VOLUME AND DENSITY OF HORNS OF DALL RAMS

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ABSTRACT

Volume determinations were carried out on 42 horns of Dall rams by means of the water displacement method. The density of the horn sheath ($\bar{x}$ = 1.227 gr/cm^3) was found to be constant and therefore can be used for volume determination if the weight of a horn sheath is known. Both horn sheath and horn core grow throughout life, but at different rates. The core's proportion of the total horn volume is higher in early ages (42% to 38%) and declines with increasing age, making up only 15% to 12% in very old rams (12 to 13 years). Total horn volume increases from about 30 cm^3 in a one year old ram to over 3000 cm^3 in 12-year old rams; over the same period the sheath volume grows from 25 cm^3 to 2600 cm^3. While the small sample sizes did not allow a reliable assessment of growth increments in volume per age class, it became obvious that volume growth is better correlated with age than horn growth in length. In contrast to growth in length, where the 2nd and 3rd annual increments are the longest, most volume is produced in the 4th to 6th year age classes.

INTRODUCTION

The horns of wild sheep are among the most coveted trophies. It is therefore not surprising that a number of trophy evaluation schemes have come into being (Boone and Crockett, Pope and Young, Safari International, Rowland Ward, and Conseil International de la Chasse et de la Conservation du Gibier), by means of which the horns of sheep can be assessed and compared. While details in methodology vary between them, all of these schemes use horn lengths and horn circumference measurements as the most important criteria. These assessment methods were therefore adopted when biologists first began to describe sheep horns for age determination (Cowan 1940, Geist 1966, Hemming 1969) or as parameters of population quality (Taylor 1962, Geist 1971, Shackleton 1973, Bunnell, 1978). Only very recently has it become apparent that the real size of a sheep horn, its mass or volume, is not properly reflected in either length or circumference measurements, nor in the conventional combinations of these two, as in the Boone and Crockett scoring formula. As an example, tightly curling horns have different volumes than large curls with the same total lengths, a given circumference measurement will describe different cross-sectional areas, depending on whether their shapes are triangular, rectangular, oval or circular. A different method is therefore called for to estimate the volume of horns. Heimer and Smith (1975) made the first attempts in this direction. They used the formula for determining the volume of a cone as an approximation, and then applied a correction factor determined from volume assessments by the water displacement method. Zingg (1980) used surface areas as an indicator for the mass of ibex horns. König and Hoefs (1982) used the water displacement method to establish the volume of whole sheep horns as well as annual increments. Here the assumption was made that the use of external features such as incremental lengths and circumference at the annuli are reliable indicators for volume determinations. The true annual increment is a fairly complicated cone-like structure, as is shown in Fig. 1. It cannot be measured externally; only with longitudinal sections of the horn can its shape be assessed. However, an estimation of incremental annual volume sizes is possible if the total volumes of horns of an adequate sample size of all age classes were known. The volume increment per given age class would then be the difference in mean volume values of neighbouring age classes. Since variations in horn growth parameters are large, a fairly substantial, homogeneous sample size is necessary, preferably from the same population. Volume assessment is complicated by the fact, that a horn consists of a bony core, which is an extension of the frontal bone, and a keratinous sheath, which grows on this core. While it was known that both core and sheath grow throughout life of a ram, it was not known whether they grow at the same rate. Differential growth will complicate volume determinations of annual growth increments.

In this analysis we addressed the following hypotheses:

1. Is the ratio of sheath to core volume a function of age, or does it remain constant throughout life?

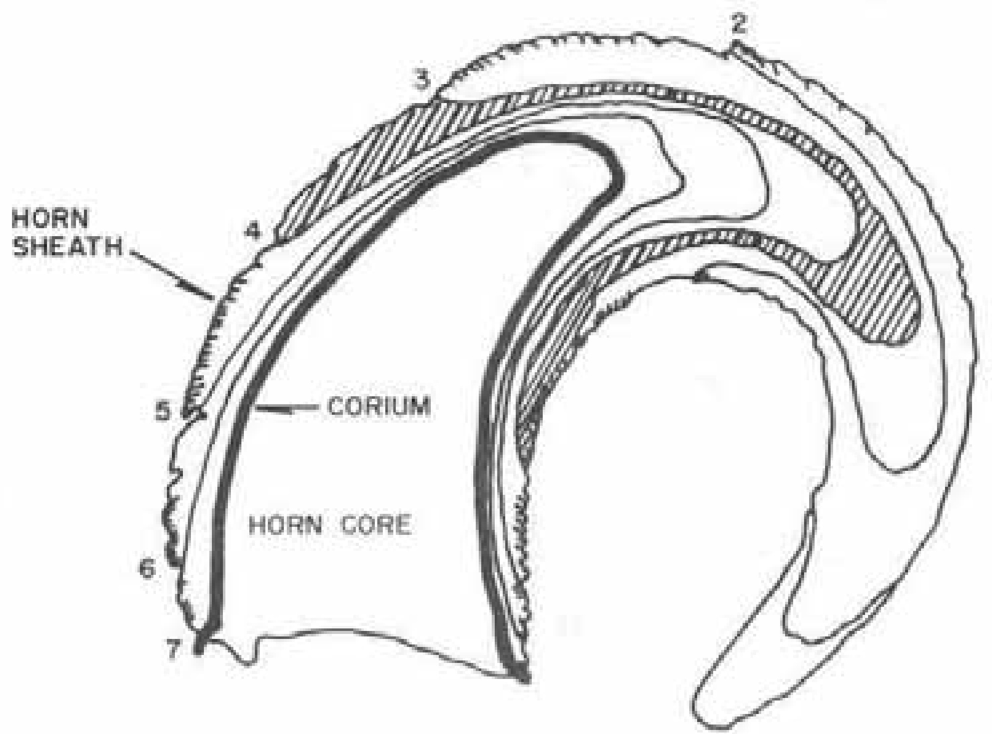
2. Does growth in horn volume follow the same pattern as growth in horn length or are the peak growth periods reached in different ages?

