MORPHOMETRY OF ELEPHANT TUSKS

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INTRODUCTION

Operators of hunting safaries in Botswana have long noted that tusks of trophy animals shot by their clients usually exceed expectations based on estimates made from observations of the live elephant. Their previous experience in East Africa makes them underestimate the weight of ivory carried by the Botswana animals. This suggested that significant morphological differences might be present in various elephant populations which might prove to be genetic markers by which the distribution and movements of herds to and from a large geographic area might be detected. Such markers would permit estimation of the degree of interchange between contiguous populations as in Rhodesia and Botswana or between a game reserve and adjacent hunting areas.

METHODS

Indian ivory merchants have long distinguished between tusks of male and female elphants by the shape of the tusk and the relative depth of the pulp cavity which they call the "nerve". Tusks of females, they say, seldom exceed 30 pounds, have a short nerve canal seldom extending to the lip line and less taper in profile, the sides being more parallel. Tusks of males are bigger, more tapering and conical in profile, with the nerve extending to the lip line or beyond (Figs. 1 and 2).

If the sex of the animal from which a tusk was taken can be thus distinguished it would greatly enhance (1) chances of finding morphological differences between populations, (2) judging the age distribution of a harvest, and (3) determining mortality rates as pointed out by Laws (1966, 28).

Hence, upon first looking at east tusk in the present study a subjective sex classification was made and recorded so that later correlations could be made on this sex-discriminatory basis. Unfortunately sex is seldom recorded or marked on tusks, even those taken by governmental agencies, and hence our studies were by necessity based on correlations with the subjective criteria outlined above. Nevertheless they proved surprisingly revealing. (A test of the validity of these subjective criteria has since been made with tusks of the Zambian elephant cropping station at Kakumbi, Luangwa valley. Autopsy records proved that only two tusks of sixty had been sexed incorrectly at first glance.)

Nearly all ivory now is legally required to be registered, the tusks numbered with a stamp and, in most countries, sold through government auction. This makes it possible to examine large numbers of tusks at government stores prior to sales to export firms, or soon thereafter. I took advantage of both situations to weigh and measure samples of tusks from Bechuanaland (now Botswana), Zambia, Uganda, and the Congo.

FIGURE 1
Profile of typical female type tusk above and male type below.

The few tusks from the Congo were found in the Ivory Room at Mombasa. This Congo ivory is referred to as "hard ivory" and is distinguished by its polished, deep yellow patina and comparative lack of small, longitudinal cracks in the surface which the trade calls "streamers".

The following measurements were taken from each tusk:

1. Length of exposed ivory, measured in centimeters with flexible steel tape along the outside curvature of the tusk from tip to lip line. The lip line was usually clearly shown by a dark band of stain deposited at the "gum" line. This line does not describe a circle of minimal diameter around the tusk but is usually elliptical with the one end of the ellipse being nearer the butt of the tusk on its inner curvature and the other end of the ellipse being somewhat farther from the butt on the outside curvature. Our end point was the mid line of this ellipse as seen in lateral view of the tusk.

FIGURE 2
The same tusks in longitudinal view.

2. Length of unexposed ivory or the amount of tusk embedded in the face as measured from the butt along the outside curvature to the midpoint of the lip line as described above.
3. Circumference of the tusk at the same mid-point of the lip line as revealed by the stain on the tusk.
4. Length of the "nerve". Actually this is the depth of the pulp cavity of the tusk as determined by inserting the steel tape down the tusk's cavity and measuring to the butt along the inner face of the outer curvature. Although a wire would provide a measure ca. 1–6 cm. longer, the $\frac{1}{2}$" wide steel tape was used to speed the operation.
5. Weight in air, taken from a dial scale accurate to $\frac{1}{8}$ pound.
6. Weight in water. Not all tusks could be so weighed but when a tank or swimming pool of suitable size could be found the tusks were suspended by a wire sling from an overhead support and slowly submerged until all air was displaced from the pulp cavity and all parts of

