MEASUREMENTS FOUND MOST USEFUL IN ESTIMATING ANTLER VOLUME[1]

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INTRODUCTION

Basic to management of any game species is a knowledge of the condition of game and the condition of habitat it occupies. This knowledge may be acquired by direct observation and measurement, but often cost involved in obtaining such information by direct methods is prohibitive. For this reason indices are often used in game management.

The extent of antler development has been accepted and widely applied in deer management as an indicator of the physical condition of deer and indirectly of range condition. More than a century ago, Buffon (1821) noted that male deer without sufficient food produced inferior antlers. Many recent studies have verified this as well as the relationships between range quality and deer antler size. If antler mass is taken as a measure of deer and range condition, ideally weight or volume of the antler should be used, but neither of these measurements has been possible or practical to make at deer checking stations. Instead, game biologists have commonly taken a number of linear measurements and counted the number of points. It is appropriate, therefore, to consider the relationships of antler mass to readily made measurements.

A thorough investigation of relationship of antler size and linear measurements and number of points has not previously been reported. In this study an attempt was made to determine this relationship and to refine one of the techniques commonly used for measuring the physiological response of deer to their environment as displayed by antler growth.

The objectives of this study were to: (1) investigate the relationship of volume of deer antlers to selected linear measurements and number of points; and (2) develop an equation for predicting volume from the number of points and one or more linear measurements.

This contribution is based on research and a thesis by the senior author (Rogers, 1965). The thesis includes an extensive review of the literature relating to indicators of deer condition and the interrelationships of deer and their range, and a detailed presentation of the statistical procedures used, some of which are omitted from this paper.

METHODS

Experimental Procedures

All antlers measured were from the white-tailed deer, *Odocoileus virginianus* (Boddaert), taken in or near southwestern and west central Alabama. Kellogg (1956:35) shows the subspecies *Odocoileus virginianus virginianus* (Zimmerman) as occupying this area.

Antler measurements were of two kinds: linear and volumetric. A flexible steel tape graduated in sixteenths of an inch was used to measure lengths of the main beams, length of points, circumferences, and distance between parts of the antlers. Diameters were measured with calipers graduated in sixteenths of an inch, and were obtained

[1] A contribution of the Alabama Cooperative Wildlife Research Unit, Auburn University Agricultural Experiment Station, The Alabama Department of Conservation, The Wildlife Management Institute, and the U. S. Fish and Wildlife Service, cooperating.

by measuring the greatest and the smallest diameter at approximately right angles to each other.

Sometimes certain measurements could not be taken because of some antler irregularity, such as a missing point or a point at the intended place of measurement. In measuring diameters and circumferences of antlers, an attempt was made to avoid warty protuberances of the main beam.

Differences in antler formation necessitated dividing them into two groups for study: (1) antlers with three or more points, and (2) antlers with one or two points. All measurements used during the study are listed in Table 1 together with the type of antler to which each measurement is applicable. The X numbers listed in Table 1 are used throughout the statistical treatment that follows. The various measurements are illustrated in Figures 1 and 2.

As a result of preliminary analysis and some practical considerations, not all measurements listed in Table 1 were used in the final statistical analysis. Use of antler volume rather than weight as a measure of antler mass was used for practical considerations. Since most of the antlers used in this study were at taxidermist shops and hunting lodges, it was not possible to remove these trophy antlers from the skulls for weighing. Volume of antlers was obtained with a

Figure 1. Diameter and circumference measurements used. Numerals refer to X Factors in Table 1 and in the text.

