10	0.323	19.4
21	2.405	251	9.59	2.91	0.304	18.2	1.47	0.153	9.2	2.80	0.292	17.5	3.08	0.322	19.3
22	2.640	277	9.54	2.87	0.301	18.1	1.37	0.145	8.7	2.78	0.292	17.5	3.07	0.322	19.3

*All volumes in board feet mill tally

Table 6, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Beech, Vermont

(1)	(2)	(3)	(4)	FELLING and BUCKING			SKIDDING			HAULING			MILLING		
D. B. H.	B. A. per Tree	Vol. * per Tree	B. A. per M	(5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	(8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	(11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	(14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
12	0.785	68	11.55	4.43	0.384	23.0	2.50	0.217	13.0	3.09	0.268	16.0	4.42	0.382	23.0
13	0.922	82	11.25	4.21	0.374	22.4	2.28	0.203	12.3	3.03	0.269	16.1	4.28	0.380	22.8
14	1.069	97	11.00	4.00	0.364	21.8	2.10	0.191	11.4	2.98	0.271	16.2	4.17	0.379	22.8
15	1.227	114	10.75	3.80	0.354	21.2	1.95	0.181	10.9	2.93	0.272	16.4	4.07	0.378	22.7
16	1.396	134	10.41	3.62	0.347	20.8	1.80	0.173	10.4	2.89	0.278	16.6	4.01	0.385	23.1
17	1.576	155	10.17	3.46	0.340	20.4	1.69	0.166	10.0	2.86	0.282	16.9	3.95	0.389	23.3
18	1.767	177	9.99	3.32	0.333	20.0	1.59	0.159	9.6	2.83	0.284	17.0	3.90	0.391	23.4
19	1.969	201	9.79	3.19	0.326	19.6	1.50	0.153	9.2	2.80	0.286	17.1	3.87	0.395	23.7
20	2.182	226	9.66	3.08	0.319	19.1	1.41	0.146	8.8	2.78	0.288	17.3	3.83	0.396	23.8

*All volumes are board feet mill tally.

Table 7, Man-minutes per Square Foot of Basal Area for Logging and Milling Operations

Sugar Maple, Northern Wisconsin.

(1)	(2)	(3)	(4)	FELLING and BUCKING			SKIDDING			HAULING			MILLING		
D. B. H.	B. A. per Tree	Vol. * per Tree	B. A. per M	(5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	(8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	(11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	(14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
12	.785	82	9.58	3.48	.361	21.8	3.90	.407	24.4	2.35	.245	14.7	7.27	.760	45.5
13	.922	103	8.95	3.32	.371	22.3	3.60	.402	24.2	2.28	.255	15.3	7.30	.816	49.0
14	1.069	125	8.54	3.14	.368	22.1	3.29	.386	23.1	2.21	.259	15.5	7.30	.855	51.3
15	1.227	149	8.23	2.96	.360	21.6	2.99	.364	21.6	2.13	.259	15.5	7.34	.891	53.5
16	1.396	172	8.11	2.84	.350	21.0	2.71	.347	20.8	2.05	.253	15.2	7.37	.909	54.5
17	1.576	195	8.08	2.72	.337	20.2	2.47	.306	18.3	1.99	.246	14.8	7.34	.909	54.5
18	1.767	229	7.72	2.64	.342	20.5	2.29	.297	17.8	1.92	.249	14.9	7.30	.945	56.7
19	1.969	245	8.04	2.59	.322	19.3	2.15	.268	16.1	1.86	.232	13.9	7.27	.905	54.3
20	2.182	270	8.10	2.57	.318	19.0	2.01	.248	14.9	1.81	.224	13.4	7.24	.894	53.6
21	2.405	295	8.15	2.55	.313	18.8	1.91	.234	14.1	1.76	.216	13.0	7.21	.885	53.1
22	2.640	319	8.28	2.52	.304	18.3	1.83	.221	13.3	1.72	.208	12.5	7.14	.863	51.7
23	2.885	342	8.45	2.53	.300	18.0	1.76	.208	12.5	1.70	.201	12.1	7.11	.842	50.5
24	3.142	366	8.60	2.54	.296	17.7	1.65	.192	11.5	1.67	.194	11.7	7.05	.820	49.2
25	3.409	389	8.77	2.57	.293	17.6	1.66	.189	11.4	1.65	.188	11.3	7.01	.800	48.0
26	3.687	410	9.00	2.61	.291	17.4	1.63	.181	10.9	1.64	.182	10.9	6.95	.772	46.3

*All volumes in board feet mill tally

Table 8, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Yellow Birch, Northern Wisconsin

(1)	(2)	(3)	(4)	FELLING and BUCKING			SKIDDING			HAULING			MILLING		
D. B. H.	B. A. per Tree	Vol.* per Tree	B. A. per M	(5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	(8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	(11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	(14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
12	.785	68	11.54	3.70	.325	19.5	3.83	.332	19.9	2.31	.200	12.0	7.53	.650	39.0
13	.922	88	10.48	3.51	.335	20.1	3.48	.332	19.9	2.23	.213	12.8	7.50	.716	43.0
14	1.069	109	9.80	3.32	.339	20.3	3.15	.322	19.3	2.16	.220	13.2	7.50	.765	46.0
15	1.227	132	9.29	3.13	.337	20.2	2.88	.310	18.6	2.09	.225	13.5	7.46	.804	48.2
16	1.396	155	9.00	2.97	.330	19.8	2.61	.290	17.4	2.02	.224	13.5	7.43	.826	49.5
17	1.576	178	8.85	2.81	.318	19.1	2.39	.270	16.2	1.94	.220	13.2	7.40	.837	50.1
18	1.767	201	8.79	2.70	.307	18.4	2.16	.246	14.8	1.88	.214	12.8	7.40	.842	50.5
19	1.969	226	8.71	2.60	.298	17.9	2.03	.233	14.0	1.82	.209	12.5	7.37	.846	50.8
20	2.182	250	8.75	2.55	.292	17.5	1.89	.216	13.0	1.77	.202	12.1	7.30	.834	50.0
21	2.405	275	8.75	2.48	.284	17.0	1.78	.204	12.2	1.71	.195	11.7	7.27	.831	49.9
22	2.640	301	8.77	2.42	.276	16.5	1.69	.193	11.6	1.67	.191	11.4	7.24	.825	49.5
23	2.885	326	8.86	2.39	.270	16.2	1.62	.183	11.0	1.64	.185	11.1	7.17	.810	48.5
24	3.142	350	8.99	2.36	.263	15.8	1.58	.176	10.5	1.61	.179	10.7	7.14	.795	47.7

*All volumes in board feet mill tally

Table 9, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Basswood, Northern Wisconsin

(1) D. B. H.	(2) B. A. per Tree	(3) Vol. * per Tree	(4) B. A. per M	FELLING and BUCKING (5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	SKIDDING (8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	HAULING (11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	MILLING (14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
13	.922	107	8.61	2.78	.323	19.4	3.91	.454	27.2	2.34	.272	16.3	10.91	1.268	76.1
14	1.069	131	8.16	2.60	.319	19.1	3.60	.441	26.5	2.25	.276	16.5	10.71	1.313	78.9
15	1.227	157	7.81	2.40	.308	18.4	3.30	.423	25.4	2.17	.278	16.7	10.52	1.349	80.9
16	1.396	184	7.58	2.29	.302	18.1	3.00	.396	23.8	2.10	.277	16.6	10.39	1.370	82.2
17	1.576	214	7.37	2.18	.296	17.8	2.74	.372	22.3	2.01	.273	16.4	10.23	1.389	83.4
18	1.767	243	7.27	2.09	.288	17.3	2.48	.342	20.5	1.94	.267	16.0	10.10	1.390	83.4
19	1.969	274	7.19	2.03	.282	16.9	2.26	.314	18.9	1.88	.262	15.7	10.01	1.391	83.5
20	2.182	305	7.17	2.00	.279	16.7	2.11	.294	17.7	1.82	.254	15.2	9.91	1.381	83.0
21	2.405	335	7.18	1.96	.273	16.4	2.00	.279	16.7	1.77	.247	14.8	9.81	1.357	82.0
22	2.640	366	7.22	1.94	.269	16.1	1.90	.264	15.8	1.74	.241	14.5	9.72	1.347	80.8
23	2.885	395	7.31	1.92	.263	15.8	1.83	.252	15.0	1.71	.234	14.0	9.62	1.316	79.0
24	3.142	422	7.45	1.91	.256	15.4	1.75	.235	14.1	1.68	.226	13.5	9.56	1.284	77.1
25	3.409	449	7.60	1.89	.249	14.9	1.67	.220	13.2	1.66	.218	13.1	9.49	1.249	75.0
26	3.687	474	7.79	1.86	.239	14.3	1.62	.211	12.6	1.64	.211	12.6	9.39	1.206	72.4
27	3.976	496	8.01	1.87	.234	14.0	1.59	.199	11.9	1.63	.204	12.2	9.33	1.166	69.9

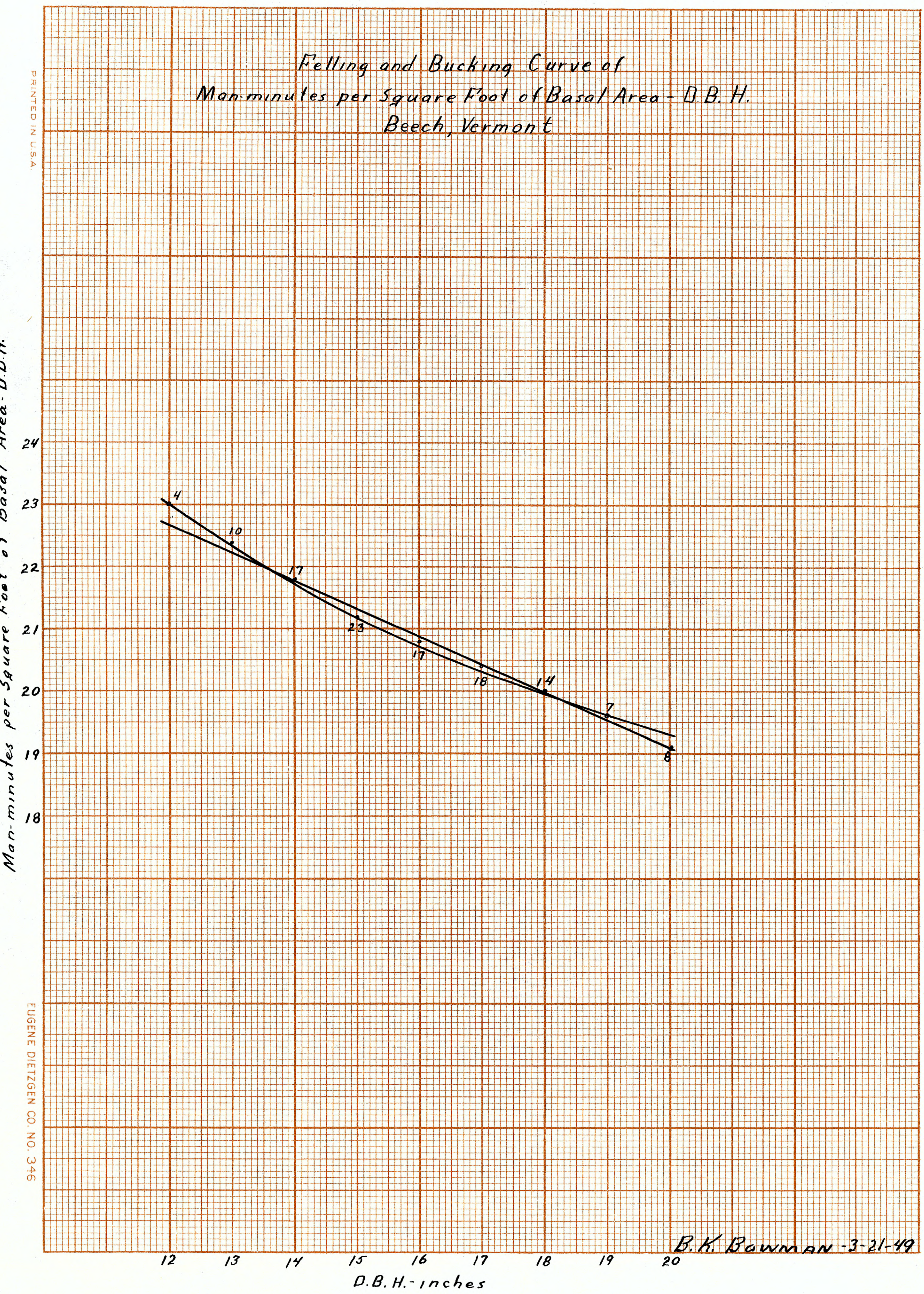
*All volumes in board feet mill tally

Table 10, Man Minutes per Square Foot of Basal Area for Logging and Milling Operations

Sugar Maple, Vermont

(1) D. B. H.	(2) B. A. per Tree	(3) Vol.* per Tree	(4) B. A. per M	FELLING and BUCKING (5) Man Hrs. per M	(6) Man Hrs. Per Sq. Ft. B. A.	(7) Man Min. Per Sq. Ft. B. A.	SKIDDING (8) Man Hrs. Per M	(9) Man Hrs. Per Sq. Ft. B. A.	(10) Man Min. Per Sq. Ft. B. A.	HAULING (11) Man Hrs. per M	(12) Man Hrs. Per Sq. Ft. B. A.	(13) Man Min. Per Sq. Ft. B. A.	MILLING (14) Man Hrs. per M	(15) Man Hrs. Per Sq. Ft. B. A.	(16) Man Min. Per Sq. Ft. B. A.
14	1.069	112	9.54	2.69	.282	16.9	3.13	.328	19.7	2.13	.224	13.4	7.56	.794	47.6
15	1.227	143	8.57	2.50	.291	17.5	2.81	.328	19.7	2.06	.240	14.4	7.40	.863	51.8
16	1.396	176	7.93	2.35	.297	17.8	2.50	.316	18.9	1.98	.250	15.0	7.21	.910	54.6
17	1.576	212	7.44	2.22	.298	17.9	2.25	.303	18.2	1.91	.257	15.4	7.01	.943	56.6
18	1.767	248	7.12	2.12	.298	17.9	2.04	.287	17.2	1.84	.258	15.5	6.85	.962	57.7
19	1.969	287	6.86	2.06	.300	18.0	1.89	.276	16.5	1.79	.261	15.7	6.69	.975	58.5
20	2.182	328	6.66	2.02	.303	18.2	1.77	.266	15.9	1.73	.260	15.6	6.50	.975	58.5
21	2.405	374	6.44	1.93	.299	17.9	1.68	.261	15.6	1.68	.261	15.7	6.38	.985	59.1
22	2.640	417	6.34	1.88	.297	17.8	1.62	.256	15.3	1.64	.259	15.5	6.18	.975	58.5
23	2.885	455	6.35	1.85	.291	17.5	1.57	.247	14.8	1.62	.255	15.3	6.02	.949	57.9
24	3.142	496	6.35	11.82	.287	17.2	1.52	.240	14.4	1.59	.251	15.0	5.86	.924	55.4
25	3.409	436	7.82	1.81	.232	13.9	1.49	.191	11.4	1.57	.201	12.0	5.69	.728	43.7
26	3.687	575	6.42	1.81	.282	16.9	1.45	.226	13.6	1.56	.243	14.6	5.57	.868	52.0
27	3.976	611	6.50	1.81	.279	16.7	1.44	.222	13.3	1.56	.240	14.4	5.44	.837	50.2
28	4.276	647	6.61	1.77	.268	16.1	1.46	.221	13.2	1.56	.236	14.2	5.31	.803	48.2