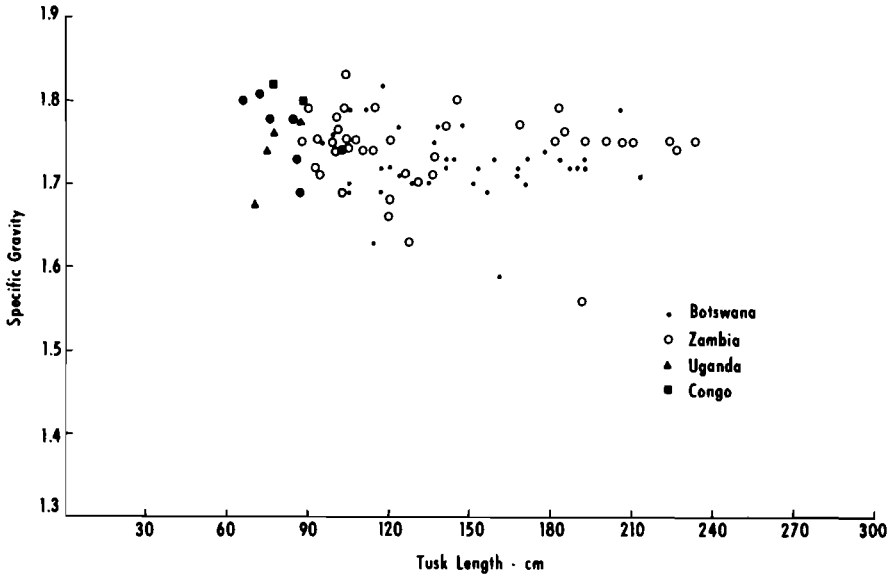


FIGURE 3
The relation between the length of elephant tusks and their density or specific gravity. The seven large dots designate determinations made from weights of small tusks weighed as groups equalling 18 pounds or more. Small dots and other symbols equal individual tusk weights.

the tusk were beneath the surface. Because our scale was only accurate to $\frac{1}{8}$ pound the error was calculated by the formula $\frac{5 \times z}{x}$ = proportional error, where z = absolute error (inherent in reading the scales) and x = weight in air. This calculation showed that among tusks weighing less than 18 pounds (or ca. 90 cm. total length) the error in computed specific gravity would be greater than 0.05. Thereafter all small tusks were weighed in groups of 4 to 8 by simultaneously suspending them in the water in a net bag.

The specific gravity of these groups of small tusks, like that of the larger, individual tusks, was determined by the formula $\frac{x}{x-y}$ = specific gravity, where x = weight in air and y = weight in water.

RESULTS

Specific gravity was plotted against total tusk length for males and females in each population. No difference was found between the two sexes and hence data from both sexes were combined in Fig. 3. This figure shows that there is no difference between the distribution of the specific

gravities in the various populations and further reveals that there is no increase in specific gravity with increasing tusk length (age of elephant). This eliminates specific gravity—within the limits of our equipment—as a possible cause of Botswana tusks appearing to be smaller in the field than their weights reveal them to be.

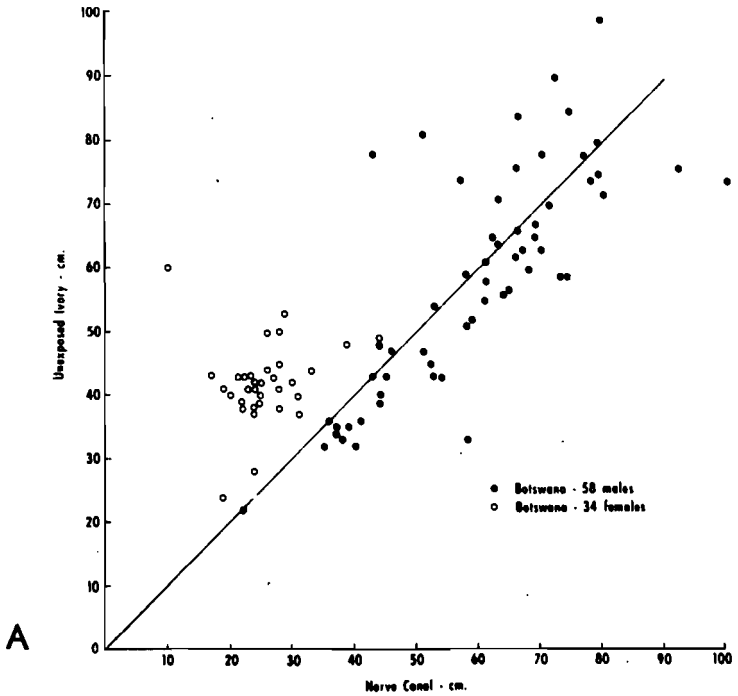
Figures 4-A,B,C show the relationship between the depth of the pulp cavity and the length of the unexposed ivory. Since the unexposed ivory is measured from the butt of the tusk to the lip line, these figures show what proportion of the tusks from each sex have a "nerve canal" that is longer or shorter than the distance to the lip line. The pulp cavity in females is nearly always shorter than the unexposed ivory while in males it is nearly always longer. In other words, the pulp cavity remains open as the males' tusks elongate and nearly always extends beyond the lip, while in females the pulp cavity fills in with increasing age and does not usually extend to the lip line. In each population it appears that the bigger female tusks have the shorter pulp cavity. The cavity may become nearly obliterated, being but 5 cm. deep in one fine symmetrical female tusk from Eastern Zambia and only 10 cm. deep in the longest female tusk from Botswana.