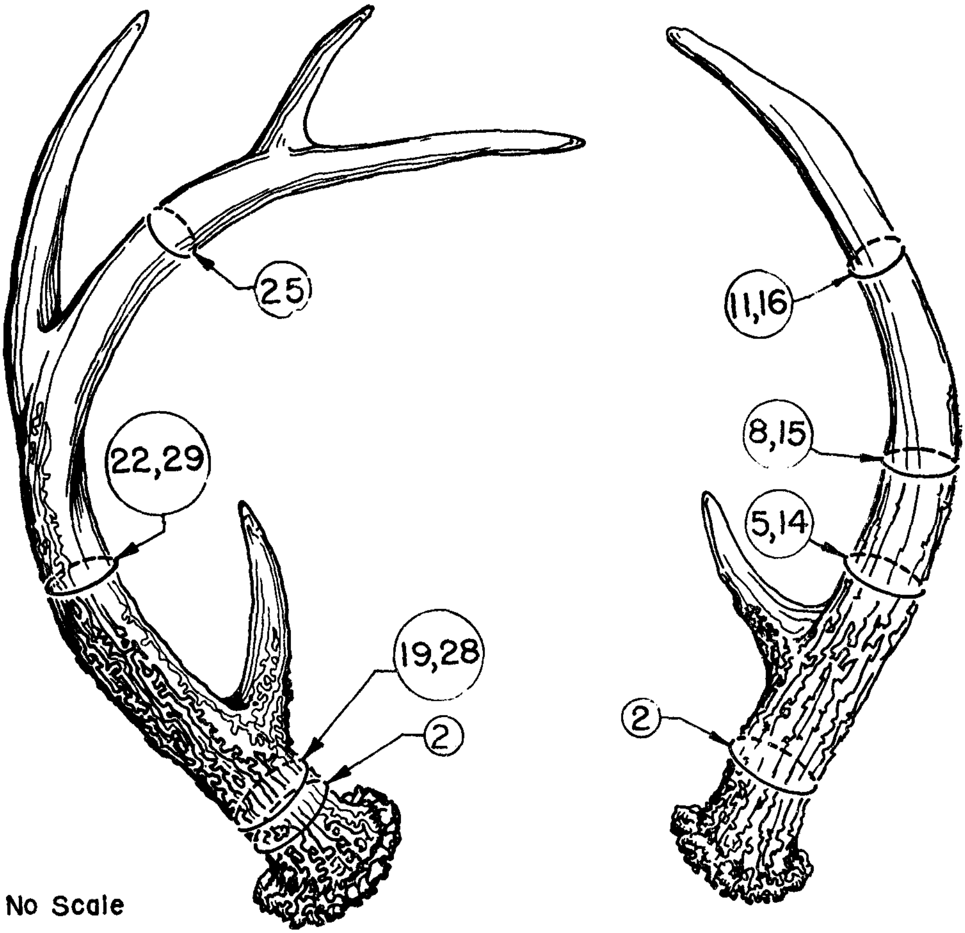
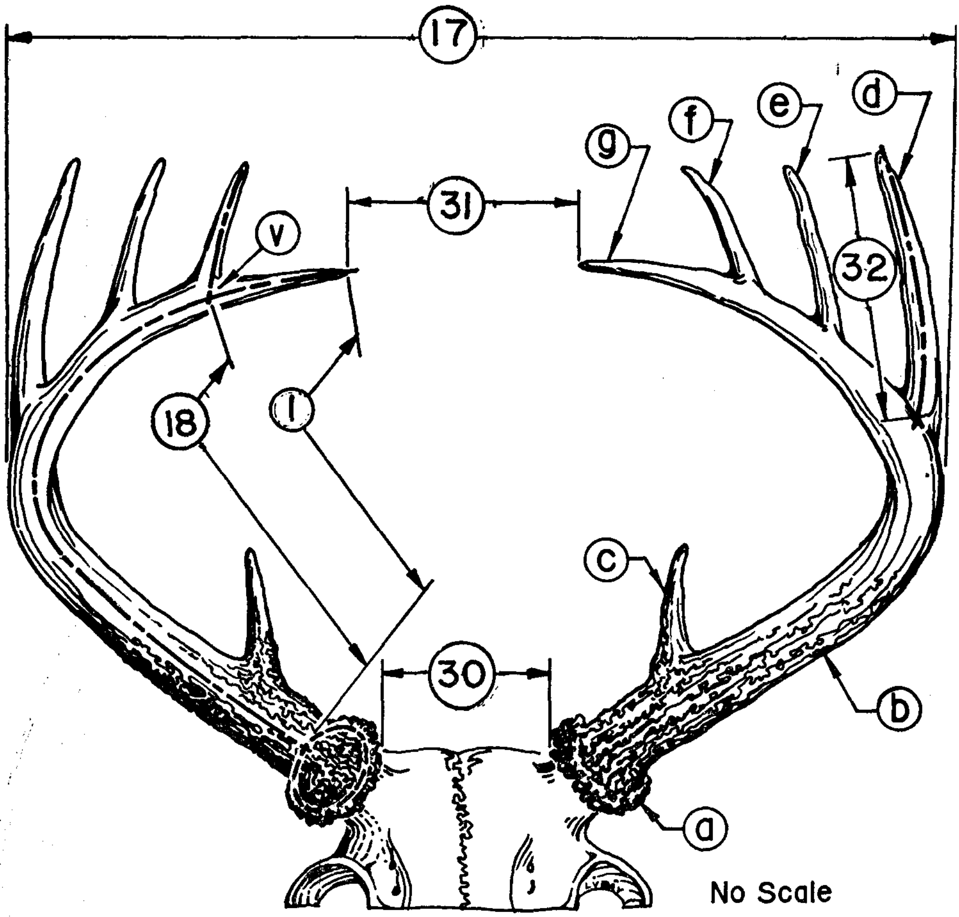