*All volumes in board feet mill tally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Beech, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
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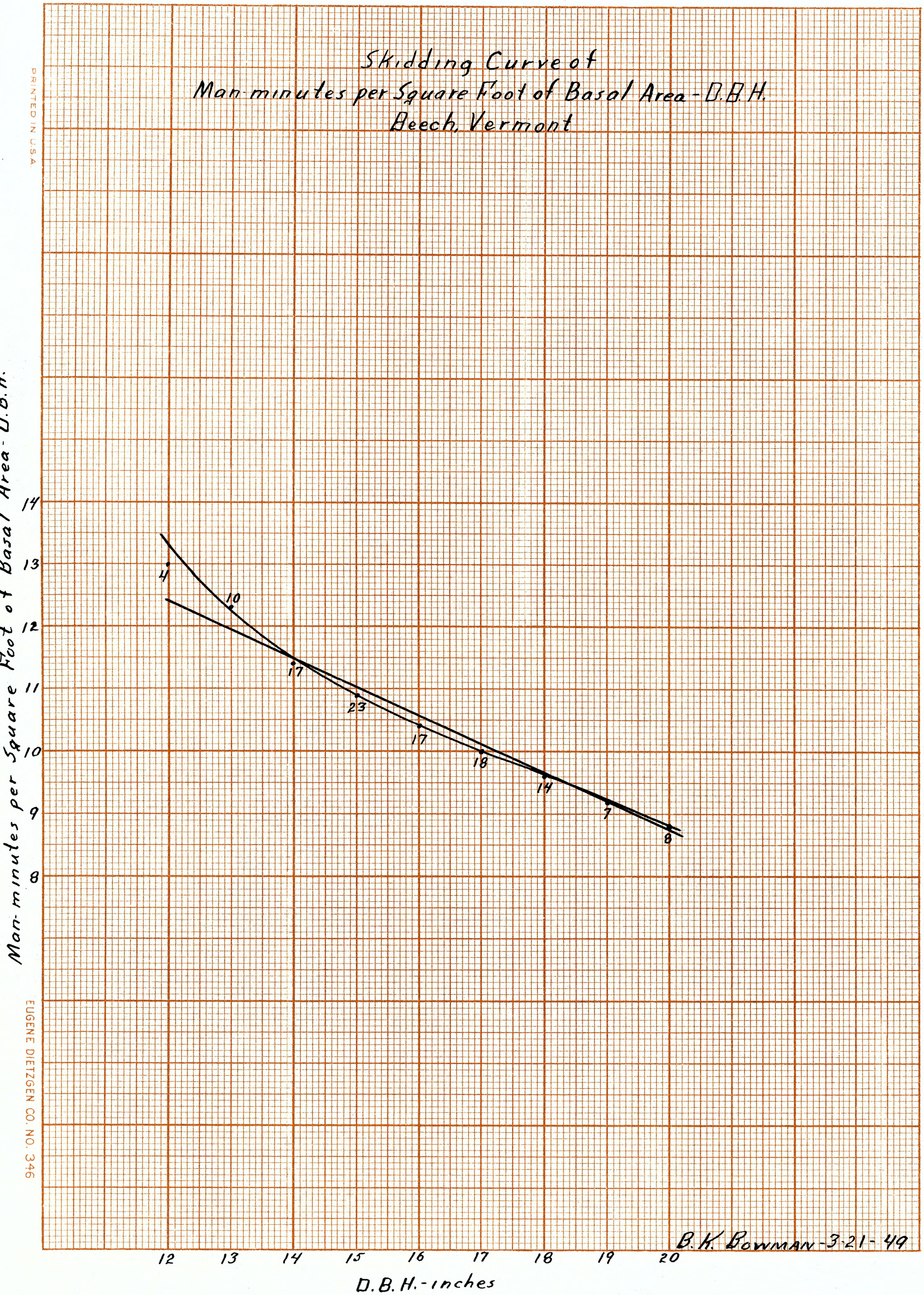
D.B.H. - inches
B.K. Bowman - 3-21-49


Skidding Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Beech, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
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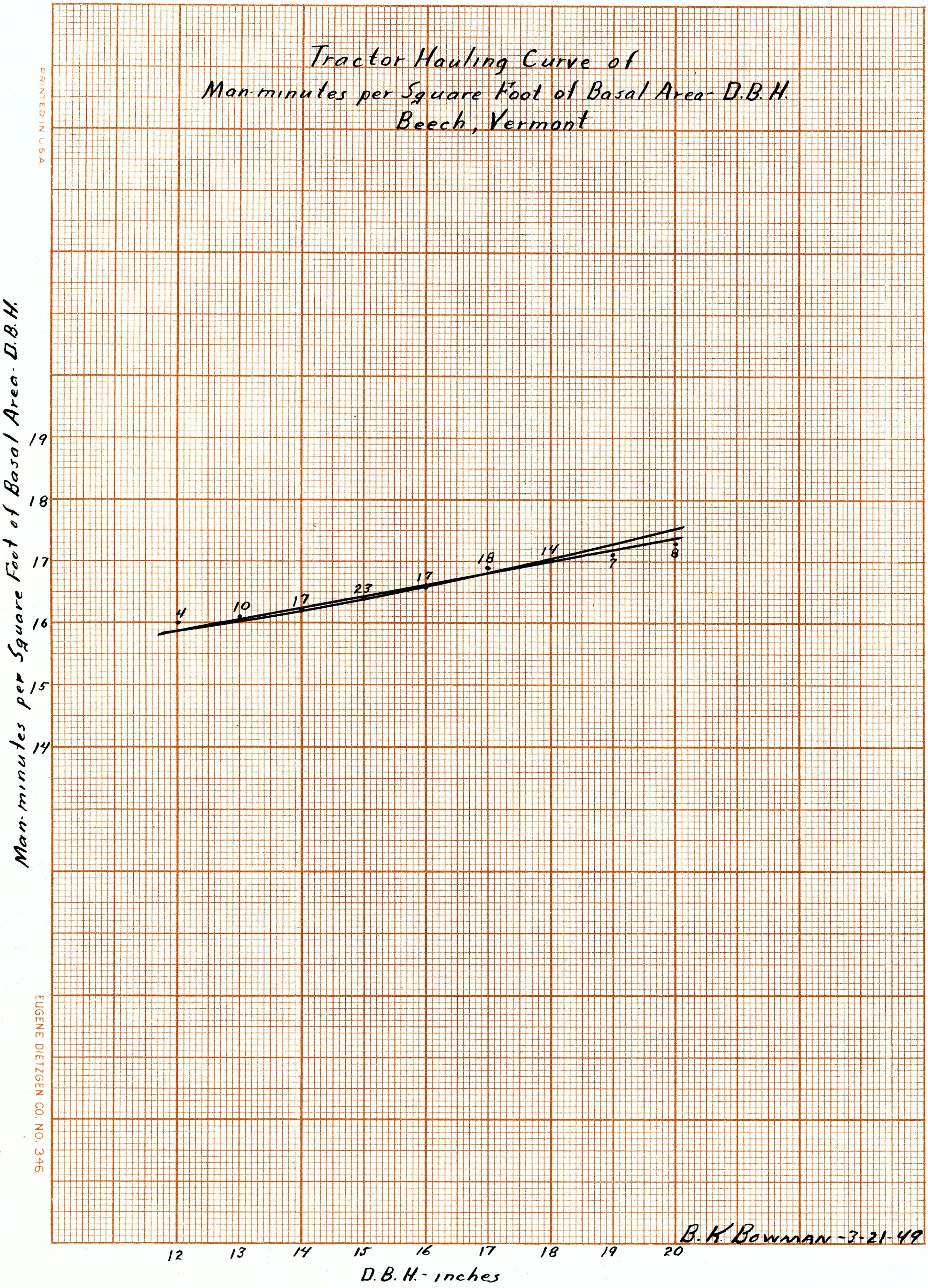
D.B.H.-inches
B.K. Bowman - 3-21-49
PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 346


Tractor Hauling Curve of
Man-minutes per Square Foot of Basal Area- D.B.H.
Beech, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
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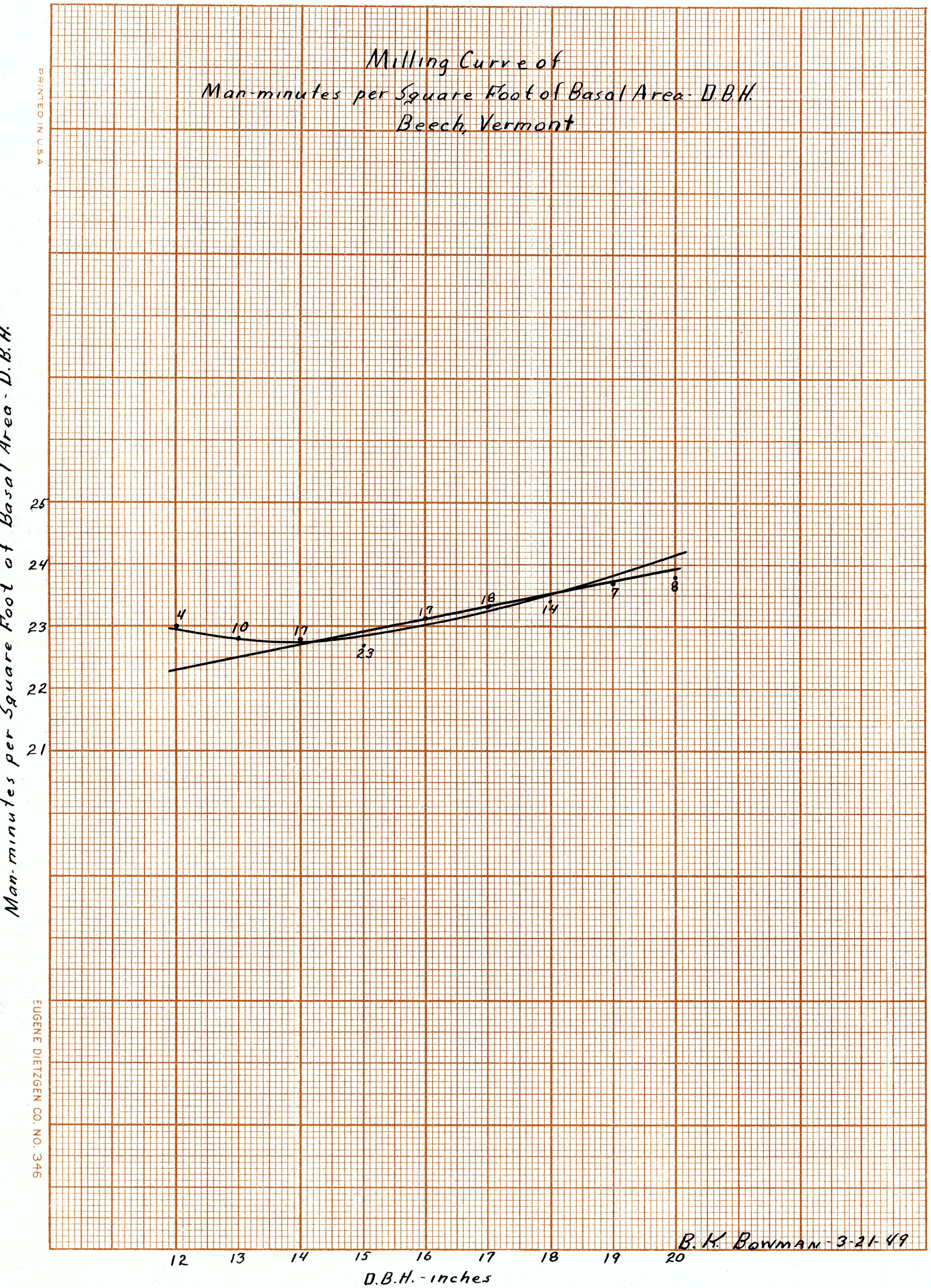
D.B.H.- inches
B. K. Bowman -3-21-49
PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 346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Beech, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
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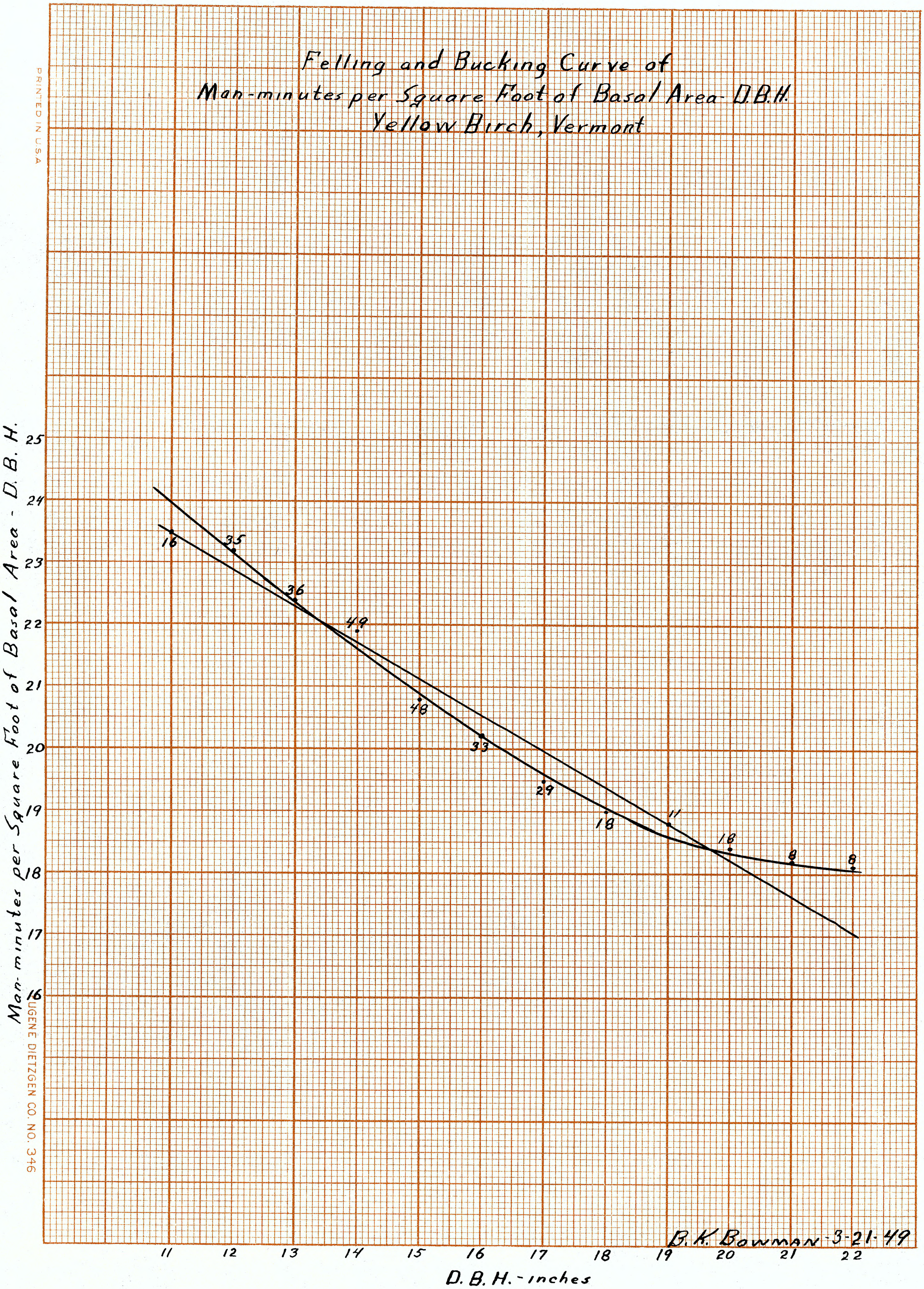
D.B.H. - inches
B. K. Bowman - 3-21-49
PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 346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Man-minutes per Square Foot of Basal Area - D.B.H.
Yellow Birch, Vermont
Man-minutes per Square Foot of Basal Area - D. B. H.
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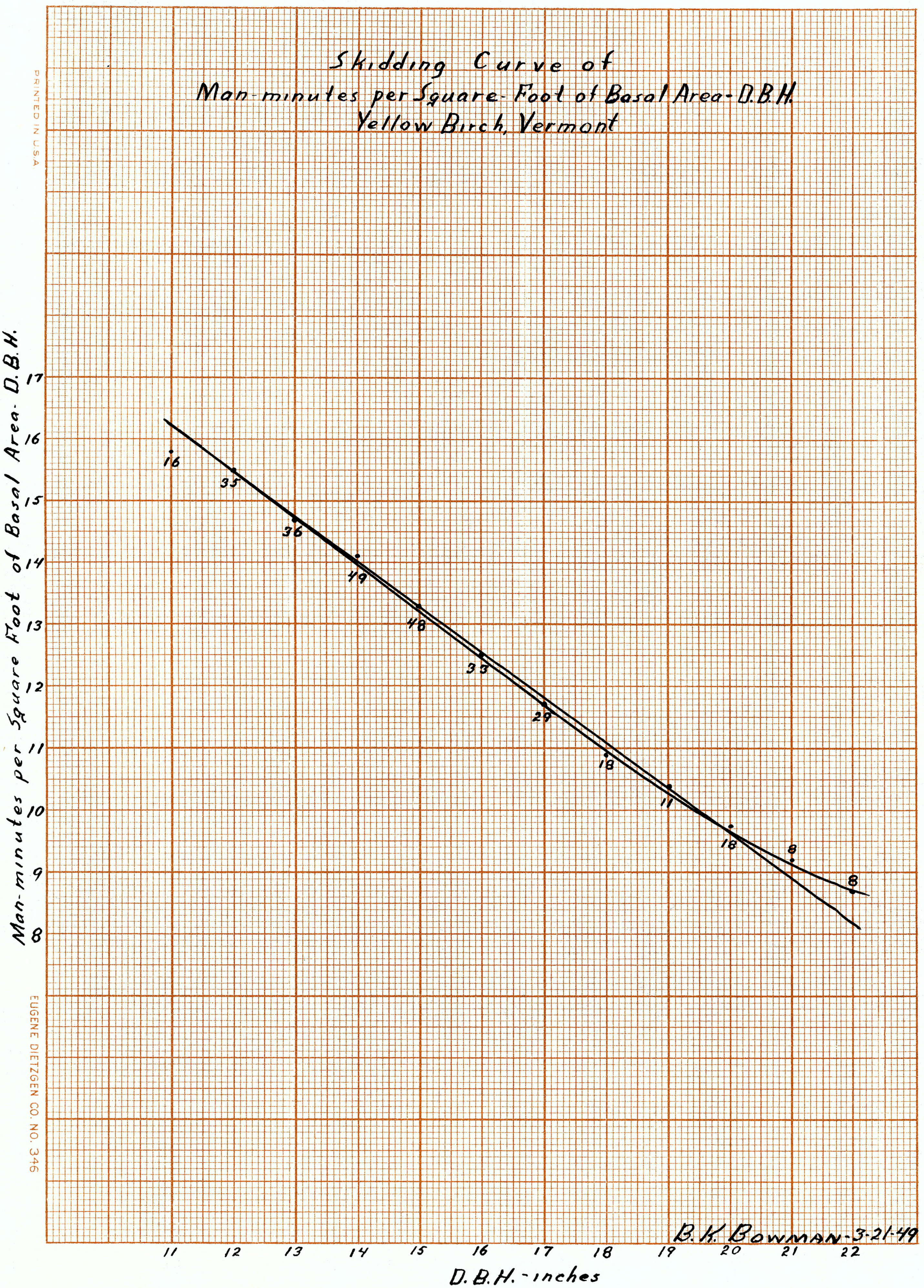
D. B. H. - inches
B. K. Bowman - 3-21-49
PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 346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Yellow Birch, Vermont
Man-minutes per Square Foot of Basal Area-D.B.H.
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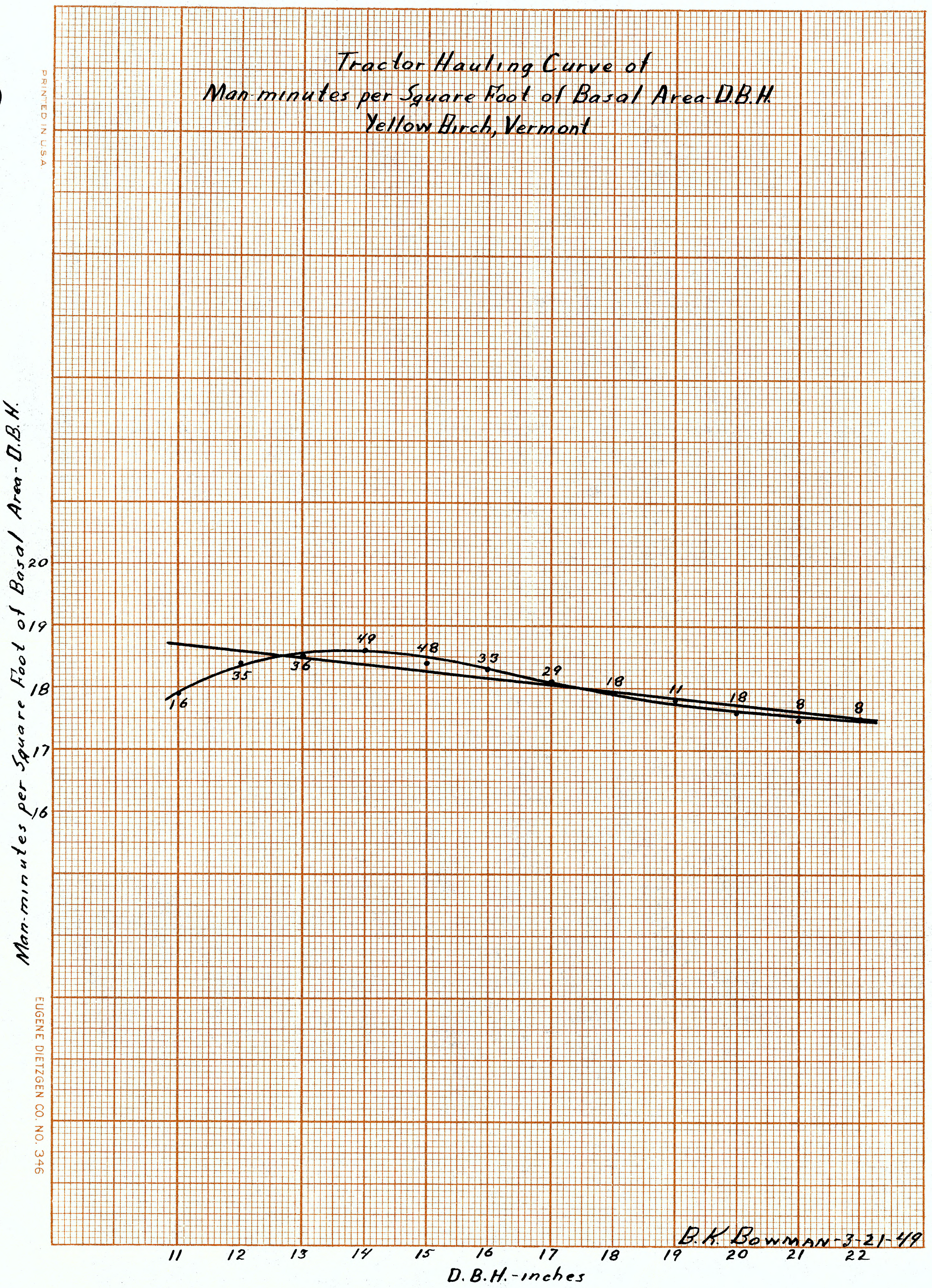
B.K. Bowman-3-21-49
PRINTED IN USA
EUGENE DIETZGEN CO. NO. 346