In each figure it is clear that when a line is drawn at 45°, with abscissa equalling the ordinate in length, nearly complete separation of the data from the two sexes is made. This shows that the relative depth of pulp cavity confirms the value judgement made upon first inspection when sex was determined by the tusk shape alone.

In tusks of larger males the nerve canal may continue to elongate and thus remain open beyond the lip line or it may start to fill in as shown in the longest tusks from Botswana. The largest tusks of animals of both sexes may show a shortening of the pulp cavity due either to slowing of growth rate of the tusk or to more deposition of ivory (dentine) within the pulp cavity.

It is also clearly shown in each figure that the length of the face or head as revealed by alveolus depth of the females ceases to grow when about half the length attained by males.

Figures 5-A,B,C show the relationship between length of the exposed ivory and the unexposed ivory contained in the alveolus of the maxilla. A clear difference between tusks from the two sexes may be seen. Not only are tusks of females shorter but the inflection point in the curve comes when female tusks are much smaller—when their exposed ivory is 60 cm. in length and the alveolus is 45 cm., while among males from both Zambia and East Africa the inflection point is not reached until 100 cm. of ivory is exposed and the alveolus has reached approximately 65 cm. in length. In the figure depicting tusk growth in Botswana elephants (Fig. 5A) the inflection point for females is not shown because no very long female tusks were measured. However, the curve for males is much steeper than for males from either Zambia or East Africa. This shows that Botswana bulls have tusks that are proportionally deeper rooted and indicates that they probably also have longer faces or bigger heads. Ultimately data may be available to show whether entire body growth is faster or the average bull is actually larger in body. The latter hypothesis seems the more likely for little inflection is seen in the curve of Botswana males and the elongation in unexposed ivory continues at least until the alveolus is nearly half as long again as in tusks from the other two populations.



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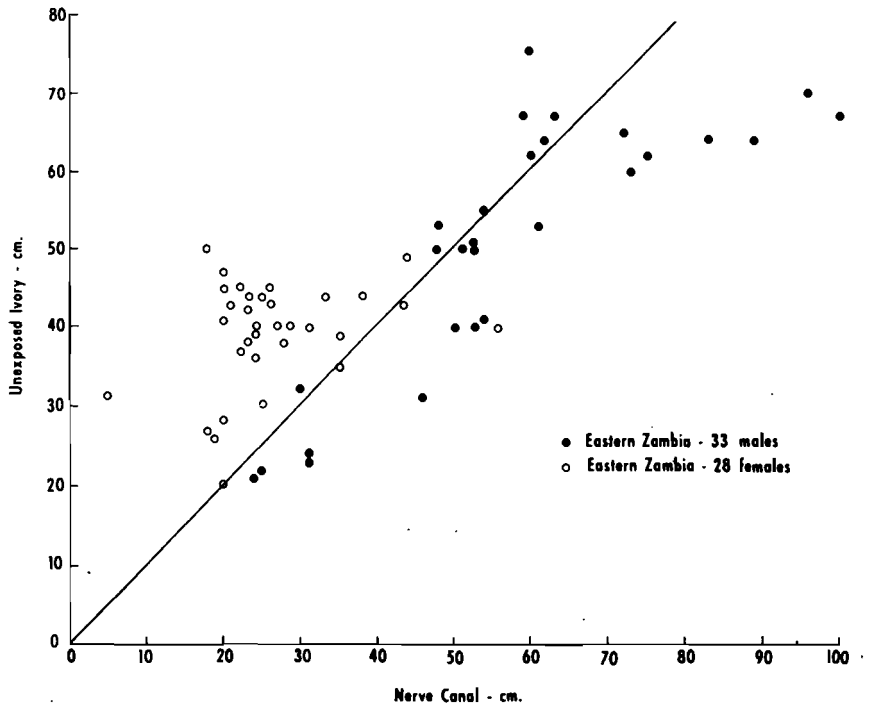