Figure 2. Length measurements and terminology used. Numerals refer to Table 1. Terminology: (a) burr; (b) main beam; (c) first point; (d) second point; (e) third point; (f) fourth point; (g) fifth point; (v) vertex of angle of last 2 points.



balance and a container of water employing Archimede's principle. The weight in grams of the trophy with one antler immersed in water subtracted from the weight in grams of the trophy in air gave the volume of the one antler in cubic centimeters. Old weathered antlers were not used.

In addition to taking the linear and volumetric measurements of deer antlers as described, the antler points were enumerated.

Statistical Procedures

After measurements had been made on 85 sets of antlers, a preliminary statistical analysis was made to: (1) determine which, if any, of the first linear measurements taken might be eliminated from subsequent field work, and (2) gain insight into any differences that might exist between right and left antlers. In this analysis, there were 17 independent variables (X1, X17-X29, X31 to X33) and 1 dependent variable (Y = antler volume). This analysis served only to refine the methods used in measuring antlers.

Table 1. Summary of all linear measurements used and the types of antlers to which each was applied. See Figures 1 and 2 for illustration. These X factors are used throughout the presentation.

X No.	Description of Measurement	Applied to: Antlers with 1 or 2 points	Applied to: Antlers with 3 or more points
X1.	Length of the main beam measured along the outside curvature from the upper part of the burr to the tip of the antler.	X	X
X2.	Greatest diameter of the main beam taken 1 inch above the upper part of the burr.	X	X
X3.	Smallest diameter of the main beam taken as in number X2.	X	X
X4.	Average diameter of the main beam taken as in number X2.	X	X
X5.	Greatest diameter of the main beam taken at one-third the length of the antler from the burr.	X	
X6.	Smallest diameter of the main beam taken as in number X5.	X	
X7.	Average diameter of the main beam taken as in number X5.	X	
X8.	Greatest diameter of the main beam taken at one-half the length of the antler.	X	
X9.	Smallest diameter of the main beam taken as in number X8.	X	
X10.	Average diameter of the main beam taken as in number X8.	X	
X11.	Greatest diameter of the main beam taken at two-thirds the length of the antler from the burr.	X	
X12.	Smallest diameter of the main beam taken as in number X11.	X	
X13.	Average diameter of the main beam taken as number X11.	X	
X14.	Circumference of the main beam taken at one-third the length of the antler from the burr.	X	
X15.	Circumference of the main beam taken at one-half the length of the antler.	X	
X16.	Circumference of the main beam taken at two-thirds the length of the antler from the burr.	X	
X17.	Greatest outside spread measured between perpendiculars at the greatest width of the antlers at right angles to the center line.	X	X
X18.	Length of the main beam from the upper part of the burr along the outside curvature to the vertex of the angle between the last two points.		X*
X19.	Greatest diameter of the main beam taken half-way between the upper part of the burr and the first point.		X
X20.	Smallest diameter of the main beam taken as in number X19.		X
X21.	Average diameter of the main beam taken as in number X19.		X

Table 1 (cont'd)

Table 1. Summary of all linear measurements used and the types of antlers to which each was applied. See Figures 1-4 for illustrations. These X factors are used throughout the presentation.