3. Is horn density a constant to be used for volume determinations, if the weight of a horn sheath is known?

METHODS AND MATERIAL

The skulls of 42 Dall rams were available for assessment. From each skull the longest or least damaged horn was used. The horn sheaths were removed from their bony cores and volume determinations were carried out by the water displacement method. First the horn sheath was submerged and assessed, afterward the hollow of the horn was filled with fine gravel and sealed off with wax. The wax layer followed the contours of the horn base as well as possible to approach the outline of the basal circumference of the horn core. The horn was submerged again and total volume was determined. The volume of

FIG.I. HORN SAGITTAL SECTION OF 7-YEAR-OLD RAM
(AFTER TAYLOR, 1962)



(HATCHED AREA INDICATES 4th INCREMENT)

FIG. 2. RELATIONSHIP OF TOTAL HORN VOLUME TO AGE (INDIVIDUAL VALUES)

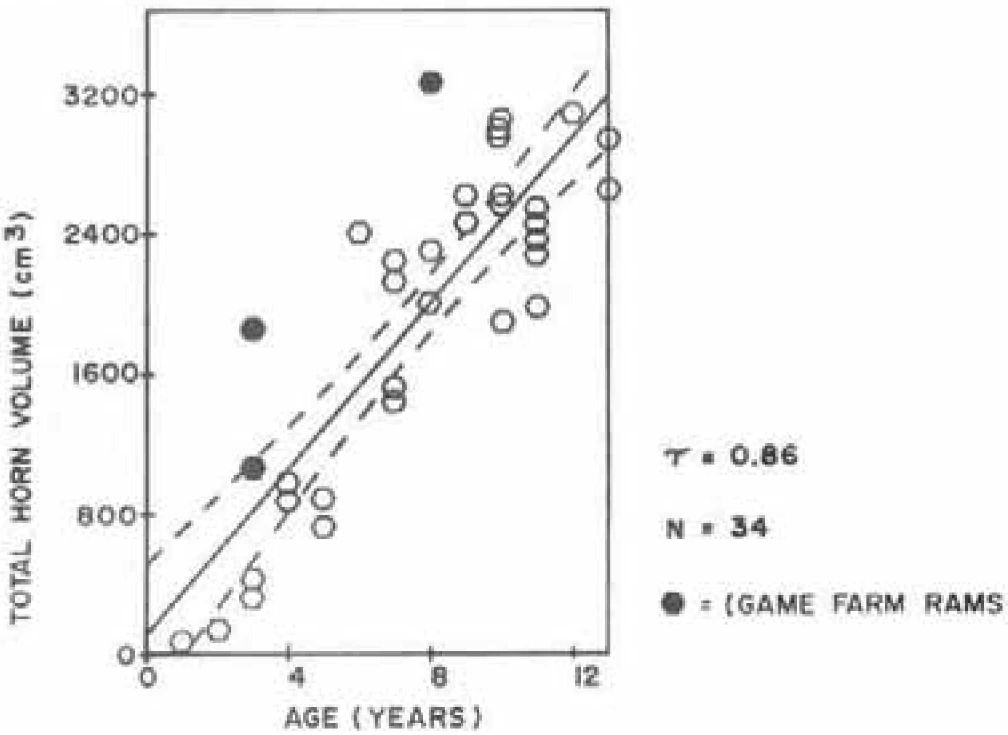
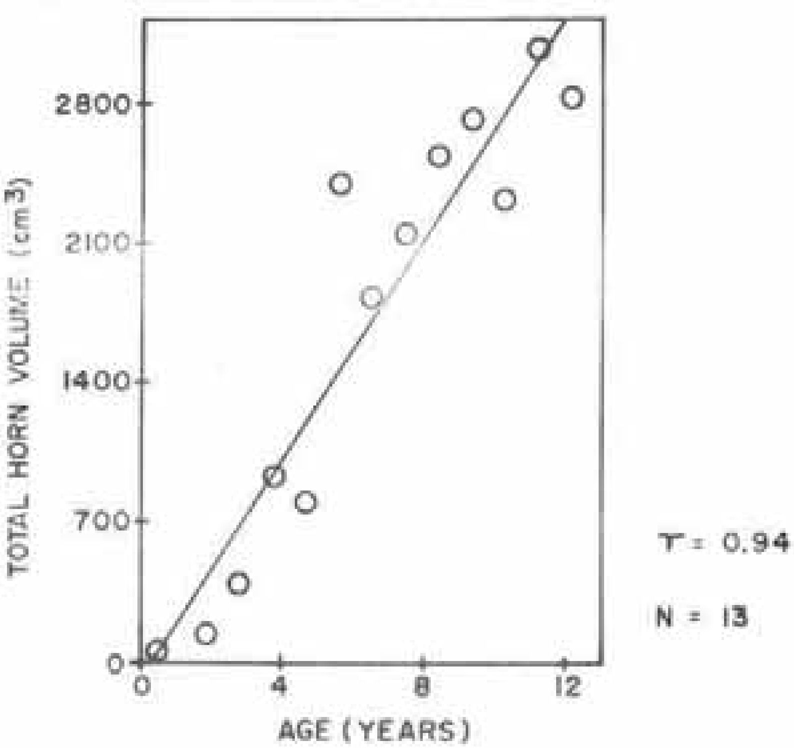