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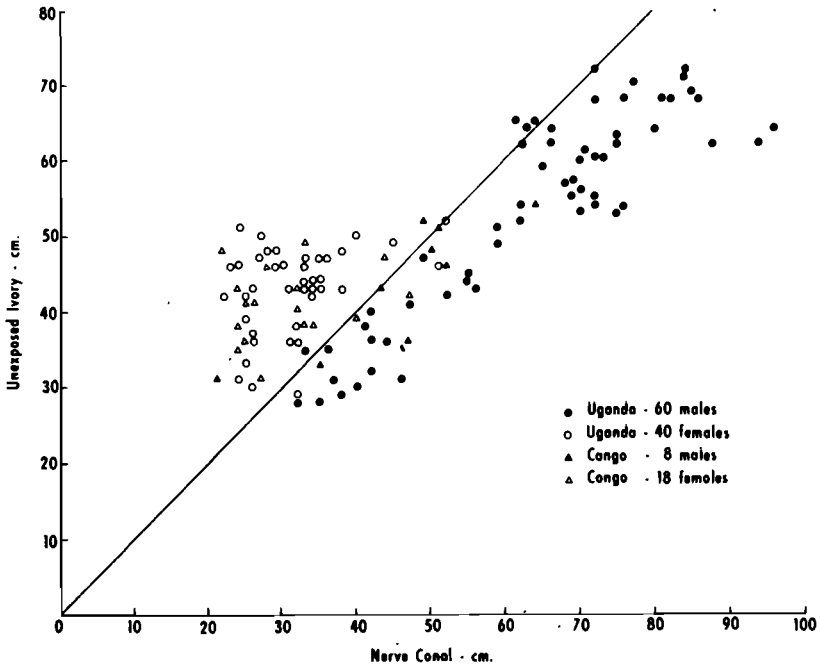
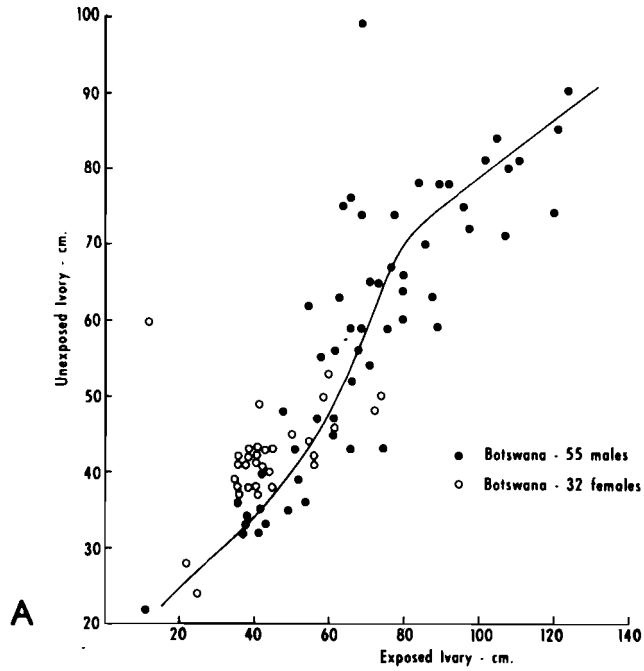