X No.	Description of Measurement	Applied to: Antlers with 1 or 2 points	Antlers with 3 or more points
X22.	Greatest diameter of the main beam taken half-way between the first and second points.		X
X23.	Smallest diameter of the main beam taken as in number X22.		X
X24.	Average diameter of the main beam taken as in number X22.		X
X25.	Greatest diameter of the main beam taken half-way between the second and third points.		X
X26.	Smallest diameter of the main beam taken as in number X25.		X
X27.	Average diameter of the main beam taken as in number X25.		X
X28.	Circumference of the main beam taken half-way between the burr and the first point.		X
X29.	Circumference of the main beam taken half-way between the first and second point.		X
X30.	Distance between the burrs.	X*	X*
X31.	Distance between the antler tips.	X*	X*
X32.	Length of the second point taken from the edge of the main beam along the center line of the point to its tip.		X
X33.	Number of points.	X	X

Following the preliminary analysis, separate regression analyses were made with data from antlers with three or more points and those with two points or less to: (1) examine more thoroughly the relationship of volume to linear measurements and the number of points, (2) determine whether a linear or a non-linear regression explained a greater amount of variability in volume as accounted for by the various independent variables, and (3) develop a prediction equation of antler size from the independent variables.

Multiple regression analyses were made also on data from antlers arranged in three different groups: (1) antlers with two points or less, (2) antlers with three or more points, and (3) antlers with measurements common to all antler types. Methods used in the regression analysis were those described by Dixon (1964:233) referred to as a stepwise regression analysis. In each step of the development of the regression equation the independnt variable is added that contributes most to the reduction of the sum of the squares of the dependent variable. The independent variable selected is the one that would have the highest F value if it were added to the equation. In addition, variables already in the equation are automatically removed if their F value becomes too low when considered in relation to variables subsequently added. The result is an equation in which the variability of the dependent variable (in this case volume) is best accounted for.

For all groups of antlers analyzed, factors were chosen on the basis of findings in the preliminary statistical analysis and use of these measurements by game technicians.

*Not used in final statistical analysis.

RESULTS

Preliminary Analysis

The preliminary statistical analysis indicated that all measurements evaluated showed a high degree of correlation with antler volume. The number of antler points (X33) showed the poorest correlation with volume (0.4040 for the right and 0.3109 for the left antler), but was retained for the final statistical analysis because of its widespread use by game technicians. The length of the main beam from burr to xertex of the last two points (X18), distance between tips of an antler set (X31), and distance between burrs (X30) were dropped from further consideration to permit inclusion of other measurements peculiar to antlers with one or two points. The preliminary analysis indicated that there was little difference between right and left antlers. On this basis, right antlers were arbitrarily selected for further study.

Final Statistical Analysis.

Coefficients of Determination.[1] The data are presented in the form of computer-derived coefficients of determination for antlers with one or two points (Table 2) and for antlers with three or more points (Table 3).

For antlers with one or two points, all measurements, except the greatest outside spread and greatest diameter at two-thirds the length of the main beam (variables X17 and X11, respectively), had coefficients of determination greater than 0.5000. Length of the main beam (variable X1) had the highest coefficient of determination

Table 2. Coefficients of Determination of Linear and Non-Linear Regression For Antlers With 1 and 2 Points.

Variable	Coefficients of Determination	
	Linear (r^2)	Non-linear (R^2)
X1	0.8461	0.9323
X2	0.6417	0.7312
X3	0.5499	0.7188
X4	0.7033	0.8385
X5	0.5941	0.7015
X6	0.6735	0.8384
X7	0.7136	0.8451
X8	0.7017	0.7299
X9	0.5716	0.7028
X10	0.7598	0.8285
X11	0.4541	0.5195
X12	0.5045	0.6642
X13	0.5734	0.6962
X14	0.7013	0.7886
X15	0.7617	0.7937
X16	0.5938	0.6725
X17	0.2592	0.2592
X33	0.6491	0.7132

(0.8461 for the linear, 0.9323 for the non-linear regression). Of the 18 independent variables tested, 17 showed higher values for the coefficient of determination resulting from fitting a second-degree polynominal.

For antlers with three or more points, all measurements for both the linear and non-linear regressions had coefficients of determination greater than 0.5000 except the number of antler points (X33). The average diameter half-way between the first and second points (variable X24) had the highest coefficient of determination

[1] The coefficient of determination, referred to as r^2 for the linear, R^2 for the non-linear regression, may be defined as the proportion of the sum of squares of the dependent variable that can be attributed to the independent variable.