FIG. 3. RELATIONSHIP OF TOTAL HORN VOLUME TO AGE (MEAN VALUES FOR AGE COHORTS)



the core was then assessed by subtracting sheath volume from total volume. In a live horn there is a third component, the membrane or tissue, which covers the core and produces both bone for core growth as well as keratin for sheath growth. The volume of this material was neglected in these assessments, since it had dried up and disintegrated in old specimens. However, the amount of this tissue is so small, that it is insignificant in volume determinations of sheath and core. Age determinations were carried out using the horn annuli technique (Hemming 1969, Geist 1966).

Most of the horns assessed came from the Sheep Mountain population of Dall sheep in Kluane National Park, which has been subject of study for a number of years (Hoefs and Bayer, 1983). The 42 horns covered all ages, but for certain cohorts the sample size was very small. The horns were also weighed and their density determined. Not all tests could be done with the full sample size since 3 horns came from rams raised in the Yukon Game Farm, which had significantly larger horns than their wild relatives, and for 4 horns reliable age determination was not possible. Therefore, tests using age as a variable were from a sample size of 35.

RESULTS

Table 1 lists individual measurements for sheath and core volumes, total volumes, ratios between these and computed densities for 42 individual horns, and in Table 2 these data are summarized per age class.

A) THE DENSITY OF HORN SHEATH KERATIN.

The density of horn sheaths averaged 1.227 gr/cm^3 with a standard deviation of 0.030 gr/cm^3 (Table 1). The lowest density recorded was for a ram less than one year old with 1.10 gr/cm^3, the highest density recorded was 1.28 gr/cm^3 for a one-year old ram. However, these extreme values must be viewed with caution, since the error in volume determination of very small horns is greater relative to those of larger horns. The density values for horns > 1 year varied between 1.16 and 1.26 and were fairly constant. Correlations between horn sheath density and age, total horn volume, horn sheath volume and core volume were not significant. The weight of the sheath is therefore a useful measure of the keratinous material produced in all age classes. Also no consideration to density variation needs to be given in the determination of ratios between horn sheath and core development, since densities remain similar in different growth relationships. The constant density of 1.227 ± 0.030 allows a reasonably accurate volume assessment of the horn sheath by weight.

B) THE GROWTH OF THE HORN

The total volume of the horns continued to grow with age, but not in a perfectly linear manner. In Fig. 2 the total horn volume of all horns is plotted as a function of age, with the exception of the horn of the lamb. The linear regression coefficient is 0.86. It is obvious from the figure that there is considerable variation in horn volume among the individual horns in each age cohort. In Fig. 3 the mean values for each age group are shown, the variation from the linear regression function is high ($r = 0.94$). This variation does not allow a reliable assessment of the type of function that

Table 1. Individual horn volume values, ratios and specific weights.