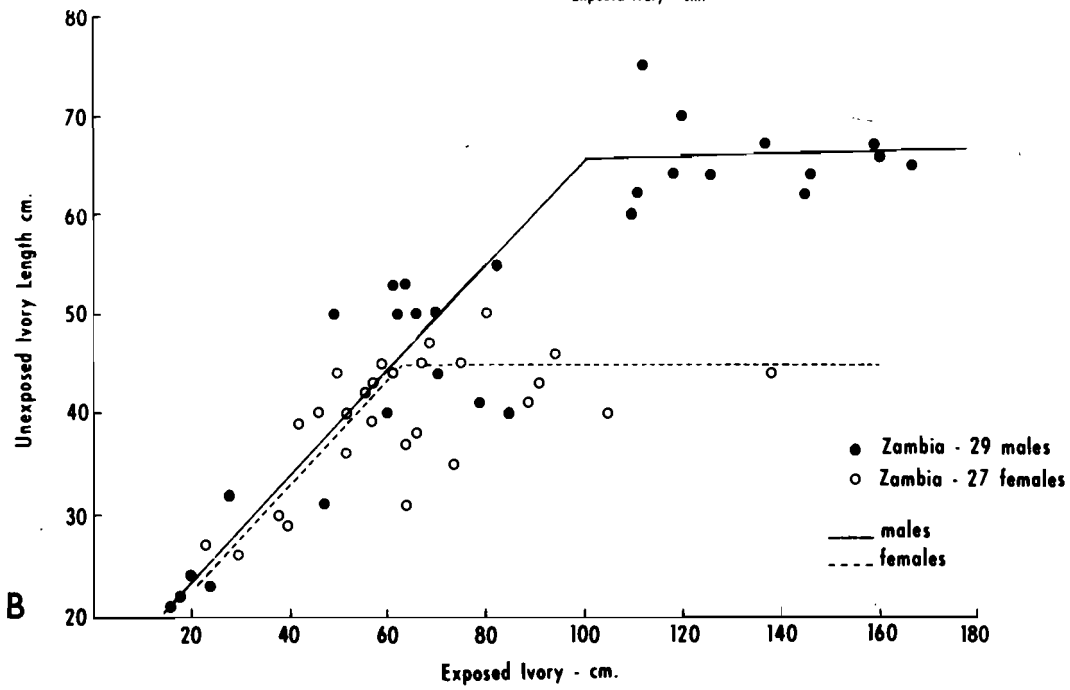
FIGURE 4
A, B, C Correlations between depth of pulp cavity (nerve canal) and length of unexposed ivory hidden within the face.

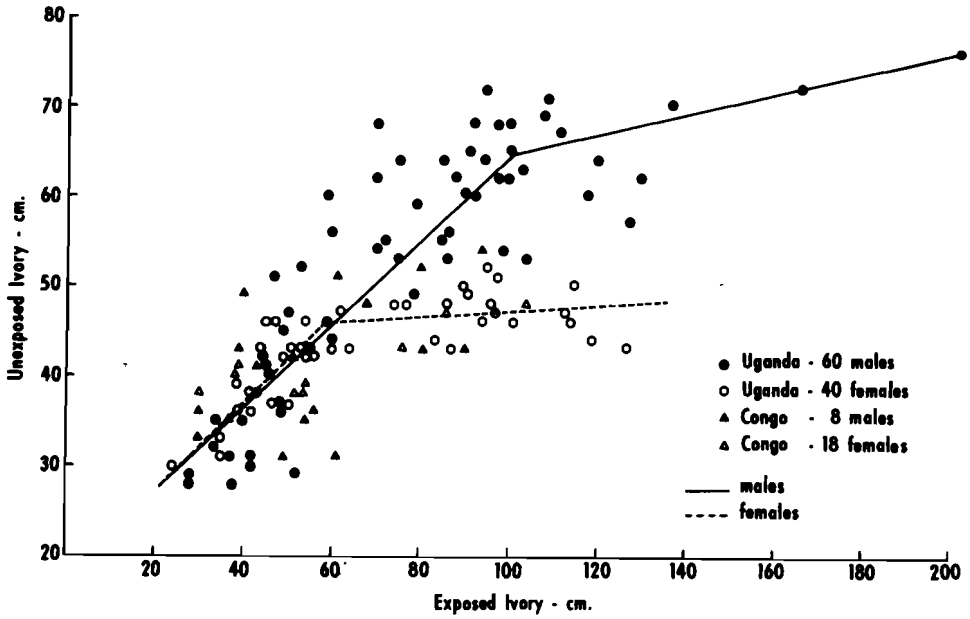
This alone could explain why experienced hunters find more tusk weight in Botswana trophies than they anticipate from viewing the animals alive.