Tractor Hauling Curve of
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Yellow Birch, Vermont
Man-minutes per Square Foot of Basal Area-D.B.H.
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D.B.H.-inches
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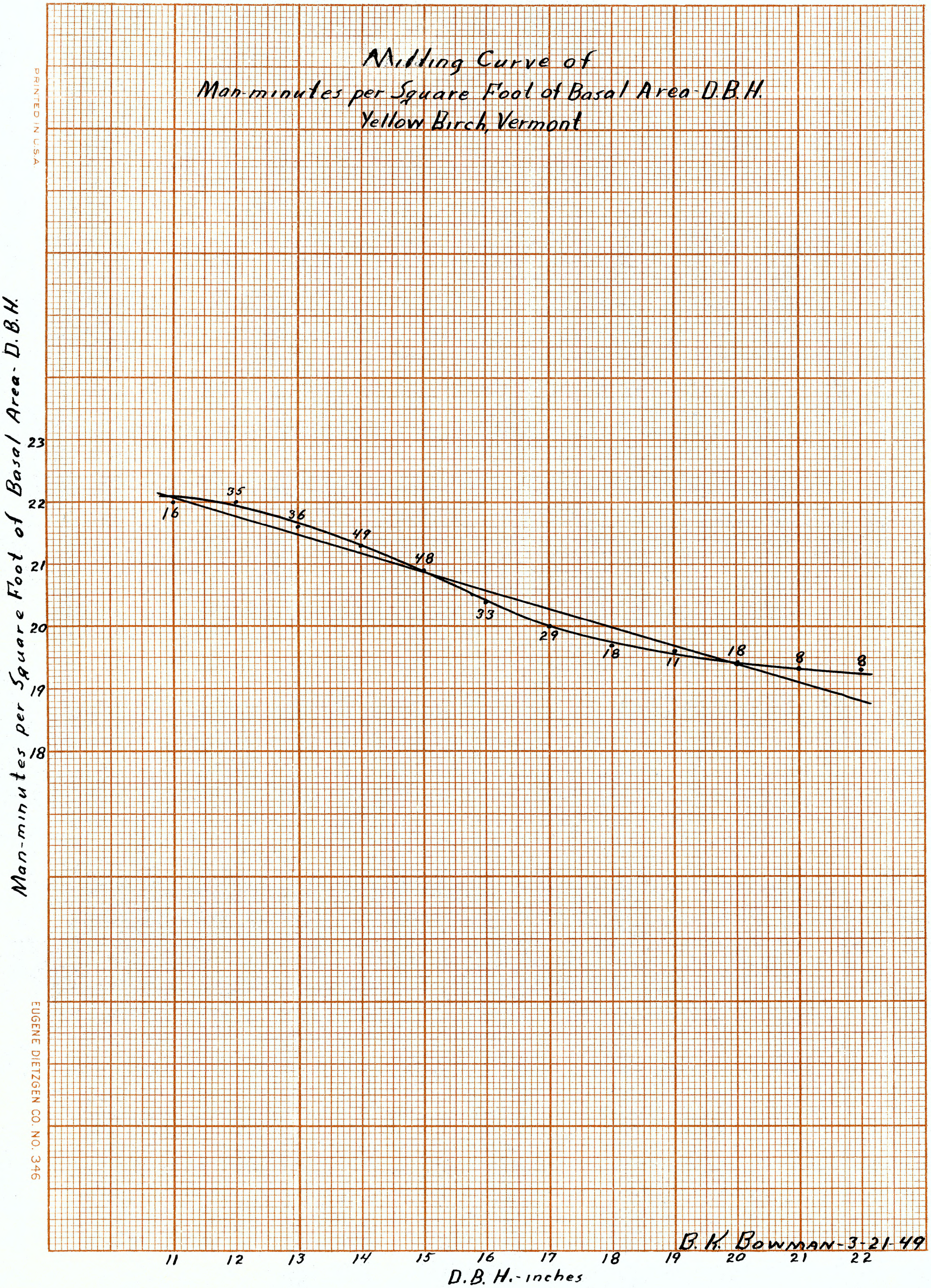

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Felling and Bucking Curves of
Man-minutes per Square Foot of Basal Area
Sugar Maple, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
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D.B.H. - inches
B. K. Bowman, 3-21-49
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EUGENE DIETZGEN CO. NO. 346

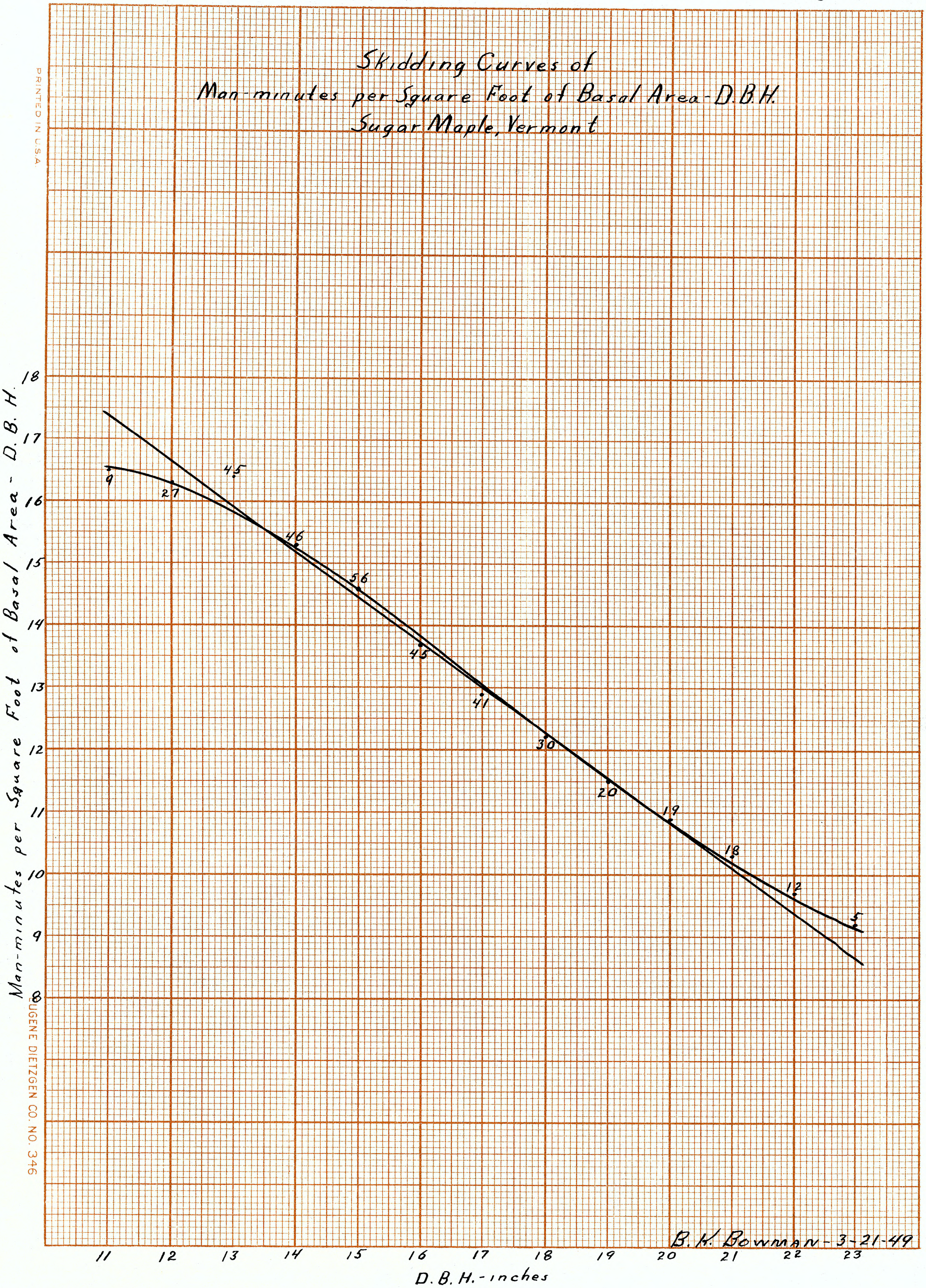
Skidding Curves of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Vermont
Man-minutes per Square Foot of Basal Area - D. B. H.
18
17
16
15
14
13
12
11
10
9
8
9
27
45
46
56
45
41
30
20
19
18
12
5
11 12 13 14 15 16 17 18 19 20 21 22 23
D.B.H.-inches
B.K. Bowman - 3-21-49
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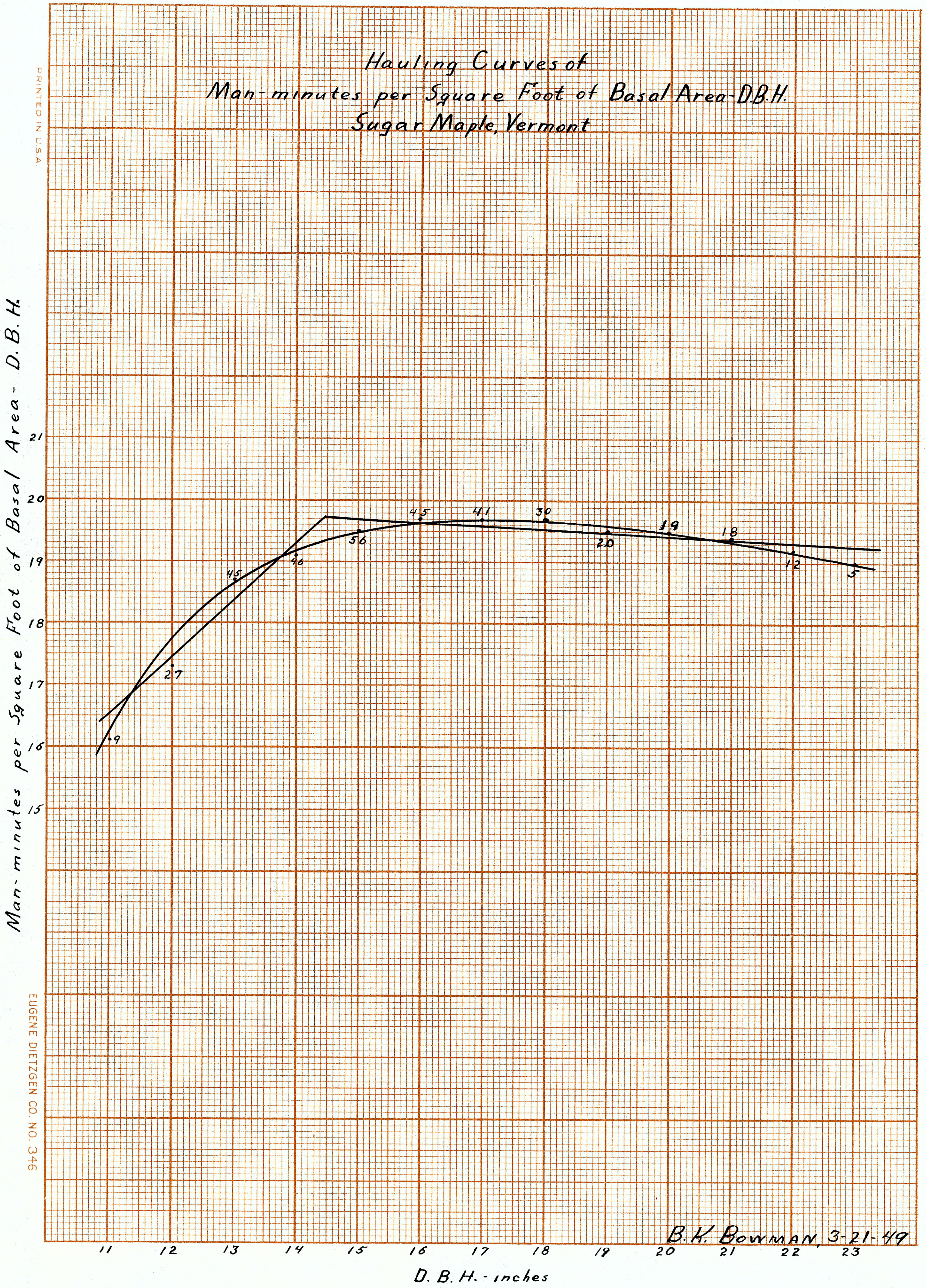
Figure 17