Age	Total Volume T	Sheath Volume S	Core Volume C	S:C	S:T	Density
<1	5	3	2	1.50	0.60	1.10
1	64	39	25	1.56	0.61	1.28
2	135	80	155	1.45	0.59	1.25
3	317	185	132	1.40	0.58	1.19
	415	255	160	1.59	0.61	1.20
	425	260	165	1.58	0.62	1.21
4	875	505	370	1.36	0.58	1.23
	975	670	305	2.20	0.69	1.24
5	720	535	185	2.89	0.74	1.25
	885	622	263	2.37	0.70	1.26
6	2400	1710	690	2.48	0.71	1.23
7	1440	1110	330	3.36	0.77	1.23
	1525	1165	360	3.24	0.76	1.24
	2125	1705	425	4.01	0.80	1.23
	2240	1830	410	4.46	0.82	1.22
8	2005	1555	450	3.46	0.78	1.22
	2300	1680	620	2.71	0.73	1.25
9	2465	1960	505	3.88	0.80	1.23
	2615	1950	665	2.93	0.75	1.26
10	1895	1455	440	3.31	0.77	1.25
	2555	2055	500	4.11	0.80	1.22
	2620	2270	350	6.49	0.87	1.23
	2950	2445	505	4.84	0.83	1.21
	2975	2350	625	3.76	0.79	1.23
	3000	2450	550	4.45	0.82	1.18
	3040	2450	590	4.15	0.81	1.22
11	1895	1455	440	3.31	0.77	1.25
	2275	1895	380	4.99	0.83	1.23
	2365	2015	350	5.76	0.85	1.24
	2450	2000	450	4.44	0.82	1.25
	2540	1990	550	3.62	0.78	1.23
12	3075	2620	455	5.76	0.85	1.24
13	2640	2240	400	5.60	0.85	1.21
	2025	2560	365	7.01	0.88	1.23
	2930	2300	630	3.65	0.78	1.24
Age unknown						
	2115	1745	370	4.72	0.83	1.23
	2225	1780	445	4.00	0.80	1.21
	2440	1950	490	3.98	0.80	1.23
	3580	2860	720	3.97	0.80	1.26
Game[3]	1055	660	395	1.67	0.63	1.23
Farm[3]	1850	1375	475	2.89	0.74	1.16
8	3260	2830	430	6.58	0.87	1.24

Table 2. Mean values for age cohorts of horn volumes and ratios (volume in cm^3).

Age	N	Total Volume T	Sheath Volume S	Core Volume C	C/S	S/T
1	1	34.5	21.0	13.5	0.66	0.61
2	1	135.0	80.0	55.0	0.69	0.59
3	3	385.7	233.3	152.3	0.65	0.60
4	2	925.0	587.5	337.5	0.60	0.65
5	2	802.5	578.5	224.0	0.39	0.72
6	1	2400.0	1710.0	690.0	0.40	0.71
7	4	1832.6	1452.5	390.0	0.27	0.79
8	3	2521.7	2021.7	500.0	0.27	0.79
9	2	2540.0	1965.0	585.0	0.30	0.78
10	7	2719.3	2225.0	494.3	0.23	0.82
11	5	2322.0	1899.0	423.0	0.22	0.82
12	1	3075.0	2620.0	455.0	0.17	0.65
13	3	2831.7	2366.7	465.0	0.20	0.84

would best describe growth in horn volume. This function may in fact be an S-shape relationship rather than a linear one, an assumption supported by incremental volume calculations (Hoefs and Barichello, 1984). It appears that there is slow volume growth to the 2nd year, then accelerated horn volume development between the 3rd and 9th year, and again a slowing down and flattening of the growth curve from the 9th year to the end of life (13 to 15 years). However, for the limited data used in this analysis, the linear function is a useful approximation. The relatively steep and constant acceleration in volume growth over a longer time period, is in contrast to the non-linear growth in horn length. Horn growth in length reaches a maximum during the 2nd or sometimes 3rd year, and decreases rapidly as the ram ages. The real horn growth expressed as volume increases is more constant over the years and reaches its maximum between the 4th and 6th year. These findings support earlier published information (Konig and Hoefs 1982),from which a relevant diagram is reproduced here (Fig. 4).

C) THE CONTRIBUTIONS OF HORN SHEATH AND HORN CORE TO THE GROWTH OF THE HORN AS A WHOLE.

Horn sheath and horn core grew at different rates. The core's proportion of the total horn volume was higher in the early ages and declined with increasing age; correspondingly, the sheath contributed little initially but significantly to the total volume as the ram aged. This means that with increasing age, keratin production accelerates relative to bone formation. For a 1 to 2 year old ram, the horn sheath made up about 60% of the total volume, compared to about 85% in 12 to 13 year old rams. The ratio of core volume to horn volume changed accordingly, from 0.655 in one-year-old rams to about 0.170 in 12-year- olds (Figs. 5 and 6). Variations among individuals in this horn growth parameter were considerable in all age groups (Fig. 6), making an estimation of the functional relationship difficult. Based on the present sample size, a linear function is a useful approximation ($r = -0.85$). The core volume also increased with age, but the correlation was weak ($r = 0.69$) (Fig. 7), and conditional to the growth of the total horn volume ($r = 0.84$) (Fig. 8). From these relationships it becomes obvious, that the contribution the core makes to total horn volume decreases with increasing horn size, regardless of rapid growth in the early years, or prolonged growth over a number of years. The ratio of core to sheath is not only an age-specific characteristic, but it is also dependent on total volume accumulation. This becomes apparent through the method of partialization of total volume (Fig. 9) (Sokahl and Rohlf, 1969). Here the correlation coefficient of the ratio core to sheath with age is $r = -0.40$. On the other hand, if there is a partialization of age, the correlation of this ratio to total volume works out to be $r = -0.51$ (Fig. 10). Therefore, both, age and growth rate influence the ratio of core to sheath. The older and the bigger a horn the smaller the contribution the core makes to total volume.