Perry (1954) states, "The tusks of females usually cease to grow after puberty . . . the tusks of the male continue to grow after puberty, but their rate of growth is retarded in most examples." However Laws (1966), also working with tusks of animals aged by tooth wear, concluded that, "In the male the rate of tusk growth increases progressively throughout life to at least 240 lbs. . . ." His figures show that tusks of females grow more slowly than do those of males but continue to increase in weight at a constant rate throughout life.

Our figures show that the increase in visible ivory continues while that of the unexposed ivory slows rather suddenly when a certain size is reached. The physiological factor responsible for slowing of the growth of the alveolus is probably puberty. But the age and size of elephants at puberty seem in doubt for Perry (1954) states that, " . . . the female usually begins to breed at eight to twelve years of age in the wild state" while Laws (1966) writes that "Recent work indicates that females in this population (Murchison Falls Park) mature on the average at 18 years . . . " and Buss and Smith (1966) contend that " . . . in Uganda some wild females begin to breed at approximztely 7 years and all females breed by approximately 11 years of age." A captive female studied by Bourlière and Verschuren (1960) did not reach sexual maturity until 23–24 years.







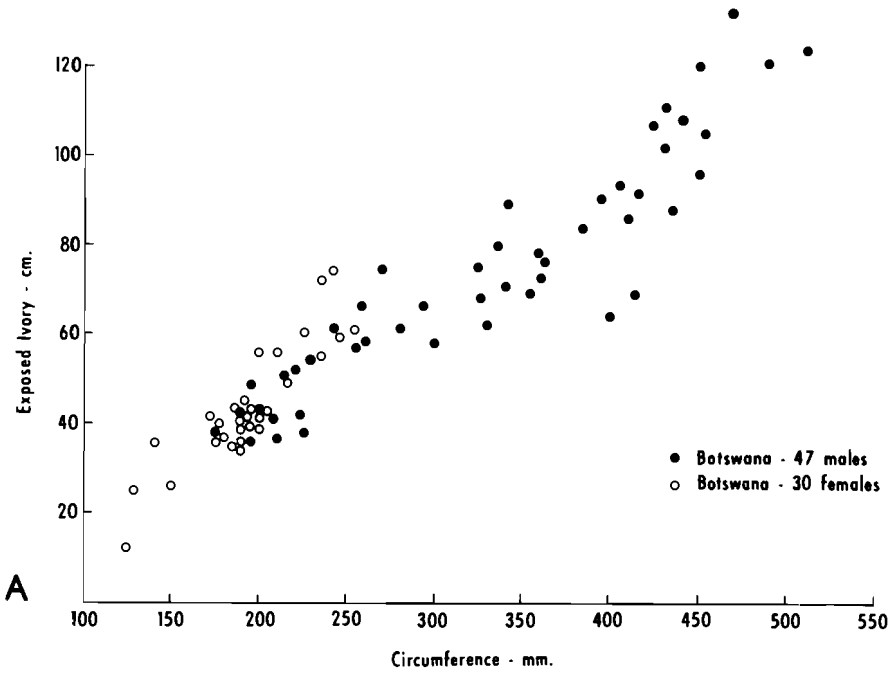
C

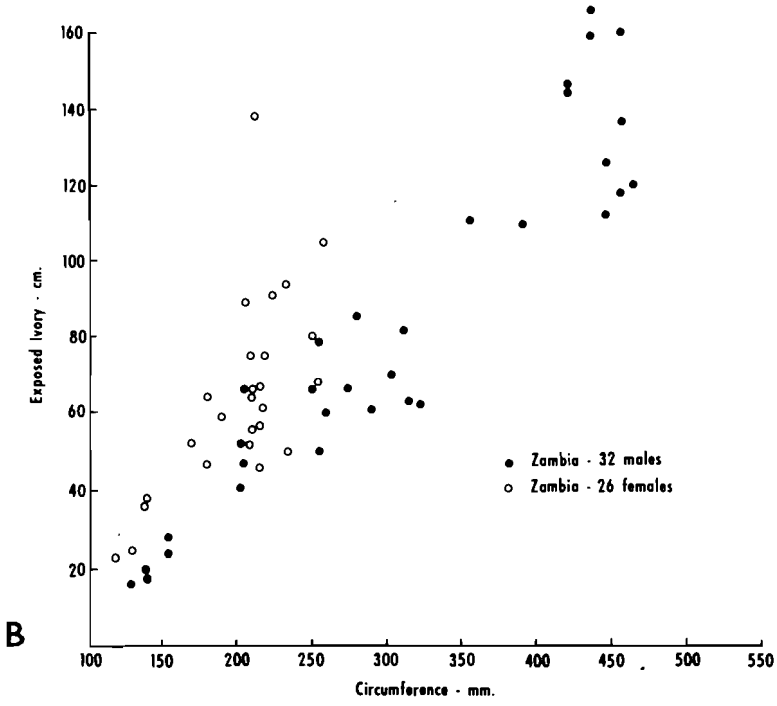
FIGURE 5
A, B, C The relation between the exposed and unexposed segments of elephant tusks. Curves drawn by inspection.