Hauling Curves of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Vermont
Man-minutes per Square Foot of Basal Area- D.B.H.
21
20
19
18
17
16
15
9
27
45
46
56
45
41
30
20
19
18
12
5
11
12
13
14
15
16
17
18
19
20
21
22
23
D.B.H.-inches
B.K. Bowman, 3-21-49
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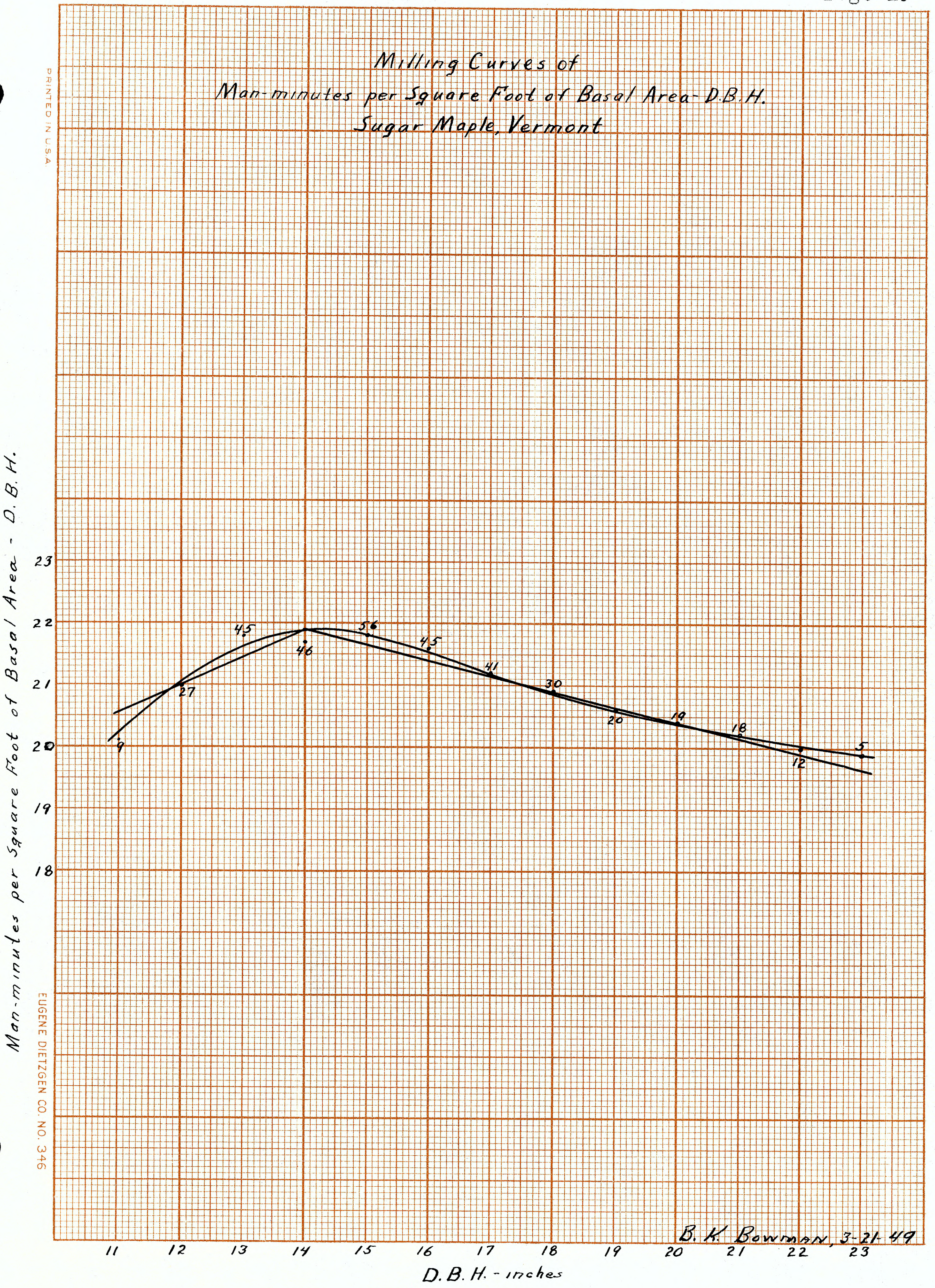
Milling Curves of
Man-minutes per Square Foot of Basal Area - D.B.H.
Sugar Maple, Vermont
Man-minutes per Square Foot of Basal Area - D.B.H.
23
22
21
20
19
18
45
46
56
45
41
27
30
20
19
18
12
5
9
11
12
13
14
15
16
17
18
19
20
21
22
23
D.B.H. - inches
B. K. Bowman, 3-21-49
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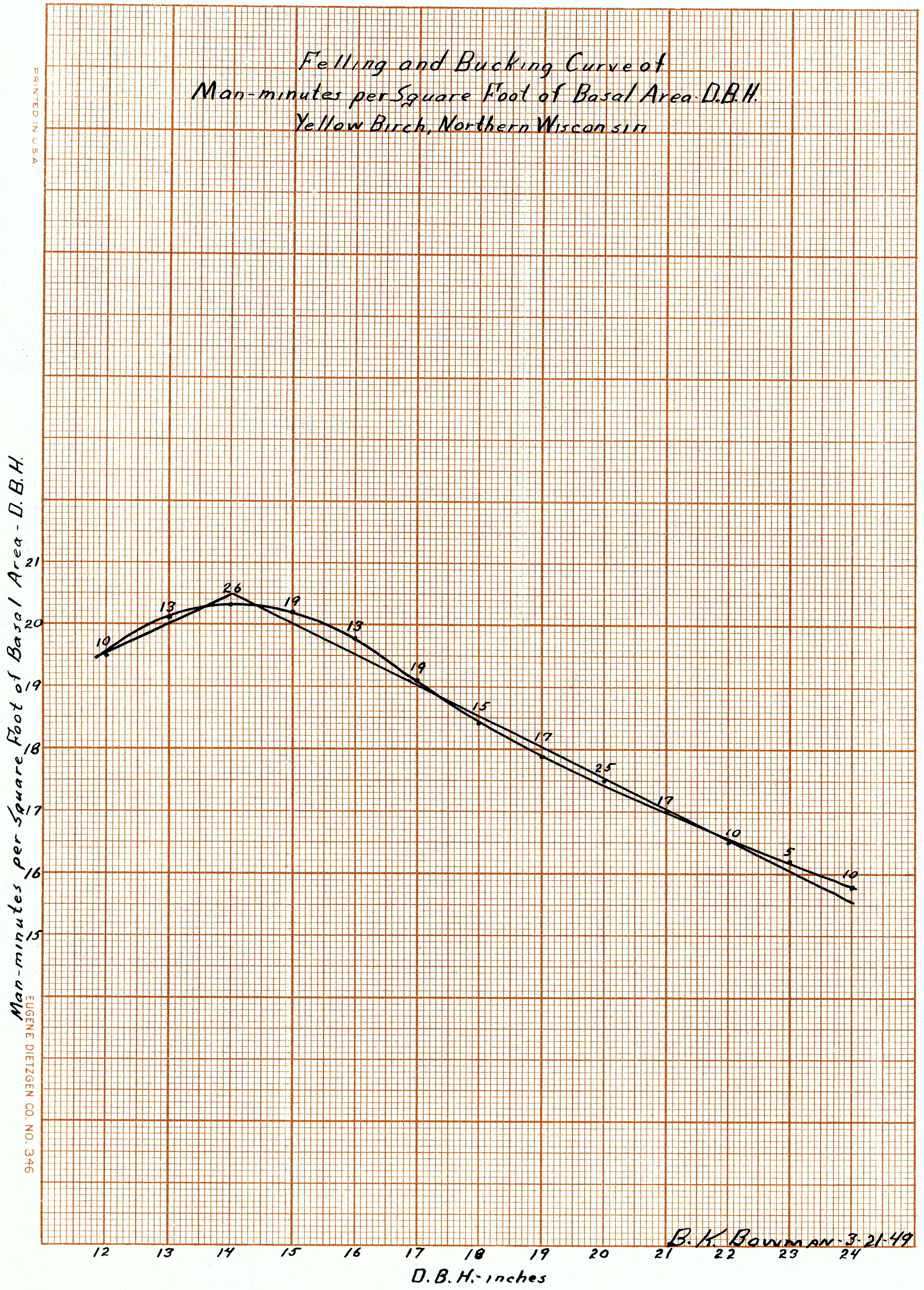
Figure 19