The fairly high remaining variation indicates, that great individual differences can be expected. At this time, it is not established whether these differences are genetic in origin or determined by environmental factors. The ratio of sheath to core volume and total horn volume may be a species-specific chracteristic. However, no detailed information is available for other *Ovis* types, so comparisons are not possible.

FIG. 4. ANNUAL HORN GROWTH OF TWO DALL RAMS EXPRESSED AS GROWTH IN VOLUME AND IN LENGTH

(KÖNIG AND HOEFS, 1982)

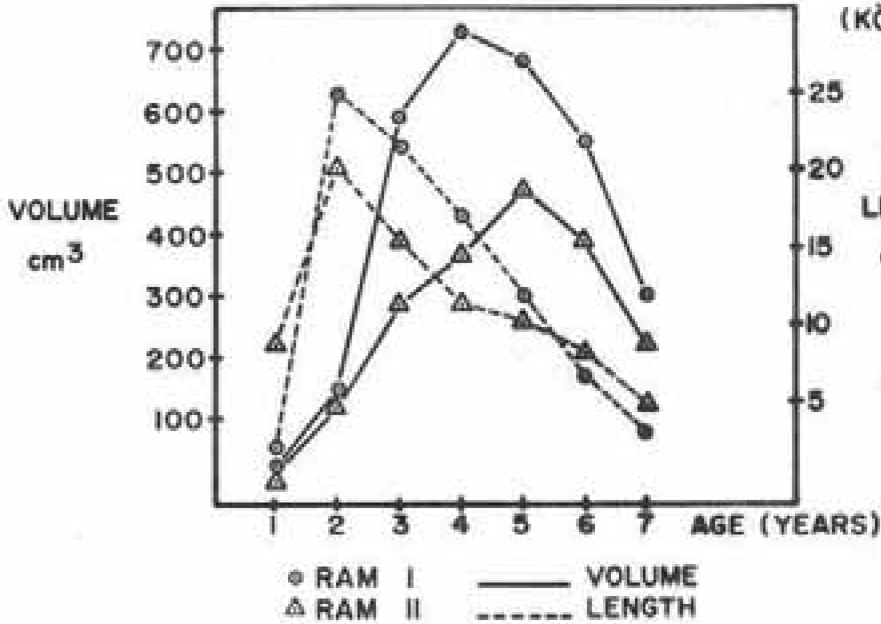


FIG. 5. RELATIONSHIP OF RATIO (CORE / TOTAL VOLUME) TO AGE (MEAN VALUES FOR AGE COHORTS)

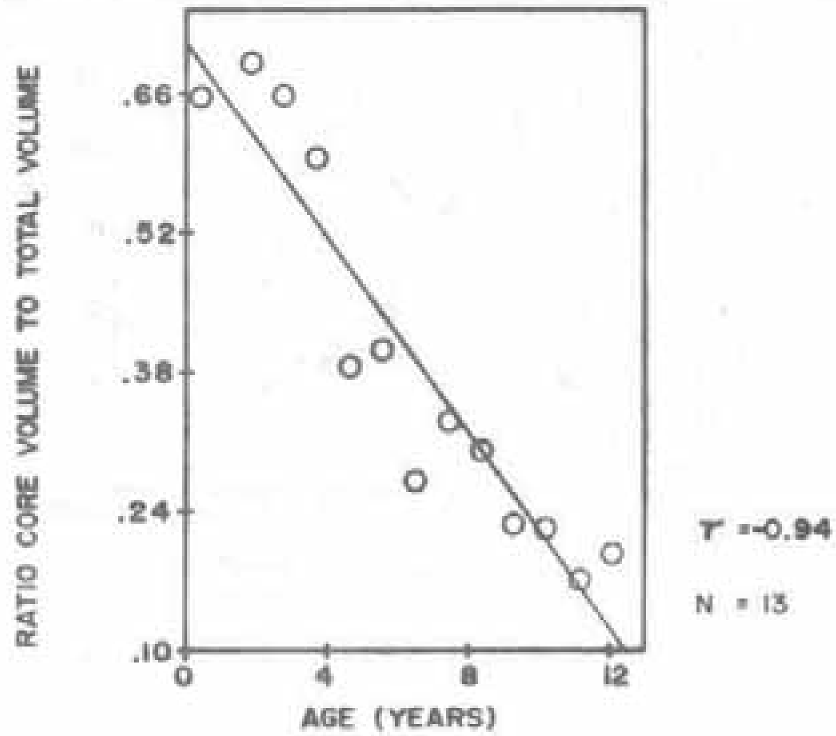


FIG. 6. RELATIONSHIP OF RATIO (CORE / TOTAL VOLUME) TO AGE (INDIVIDUAL VALUES)