Table 3. Coefficients of Determination of Linear and Non-Linear Regression For Antlers With 3 or More Points.

Variable	Coefficients of Determination	
	Linear (r^2)	Non-linear (R^2)
X1	0.7573	0.7825
X17	0.5805	0.5834
X19	0.6495	0.6505
X20	0.6318	0.6477
X21	0.7180	0.7207
X22	0.7823	0.7823
X23	0.7655	0.7726
X24	0.8597	0.8626
X25	0.6114	0.7003
X26	0.7113	0.7113
X27	0.7426	0.7543
X28	0.7330	0.7355
X29	0.8386	0.8395
X32	0.5252	0.5270
X33	0.1725	0.1833

(0.8597 for the linear, 0.8626 for the non-linear regression). Most values of the coefficients of determination were greater than 0.7000. Of 15 independent variables tested, six showed higher coefficients of determination because of fitting a second-degree polynominal, while nine showed the same values for linear as for non-linear regression.

In summary, the linear and non-linear regressions showed that most linear measurements considered in the analyses bore a close relationship to total volume of deer antlers. The number of antler points bore the poorest relationship to volume. The reduction in sums of squares because of fitting a second-degree polynominal was larger than the reduction attributable to linear regresson. The problem then was to learn which of the measurements best reflected volume.

Development of Regression and Prediction Equations. General multiple regression equations were computed for each of three sets of observations with the linear measurements and number of antler points expressed as independent variables (X) and Y = total predicted volume of deer antler. From each of the three general regresson equations, prediction equations were developed. In the deletion of variables from the general regression equations, the following procedure was followed: a variable was dropped if the linear effect was not significant at a probability level less than or equal to 0.005; if a non-linear effect was not significant at this level of probability, but the linear effect was significant, that variable was kept for the next regression analysis.

For antlers with 1 or 2 points, 56 observations using 18 independent variables with a non-linear effect for each variable were included in the general regression analysis. Variables that did not reduce the sum of the squares were not included in the regression equation. This equation: $Y = 96.967 - 5.410\ X1 - 125.028\ X3 - 305.561\ X4 + 304.850\ X5 - 622.709\ X7 - 148.552\ X8 - 15.402\ X9 - 167.511\ X11 + 81.768\ X12 + 18.621\ X14 + 74.859\ X15 + 121.858\ X16 + 8.907\ X17 + 0.498\ X1^2 + 260.660\ X2^2 + 417.133\ X3^2 - 333.704\ X4^2 - 284.920\ X5^2 - 82.367\ X6^2 + 631.792\ X7^2 + 54.564\ X8^2 - 39.594\ X9^2 + 121.898\ X10^2 + 49.669\ X11^2 - 202.996\ X12^2 + 200.816\ X13^2 - 4.431\ X14^2 - 17.120\ X15^2 - 32.601\ X16^2 - 0.523\ X17^2 + 1.345\ X33^2$ had an R^2 of 0.9952. (1a)

Variables that were not significant at a probability level less than or equal to 0.005 were deleted and a new equation was computed. This procedure was repeated until at least one effect of each of the remaining variables was significant at the specified probability level. The equation at this point contained two independent linear variables and their non-linear effects. This prediction equation: $Y = 156.635 + 4.504\ X4 - 646.960\ X10 + 78.115\ X4^2 + 491.970\ X10^2$ had an R^2 of 0.9753. (1b)

An analysis of variance showing source of variation, degrees of freedom, and F ratio was used to determine significance of the various effects. All variables tested, as shown in Table 4, were significant at the 0.005 level. The F ratio for the linear effect of average diameter 1 inch above the burr (X4) indicated that this term had a highly significant effect in predicting total antler volume, with the linear effect of the average diameter at one-half the length of main beam (X10) second. Non-linear effects of the average diameter at one-half the length of main beam and 1 inch above the burr had third and fourth highest F ratios, respectively.

Table 4. Analysis of Variance of Total Deer Antler Volume (Equation lb) Antlers With 1 or 2 Points.