Felling and Bucking Curve of
Man-minutes per Square Foot of Basal Area D.B.H.
Yellow Birch, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
21
20
19
18
17
16
15
10
13
26
19
13
19
15
17
25
17
10
5
10
12
13
14
15
16
17
18
19
20
21
22
23
24
D.B.H.-inches
B. K. Bowman - 3-21-49
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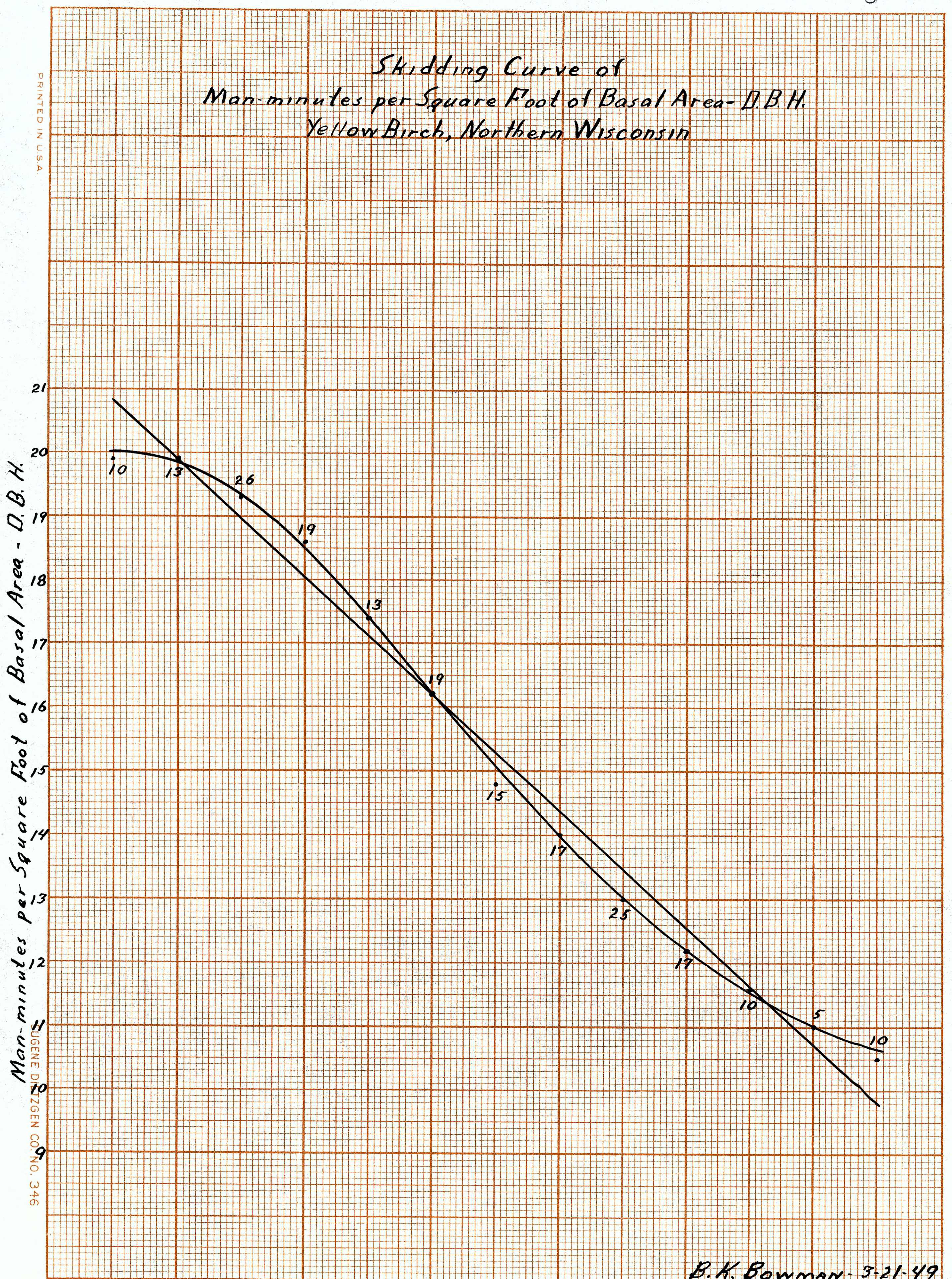
Skidding Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Yellow Birch, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
21
20
19
18
17
16
15
14
13
12
11
10
9
10
13
26
19
13
19
15
17
25
17
10
5
10
12
13
14
15
16
17
18
19
20
21
22
23
24
D.B.H.-inches
B.K. Bowman - 3-21-49
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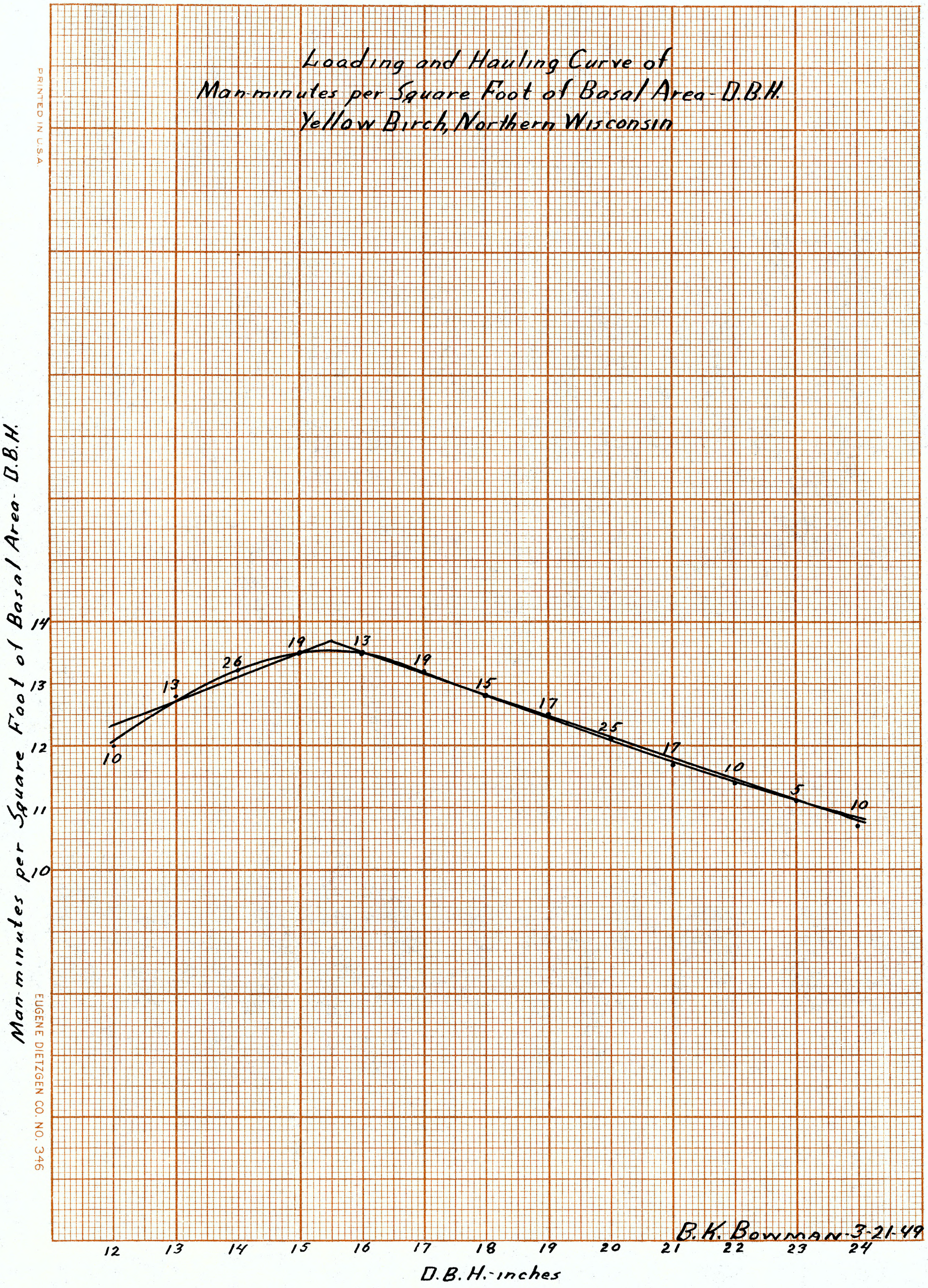
Loading and Hauling Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Yellow Birch, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
14
13
12
11
10
10
13
26
19
13
19
15
17
25
17
10
5
10
B. K. Bowman - 3-21-49
12
13
14
15
16
17
18
19
20
21
22
23
24
D.B.H. - inches
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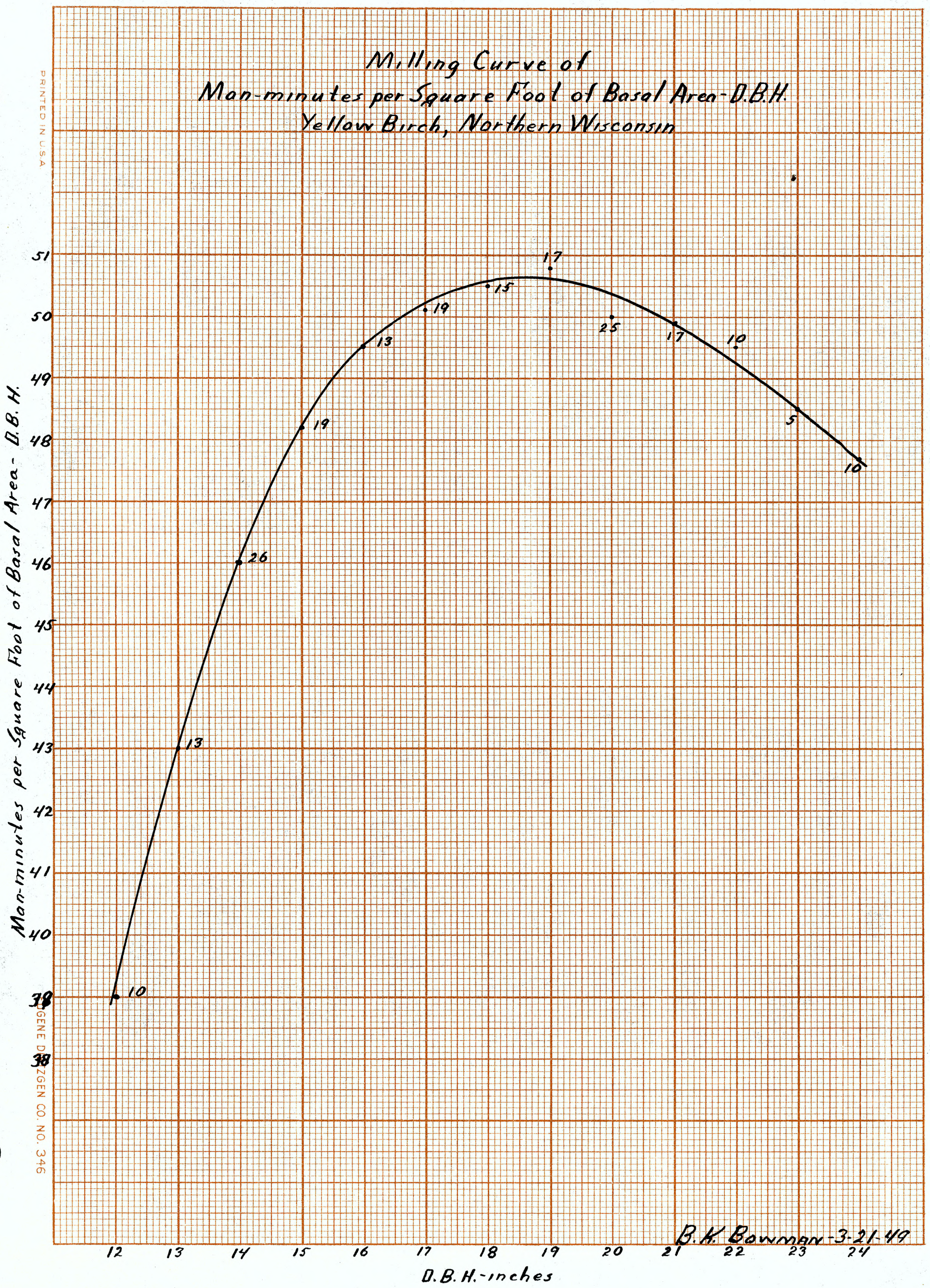
Milling Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Yellow Birch, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
D.B.H.-inches
12 13 14 15 16 17 18 19 20 21 22 23 24
38 39 40 41 42 43 44 45 46 47 48 49 50 51
10 13 26 19 13 19 15 17 25 17 10 5 10
B.K. Bowman - 3-21-49
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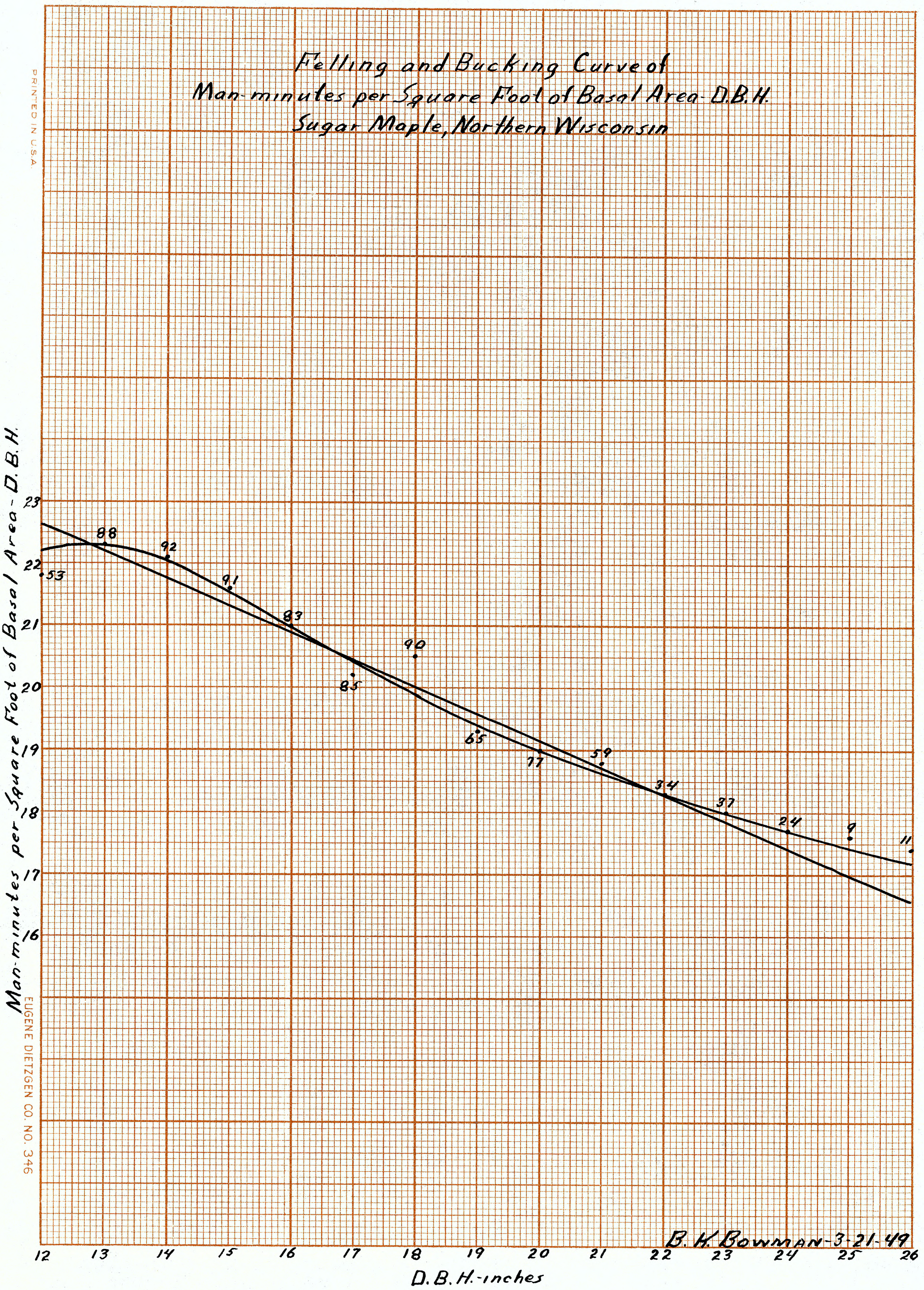
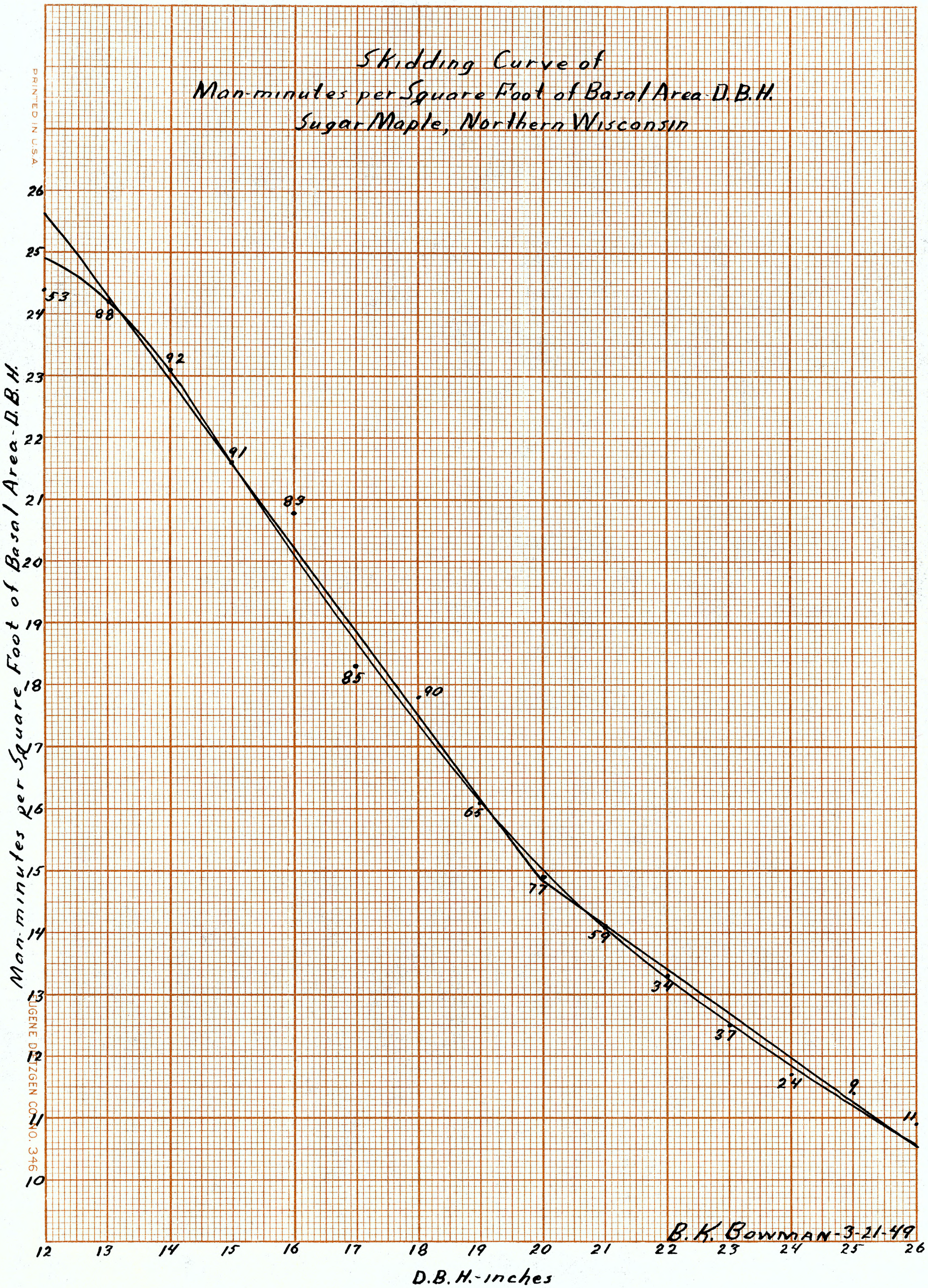

Felling and Bucking Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Northern Wisconsin
Man-minutes per Square Foot of Basal Area-D.B.H.
D.B.H.-inches
23
22
21
20
19
18
17
16
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
53
88
92
91
83
85
90
65
77
59
34
37
24
9
11
B. K. Bowman-3-21-49