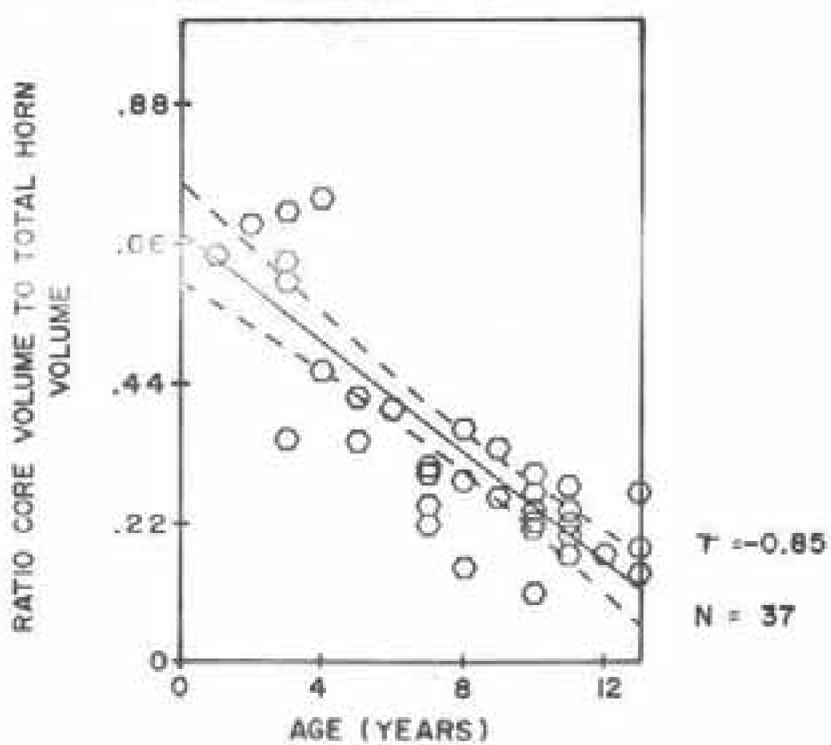


FIG. 7. RELATIONSHIP OF CORE VOLUME TO AGE

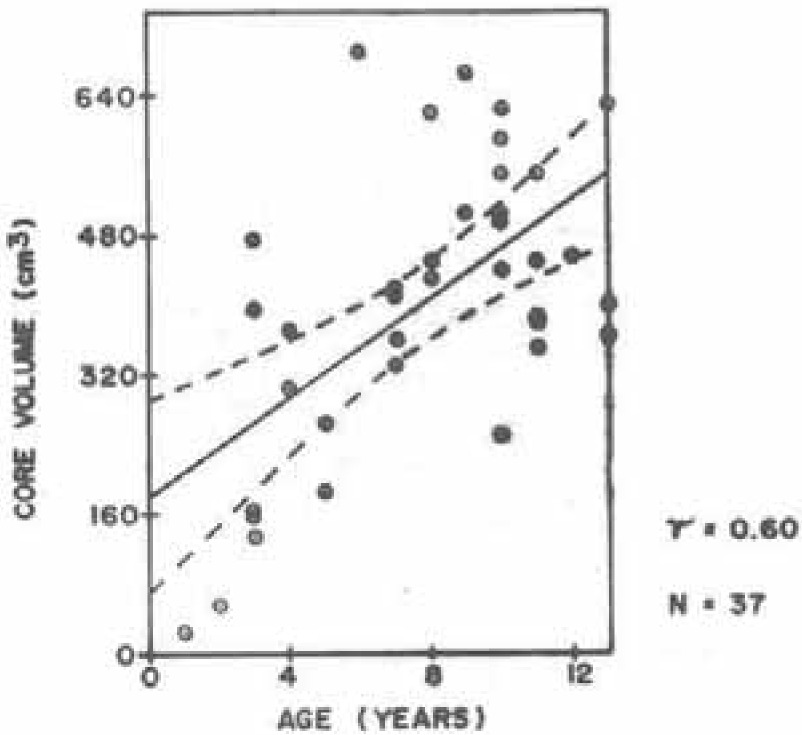


FIG. 8. RELATIONSHIP OF CORE VOLUME TO TOTAL HORN VOLUME