Source of variation	Degrees of freedom			F
Total (N=56)				
Mean	1			
Regression	4			
Linear		2		
X4			1	296.97***
X10			1	47.99***
Non-linear		2		
$X4^2$			1	36.19***
$X10^2$			1	47.44***
Residual	51			

***In this and/or future tables, the triple asterisk will indicate a probability level less than or equal to 0.005.

For antlers with 3 or more points, 123 observations using 15 independent variables with a non-linear effect for each variable were included in the general regression equation. This equation had an R^2 value of 0.9813. Using the same procedure as was used in developing equation lb, deletion of nonsignificant variables, a new equation was computed. This equation contained five linear variables and the non-linear effect of each variable. This equation: $Y = 122.649 - 4.369\ X1 - 380.567\ X24 + 35.920\ X27 + 0.258\ X28 - 4.194\ X32 + 0.424\ X1^2 + 293.242\ X24^2 + 54.817\ X27^2 + 2.488\ X28^2 + 0.866\ X32^2$ had an R^2 of 0.9703. (2)

An analysis of variance showing source of variation, degrees of freedom, and F ratio was used to determine the significance of the various effects. This analysis is shown in Table 5.

The non-linear effect of the average diameter halfway between the first and second points showed the highest F-value in the prediction equation. The non-linear effects of average diameter halfway between the second and third points, the length of main beam, length of second point, and circumference halfway between burr and first point showed F ratios that were second, third, fourth, and fifth in value, respectively. The only linear effect significant at the 0.005 level of probability was that for the average diameter halfway between the first and second points. None of the remaining linear effects were significant at a probability level of 0.100 or less.

The F value for non-linear effect of the average diameter halfway between first and second points (X24), as shown in Table 5, indicated that this term had a highly significant effect in predicting total deer antler volume.

For this group of antlers (those with three or more points), the diameter measurements 1 inch above the burr were not included in the multiple regression analyses since they were few in number and

Table 5. Analysis of Variance of Total Deer Antler Volume (Equation 2)

Source of variation	Degrees of freedom		F
Total (N=123)			
Mean	1		
Regression	10		
Linear	5		
X1		1	0.30ns
X24		1	9.13***
X27		1	0.30ns
X28		1	0.00ns
X32		1	0.47ns
Non-linear	5		
$X1^2$		1	80.24***
$X24^2$		1	755.93***
$X27^2$		1	98.15***
$X28^2$		1	14.75***
$X32^2$		1	28.75***
Residual	112		

meaningful results were considered unobtainable. Most of the data collected for this measurement were on antlers with one or two points. The inclusion of the variable in the multiple regression analyses for antlers with three or more points might have produced results similar to those obtained in equation 1b for antlers with one or two points.

For antlers with measurements common to all antler types, 56 observations using six independent variables with a non-linear effect for each variable were included in the general regression equation. X factors that did not reduce the sum of the squares were deleted. This equation:

$Y = 83.281 - 6.586\ X1 - 208.662\ X3 - 121.244\ X4 + 9.758\ X17 + 0.605\ X1^2 + 297.481\ X2^2 + 520.072\ X3^2 - 515.545\ X4^2 - 0.579\ X17^2 + 1.501\ X33^2$ had an R^2 of 0.9806. (3a)

A new equation was computed after deleting the variables that were not significant at a probability level less than or equal to 0.005. This equation:

$Y = 65.581 + 3.018\ X1 + 8.068\ X3 - 272.585\ X4 + 0.030\ X1^2 + 246.534\ X3^2 + 0.004\ X4^2$ had an R^2 of 0.9677. (3b)

An analysis of variance showing source of variation, degrees of freedom, and F ratio was used to determine the significance of the various effects. This analysis is shown in Table 6.

The non-linear effect of the length of main beam showed highest F value in the prediction equation. The non-linear effect of the smallest diameter 1 inch above burr and linear effect of the average diameter 1 inch above burr showed second and third highest F values, respectively. All remaining effects, both linear and non-linear, were not significant at the 0.005 level.

The F value for the non-linear effect of main beam length, as shown in Table 6, indicates that this measurement had a highly significant effect in predicting total volume of deer antlers.