Skidding Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Northern Wisconsin
Man-minutes per Square Foot of Basal Area-D.B.H.
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
53
88
92
91
83
85
90
65
77
59
34
37
24
9
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
D.B.H.-inches
B.K. Bowman-3-21-49
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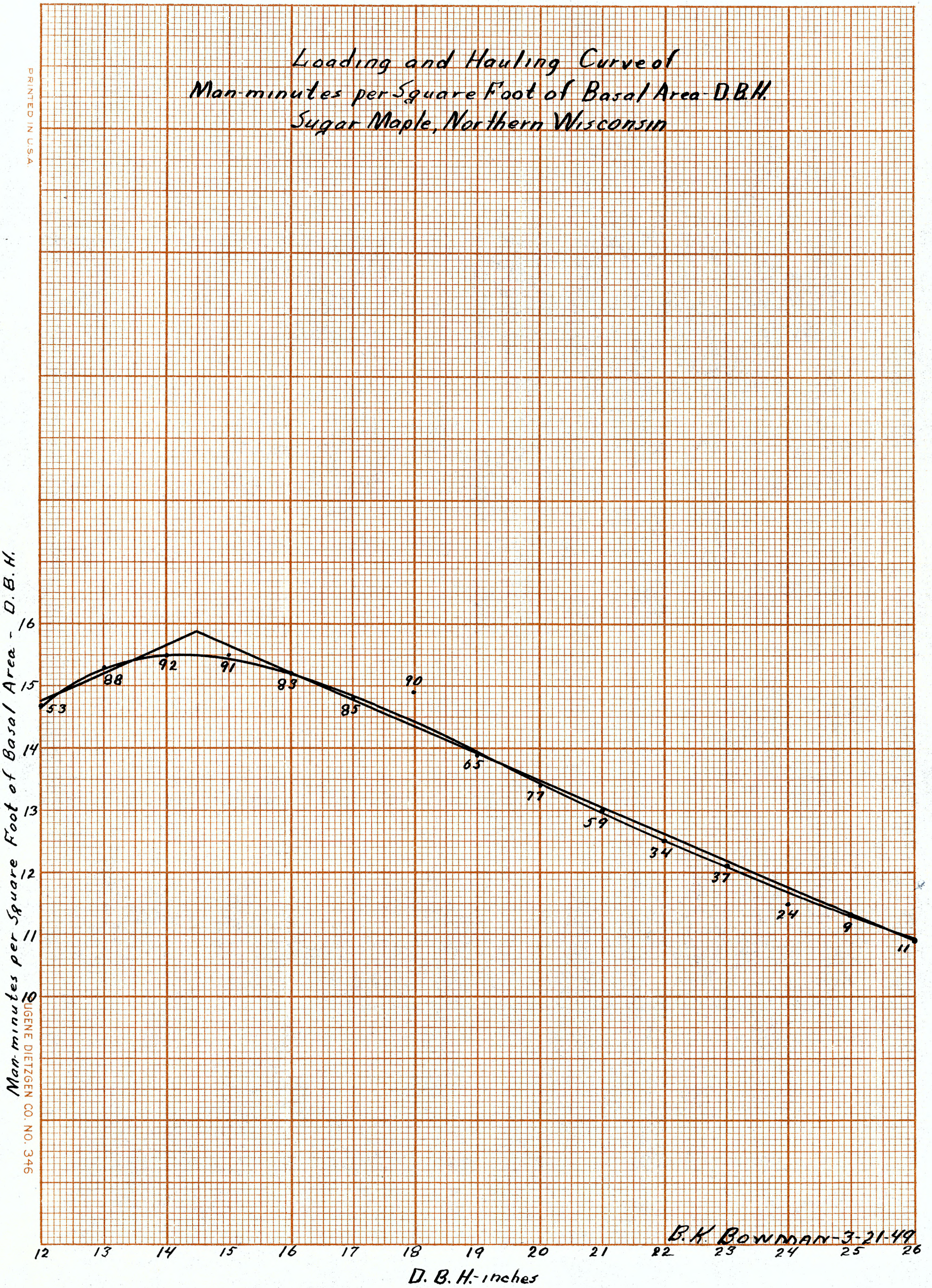
Loading and Hauling Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
D.B.H.-inches
16
15
14
13
12
11
10
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
53
88
92
91
93
90
85
65
77
59
34
37
24
9
11
B.K. Bowman-3-21-49
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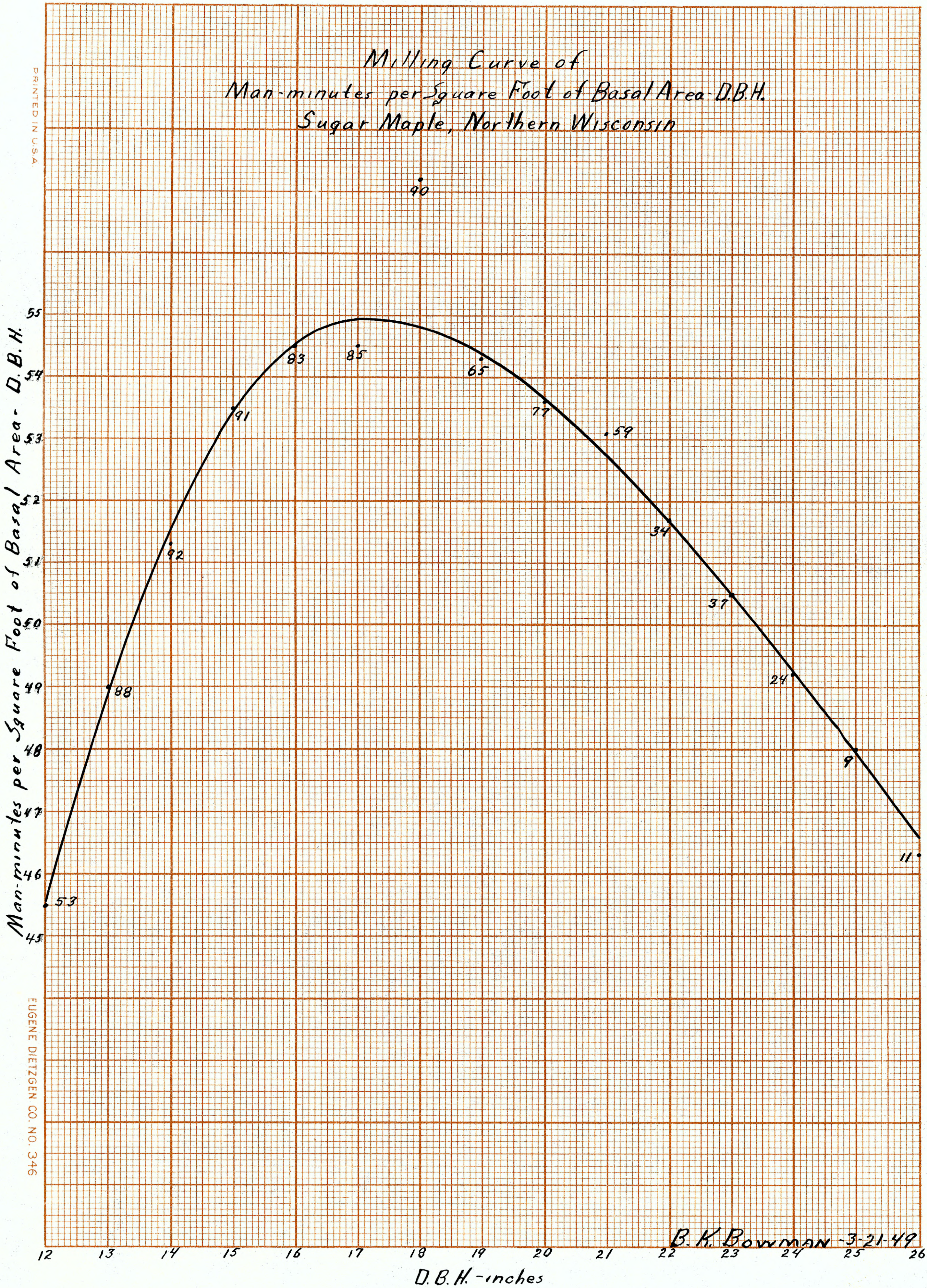
EUGENE DIETZGEN CO. NO. 346