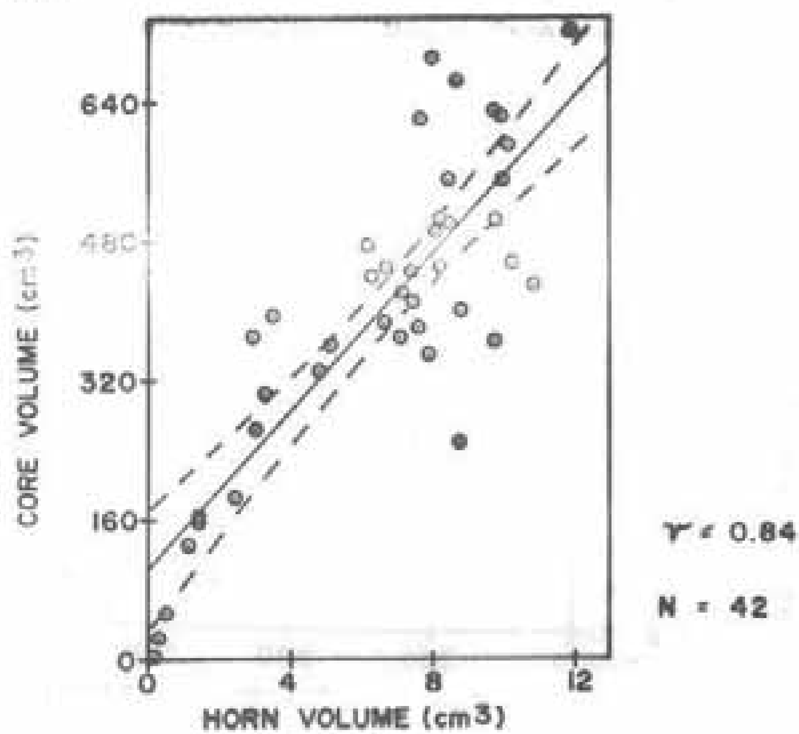


FIG. 9. PARTIAL CORRELATION OF C/T ON AGE (T CONSTANT)

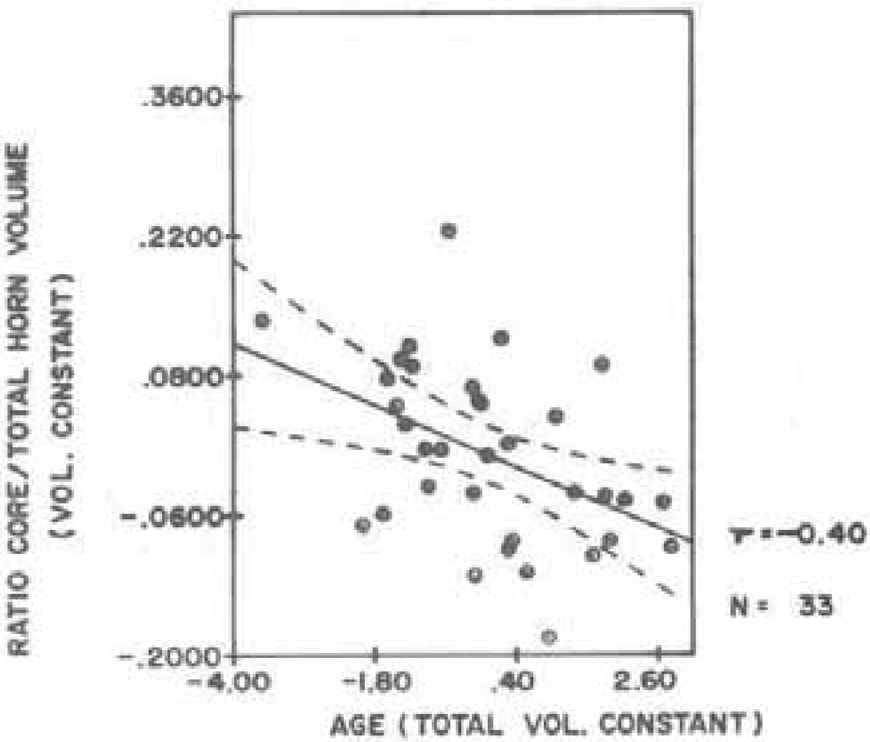


FIG. 10. PARTIAL CORRELATION OF C/T ON TOTAL HORN VOLUME (AGE CONSTANT)