DISCUSSION AND CONCLUSIONS

The statistical analyses used in this study indicated that many of the linear measurements made bore a close relationship to total volume of deer antlers. Results of this study appear to justify the use of linear measurements as indices to antler mass. Of the 32 different linear measurements and number of points that were considered in their relationship to antler volume, distance between burrs,

Table 6. Analysis of Variance of Total Deer Antler Volume (Equation 3b)

Source of variation	Degrees of freedom		F
Total (N=56)			
Mean	1		
Regression	6		
Linear	3		
X1		1	0.47ns
X3		1	0.19ns
X4		1	18.48***
Non-linear	3		
$X1^2$		1	606.24***
$X3^2$		1	41.87***
$X4^2$		1	1.55ns
Residual	49		

distance between tips of an antler set, greatest outside spread, and number of points bore the poorest relationship to antler development.

Multiple regression analyses were done for data from three different groups of antlers in the development of an equation for predicting antler volume from linear measurements and number of antler points: (1) antlers with one and two points, (2) antlers with three or more points, and (3) antlers with measurements considered common to virtually all antler types. For each of these groups, general regression equations were computed from which prediction equations were derived. Evaluation of the measurements in the three different prediction equations took into consideration the following points: (1) the number of measurements involved, (2) ease in taking the measurements, (3) practicality of measurements, (4) how much of the variability in total volume of antlers was accounted for by the measurements, and (5) applicability to most antler types.

For antlers with one and two points, the prediction equation (1b) had an R^2 of 0.9753. This equation contained two independent linear variables and their non-linear effects: the average diameter one inch above burr and the average diameter at one-half the length of main beam. Both variables were significant at the 0.005 level. The variable with the highest F ratio was the average diameter one inch above the burr. This equation met all the requirements previously named except the very important one of not being applicable to all antler types. The diameter measurements at one-half the length of main beam would be restricted in its use since frequently an antler point would occur at the half-way mark where the specified measurement would be taken, making the measurements meaningless. This prediction equation, although applicable to this antler group (antlers with one and two points), would seem inadequate as a prediction equation for all antler types.

For antlers with three or more points, the prediction equation (2) had an R^2 of 0.9703. This equation contained five linear variables and non-linear effect of each variable: length of the main beam, average diameter halfway between the first and second points, average diameter halfway between the second and third points, circumference halfway between burr and first point, and length of the second point. The non-linear effect of the average diameter halfway between first and second points showed the highest F value in the prediction equation. This equation was considered to be unacceptable for these reasons: (1) too many measurements involved, and (2) not applicable to most antler types. The definition of three of these measurements specified that they be taken halfway between the burr and first point or between two points; a missing point would render these measurements meaningless. Therefore, this prediction equation was considered inadequate as an index to antler size.

For antlers with measurements common to all antler types, the prediction equation (3b) had an R^2 of 0.9677. This equation contained three linear variables and the non-linear effect of each variable: length of main beam, smallest diameter one inch above burr, and average diameter one inch above burr. The non-linear effect of the length of main beam showed the highest F value in the prediction equation. Although equation 3b contained three independent variables, there were actually only two linear measurements: length of the main beam and diameter one inch above burr. Both of these measurements could be taken with very few exceptions. In the regression analysis of this equation, a single measurement, the non-linear effect of length of main beam, gave an R^2 of 0.9182. This high value pointed to the possibility of using a single antler measurement as an index to antler development. In equation 3b, the addition of one other variable, the non-linear effect of smallest diameter one inch above burr, increased the value of R^2 to 0.9543, a considerable increase. Further addition to the prediction equation of the non-linear effect of average diameter one inch above burr gave an R^2 of 0.9677, a small increase.

Using foregoing criteria for judging the "best" prediction equation to determine total volume of deer antler, the equation that was considered applicable to virtually all antler types (3b) appeared to rank first. Should a single antler measurement be used to evaluate antler development, the length of main beam or average diameter one inch above burr appeared to be about equally effective.

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THE INCIDENCE AND DEGREE OF INFECTION OF *PNEUMOSTRONGYLUS TENUIS* IN THE WHITE-TAILED DEER OF WESTERN VIRGINIA[1]

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[1] This investigation was conducted as part of a Master of Science graduate program.

[2] Virginia Polytechnic Institute, Virginia Commission of Game and Inland Fisheries, The Wildlife Management Institute, and U. S. Fish and Wildlife Service cooperating.