Milling Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Sugar Maple, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
D.B.H.-inches
55
54
53
52
51
50
49
48
47
46
45
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
90
83
85
65
91
77
59
92
34
37
88
24
9
11
53
B.K. Bowman 3-21-49
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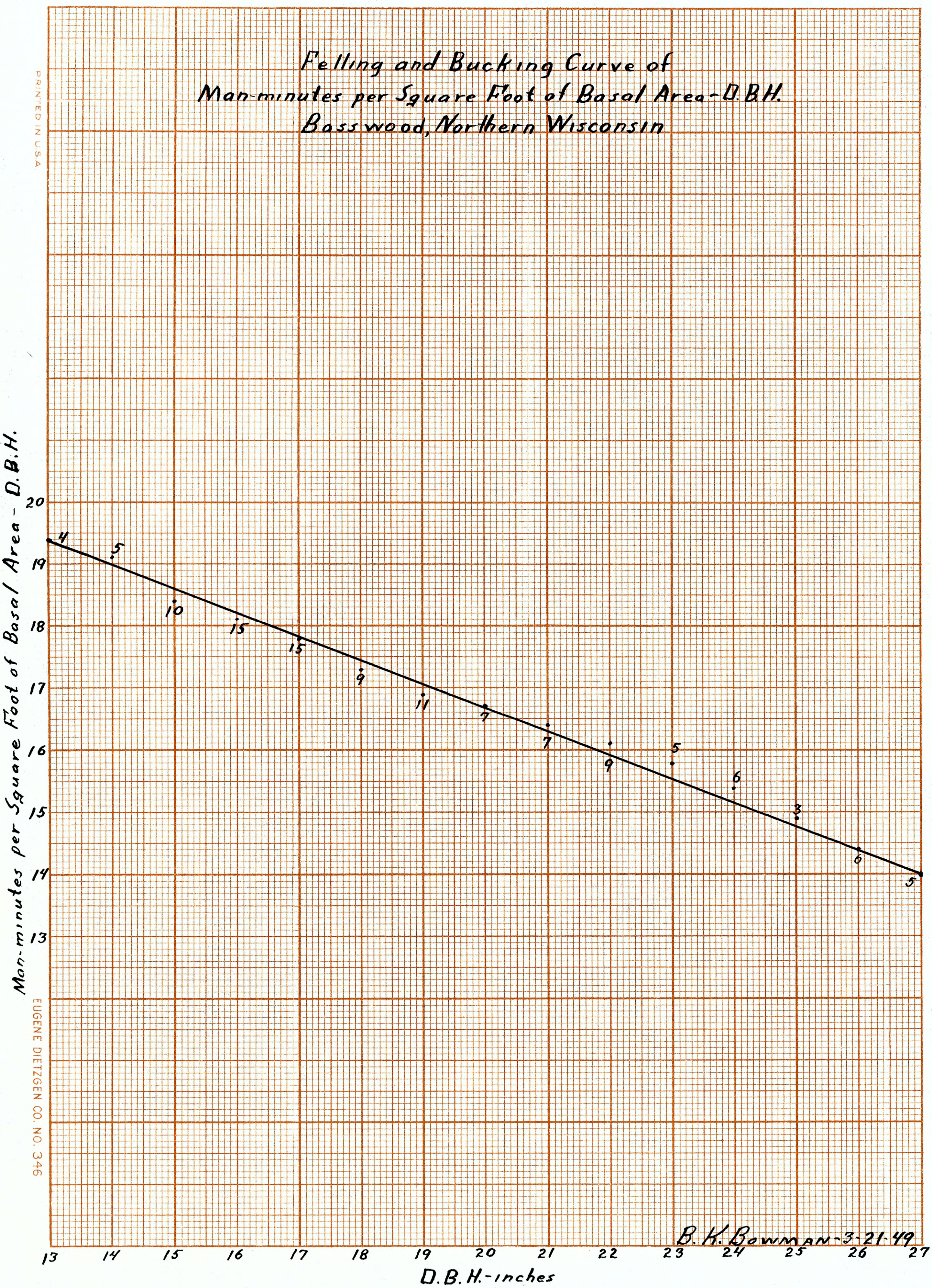
Felling and Bucking Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Basswood, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
20
19
18
17
16
15
14
13
4
5
10
15
15
9
11
7
7
9
5
6
3
6
5
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
D.B.H.-inches
B. K. Bowman - 3-21-49
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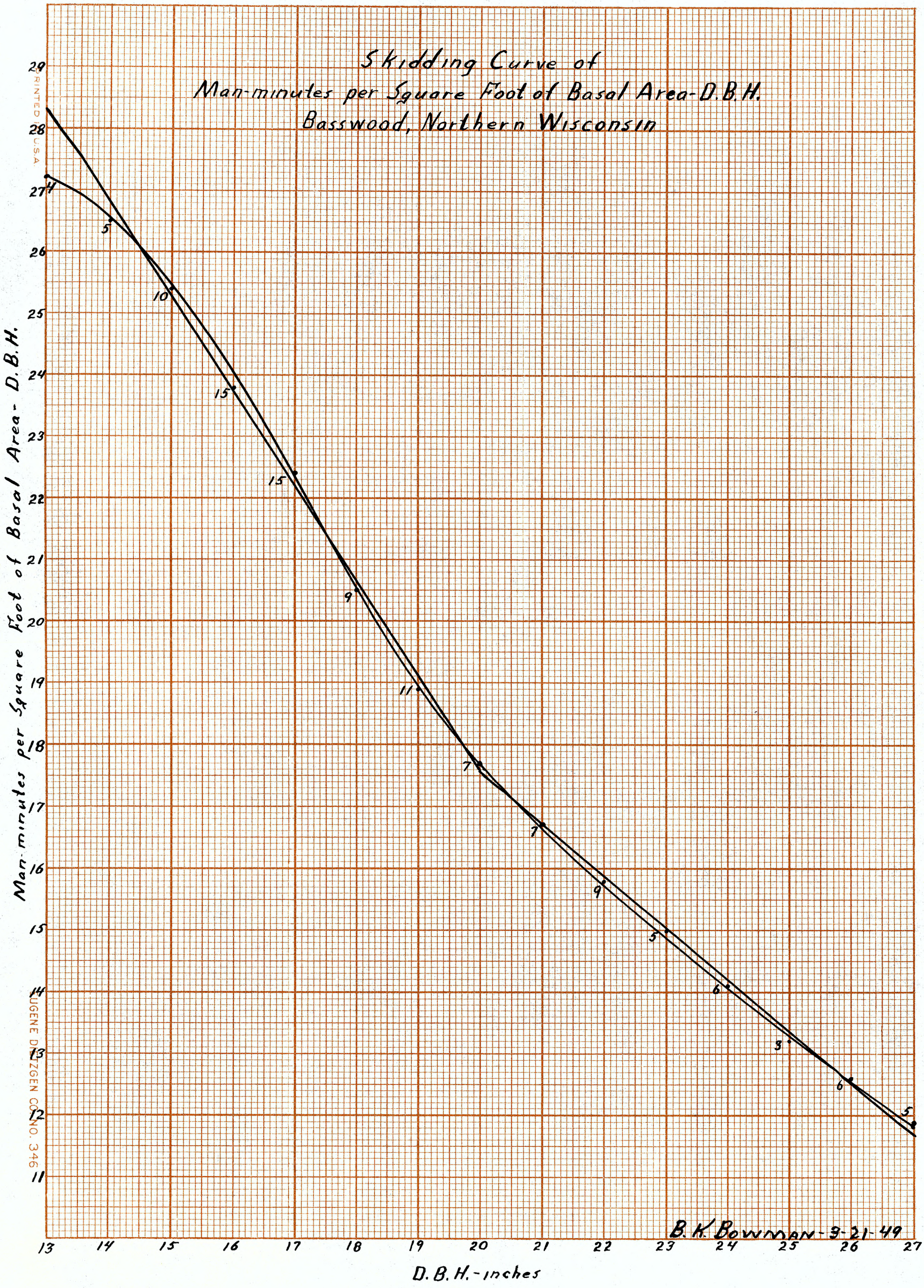
Skidding Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Basswood, Northern Wisconsin
Man-minutes per Square Foot of Basal Area- D.B.H.
D.B.H.-inches
B.K. Bowman-3-21-49
EUGENE DIETZGEN CO. NO. 346
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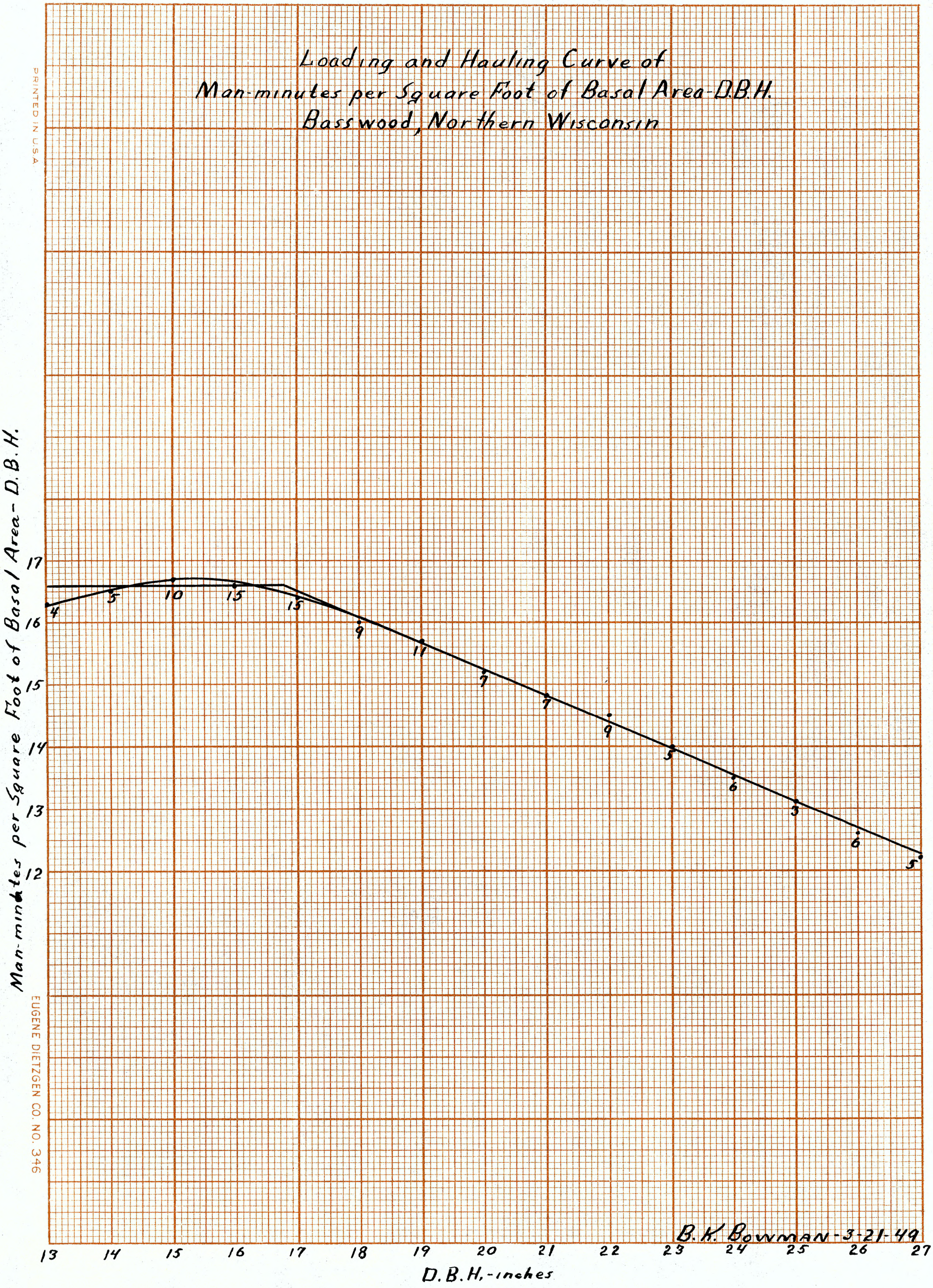
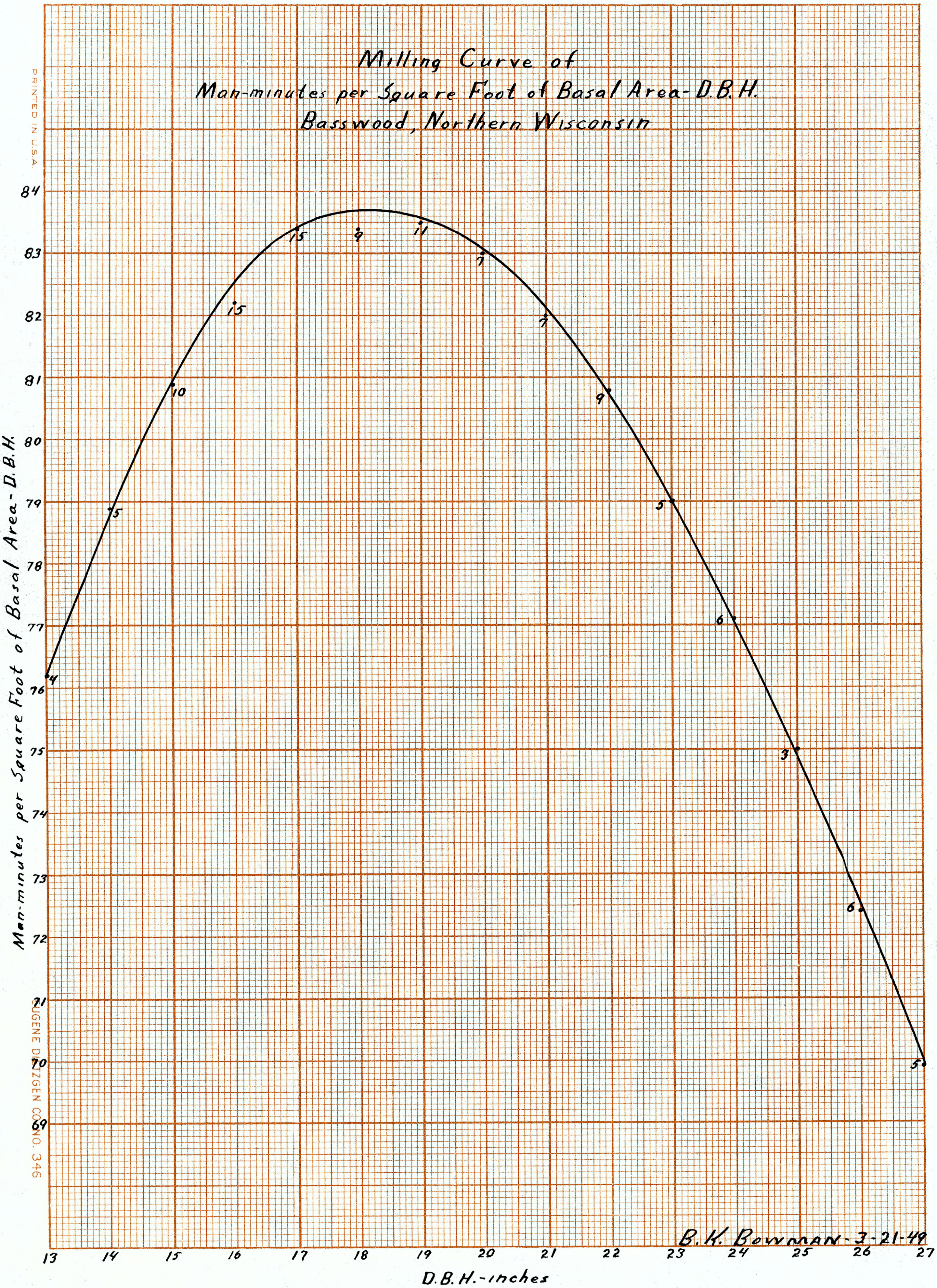
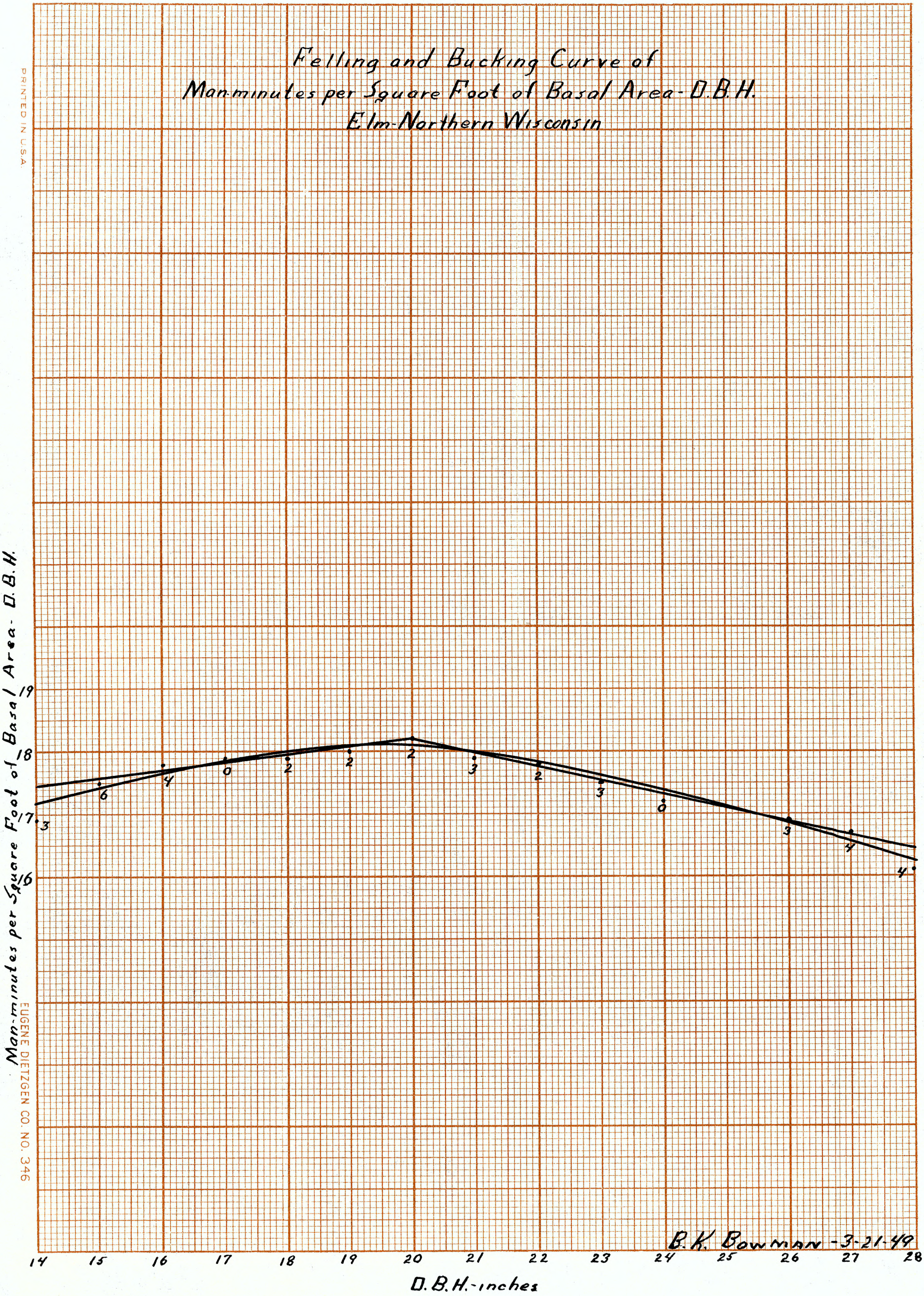
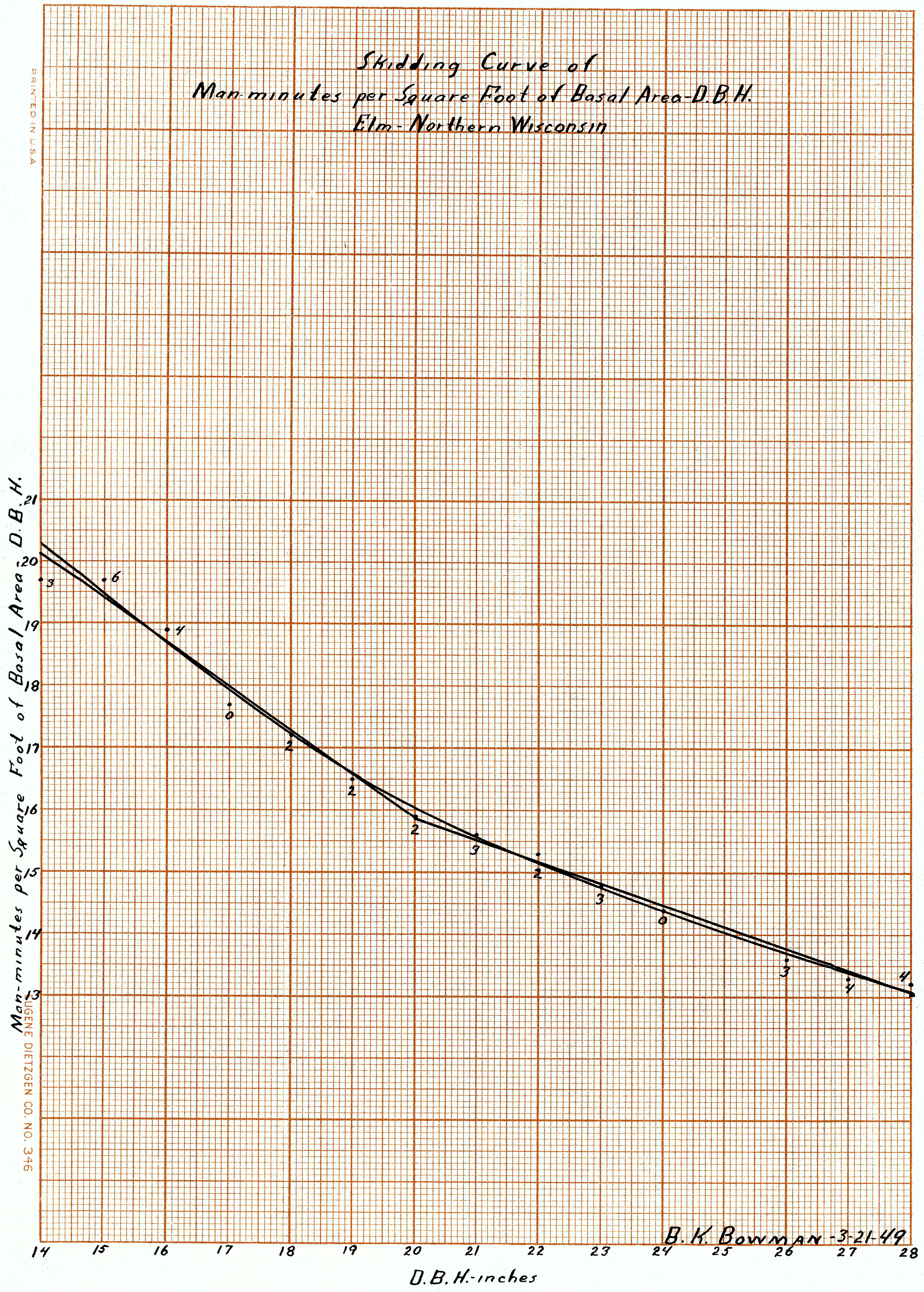

Loading and Hauling Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Basswood, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
17
16
15
14
13
12
4
5
10
15
15
9
11
7
7
9
5
6
3
6
5
B.K. Bowman - 3-21-49
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
D.B.H.,-inches


Milling Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Basswood, Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
D.B.H. - inches
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
69
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
B. K. Bowman - 3-21-49


Felling and Bucking Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Elm-Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
19
18
17
16
3
6
4
0
2
2
2
3
2
3
0
3
4
4
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
D.B.H.-inches
B.K. Bowman - 3-21-49