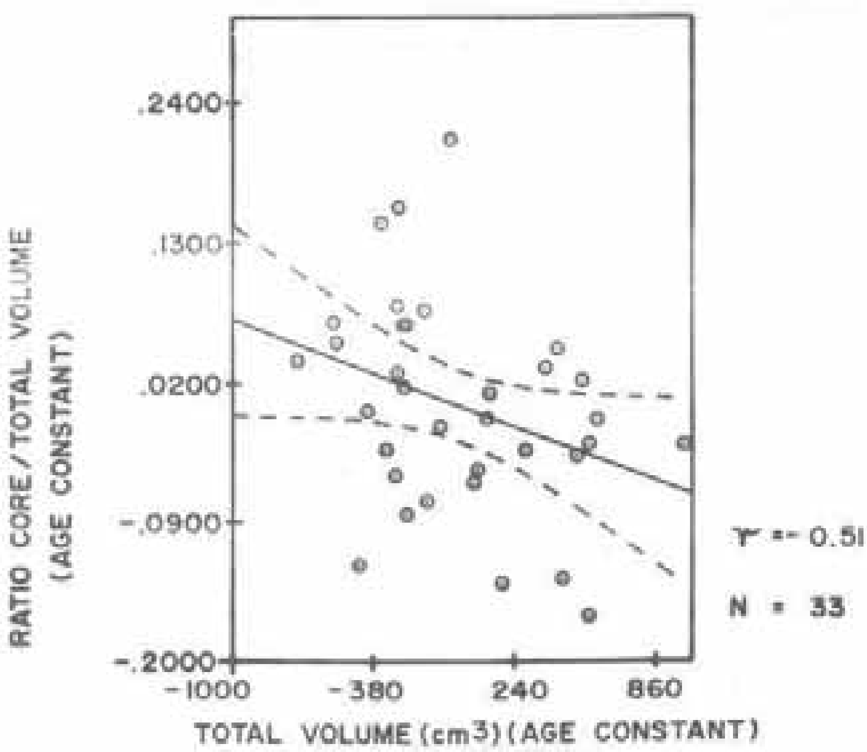
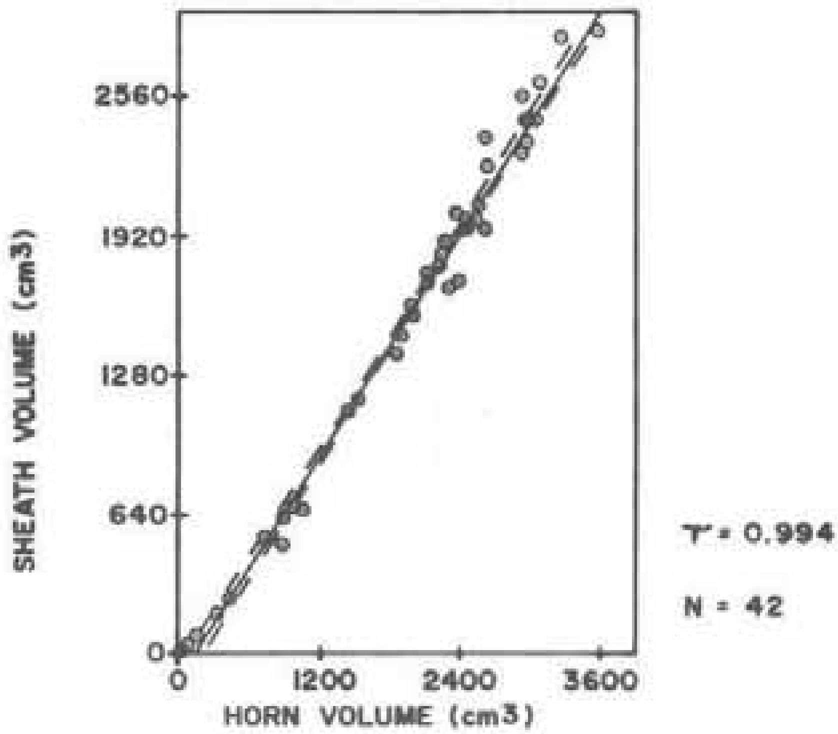


FIG. II. RELATIONSHIP OF SHEATH VOLUME TO TOTAL HORN VOLUME



DISCUSSION AND SUMMARY

The true volume of Dall ram horns increases more uniformly with age, than indicated from measurements of length and circumference, with the latter having been previously applied almost exclusively. The annual increments in volume are substantial from the 2nd year up to and beyond the 10th year.

Wear of the horn tip over time, which may exceed horn growth in length after the 9th year (Hoefs and Nette, 1982) is insignificant in relation to volume change. The volume of the first increment - even in horns with well preserved tips - amounts to less than 4% in 10 year-old rams.

Unfortunately the small sample sizes in certain age classes do not allow an accurate determination of the growth function in horn volume, or the magnitude of the annual increment rates. We know, from detailed measurements of individual horns (König and Hoefs, 1982) that the largest growth in volume takes place during the 4th, 5th, and 6th year, which is in contrast to horn growth in length, where the 2nd and sometimes the 3rd years produce the longest increments.

The contribution of the bony core to the total horn volume decreases with increasing volume. This relationship applies to increasing age as well as magnitude of volume growth within an age class. During the first 3 years the core makes up 38% to 42% of the horn volume, it decreases to 18% to 24% in 7-year-old rams, and in the very old age cohorts it may be as low as 12% to 15%.

In the largest horns, with a volume in excess of 3000 cm^3, the core makes up 13% to 20%, in medium sized horns with a volume of 2000 to 3000 cm^3 it contributes 12% to 29%, in horns of 1000 to 2000 cm^3 volume, about 25% of the total volume consists of bony core.

Since the volume of the horn sheath makes up the largest portion of the total horn volume, and since it grows with the latter in a linear manner, each of these volumes can be estimated fairly accurately, if the other one is known (Fig. 11). The regression coefficient between sheath volume and total horn growth is 0.994. Another constant parameter is horn density (1.227 gr/cm^3) which is independent of age or volume. It can be used to calculate sheath volume with little error, once the weight of the sheath has been determined.

It is recommended that volume determination should become part of routine evaluations carried out by many wildlife management agencies or hunting clubs on trophies harvested by hunters. Volume is a more appropriate indicator of trophy value than the linear measurements applied to date, and a more reliable indicator of population quality.

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