Skidding Curve of
Man-minutes per Square Foot of Basal Area-D.B.H.
Elm-Northern Wisconsin
Man-minutes per Square Foot of Basal Area D.B.H.
D.B.H.-inches
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
B. K. Bowman -3-21-49
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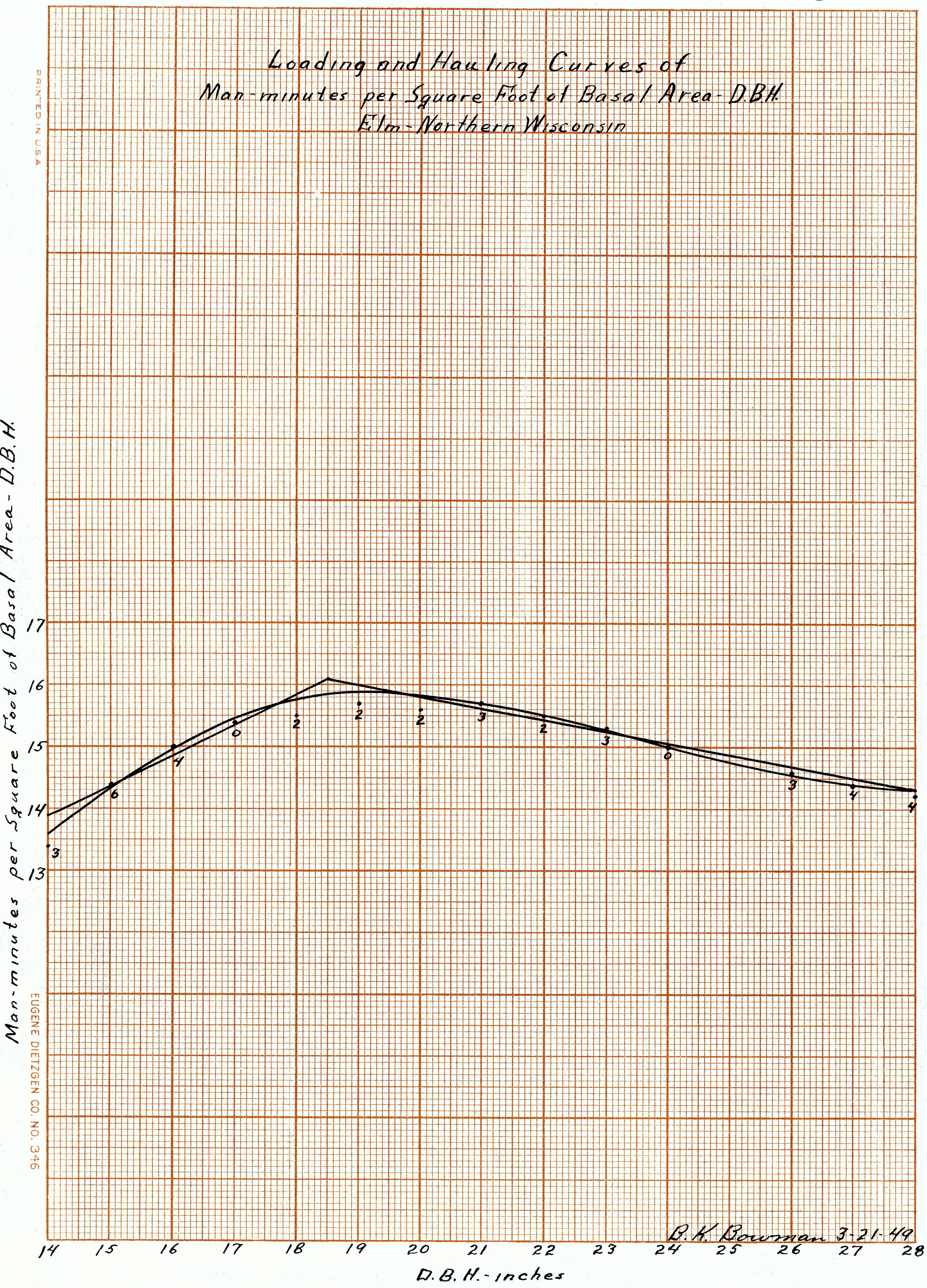
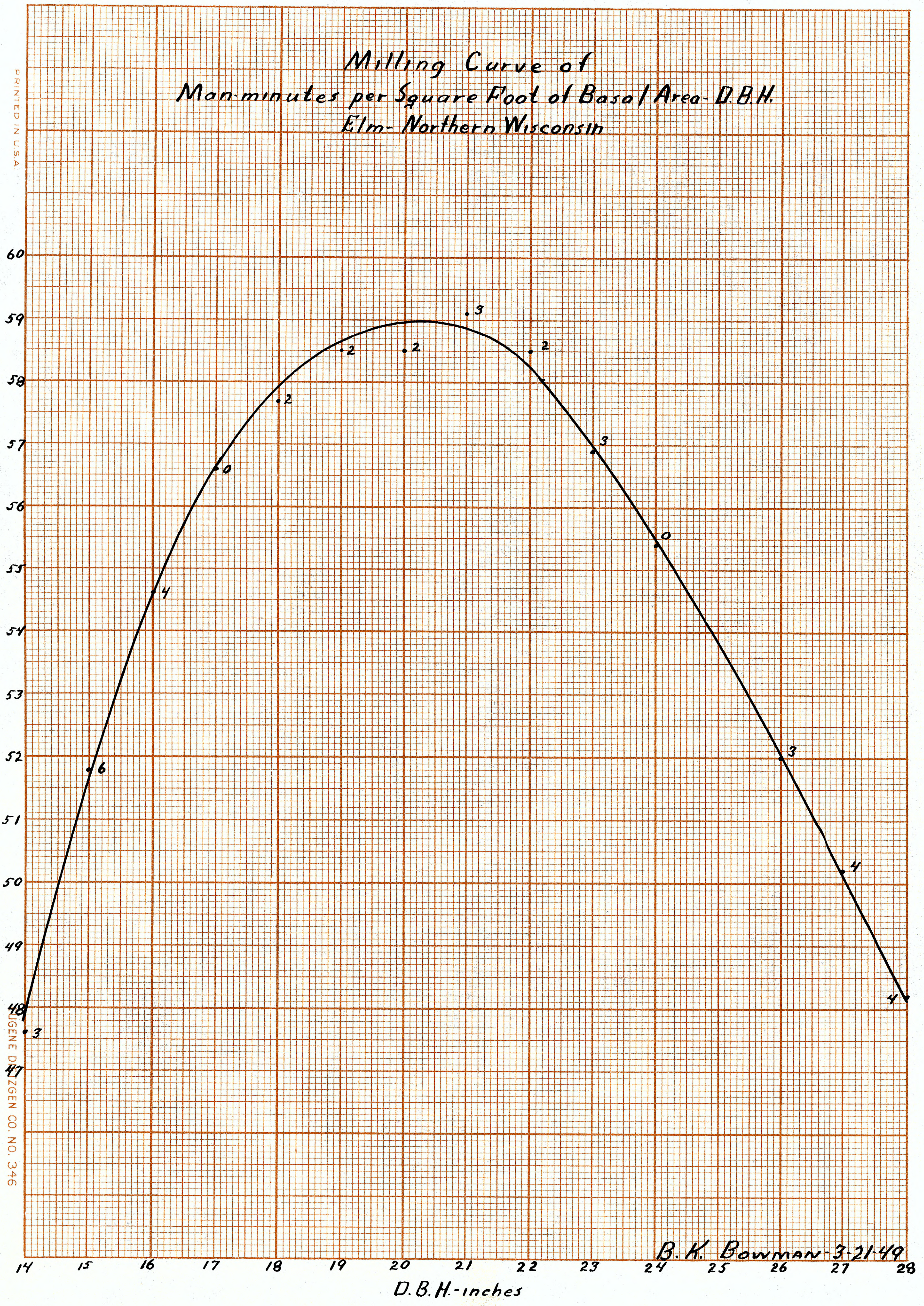


Loading and Hauling Curves of
Man-minutes per Square Foot of Basal Area - D.B.H.
Elm - Northern Wisconsin
Man-minutes per Square Foot of Basal Area - D.B.H.
13
14
15
16
17
3
6
4
0
2
2
2
3
2
3
0
3
4
4
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
D.B.H. - inches
B.K. Bowman 3-21-49
PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 346


Milling Curve of
Man-minutes per Square Foot of Basal Area - D.B.H.
Elm - Northern Wisconsin
60
59
58
57
56
55
54
53
52
51
50
49
48
47
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
D.B.H.-inches
B. K. Bowman - 3-21-49
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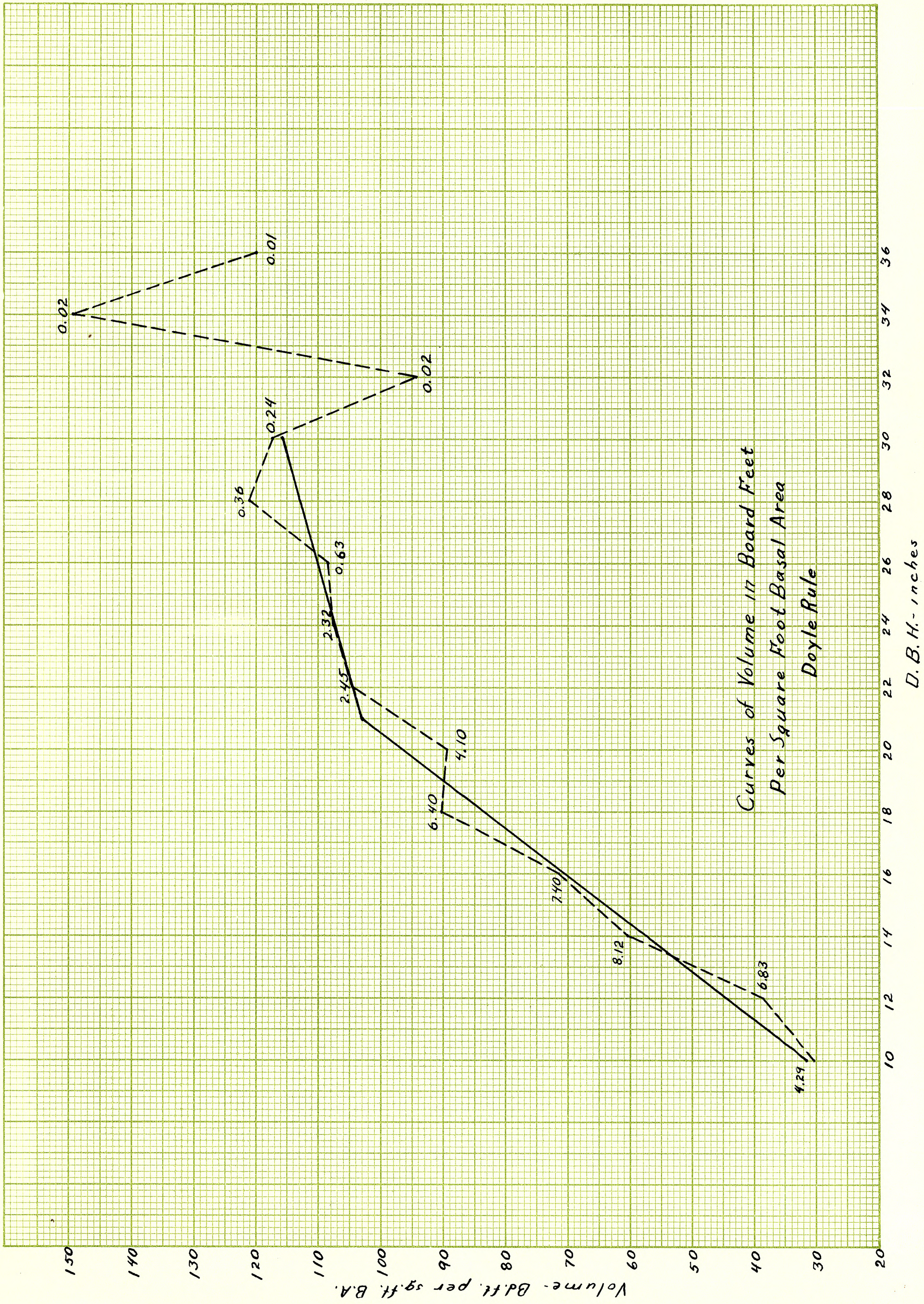
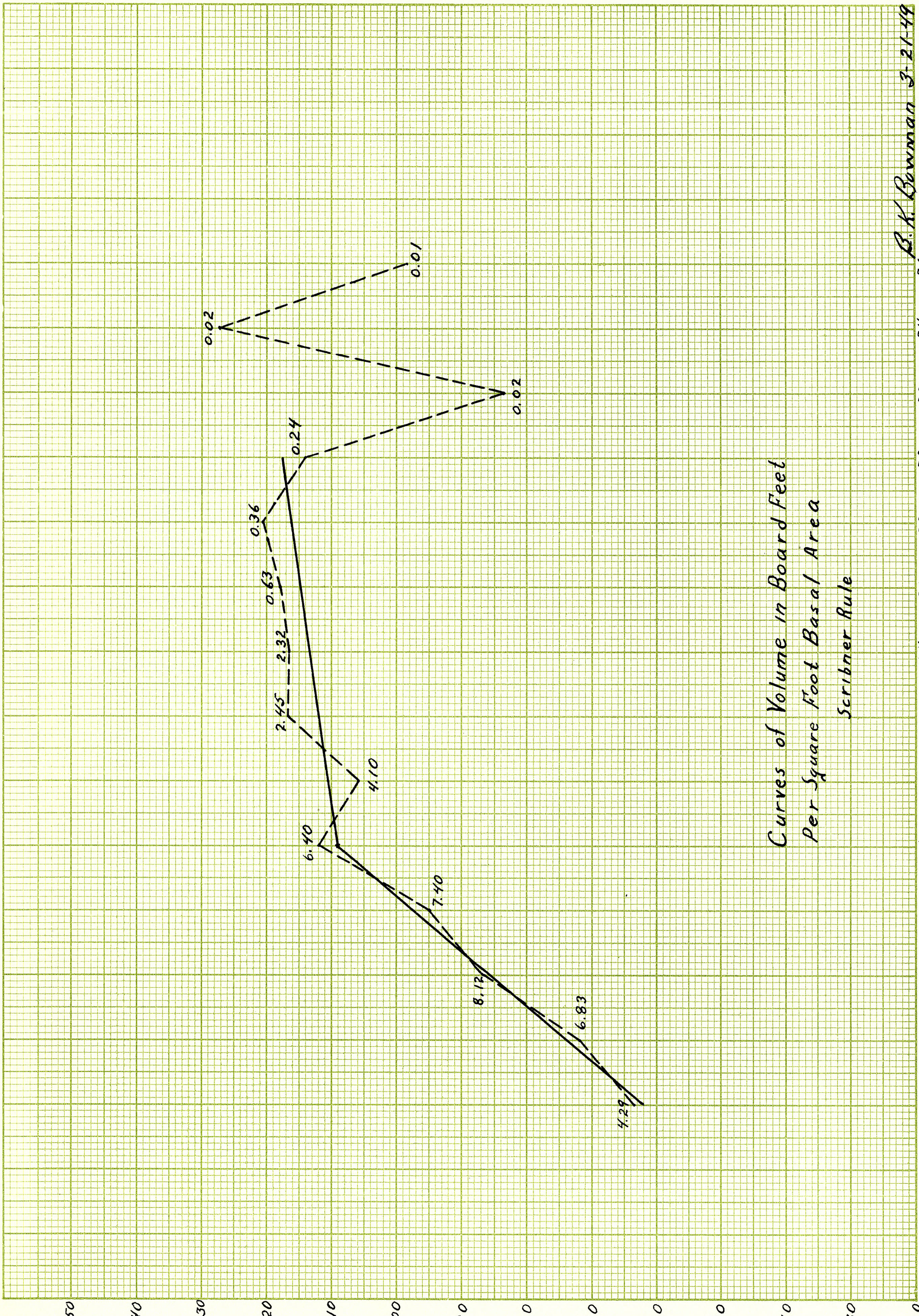
Appendix D

Basal Area - Volume Conversion

Formulae and Graphs


Curves of Volume in Board Feet
Per Square Foot Basal Area
Doyle Rule
D. B. H.- inches
Volume- Bd.ft. per sq.ft. B.A.
10 12 14 16 18 20 22 24 26 28 30 32 34 36
150 140 130 120 110 100 90 80 70 60 50 40 30 20
4.29 6.83 8.12 7.40 6.40 4.10 2.45 2.32 0.63 0.36 0.24 0.02 0.02 0.01
KEUFFEL & ESSER CO. N. Y. NO. 358-11
10 x 10 to the 1/2 inch, 5th lines accented.
Engraving, 7 X 10 in.
MADE IN U. S. A.


Curves of Volume in Board Feet
Per Square Foot Basal Area
Scribner Rule
D. B. H. - inches
Volume - Bd.ft. per sq.ft. B.A.
B.K. Bowman 3-21-49
10 12 14 16 18 20 22 24 26 28 30 32 34 36
150 140 130 120 110 100 90 80 70 60 50 40 30 20
4.29
6.83
8.12
7.40
6.40
4.10
2.45
2.32
0.63
0.36
0.24
0.02
0.02
0.01

Appendix D

Conversion Formulae

Doyle Rule

10" to 21" diameters

$V = 6.5\ D\ B\ H - 33.3$

21" to 30" diameters

$V = 1.39\ D\ B\ H + 74$

Scribner Rule

10" to 18" diameters

$V = 5.9\ D\ B\ H + 3$

18" to 30" diameters

$V = 0.7\ D\ B\ H + 96.5$