The tusk circumference was plotted against the length of exposed ivory in Figs. 6-A,B,C in order to see the relationship between length and thickness of tusks as viewed in the field. These curves simply illustrate the fact that tusks of females grow long and slender while those of males continue to thicken as they lengthen. Among males with tusks between 250 and 350 mm. circumference the tusks are actually increasing in thickness more rapidly than at any other period. Perhaps this represents the period of adolescence, for after this period growth in thickness slows while length of tusk continues to increase. This slowing in diameter increment is not so sharp and fixed as among females. In females the tusk simply ceases to increase in thickness after the exposed ivory reaches about 60 cm.

The tusk circumference at the lip line was plotted against the length of unexposed ivory in Figs. 7-A,B,C. These show the relationship between length and thickness of the portion of the tusk within the face. These two dimensions appear to increase proportionally in both sexes in all three populations, but in all three the tusks of the females show a very different distribution than do those of the males. The alveolus of the female, as revealed by length of the unexposed ivory, seldom exceeds 53 cm. while in males it may reach nearly twice that length. Again the great length of hidden ivory is shown by the tusks of males from Botswana.

Fig. 8 shows the relationship between the total length and the circumference of tusks in





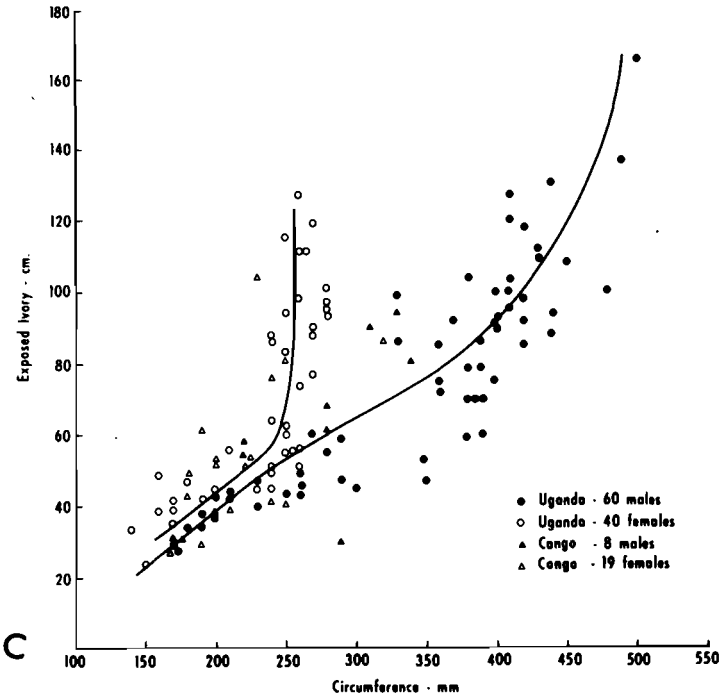


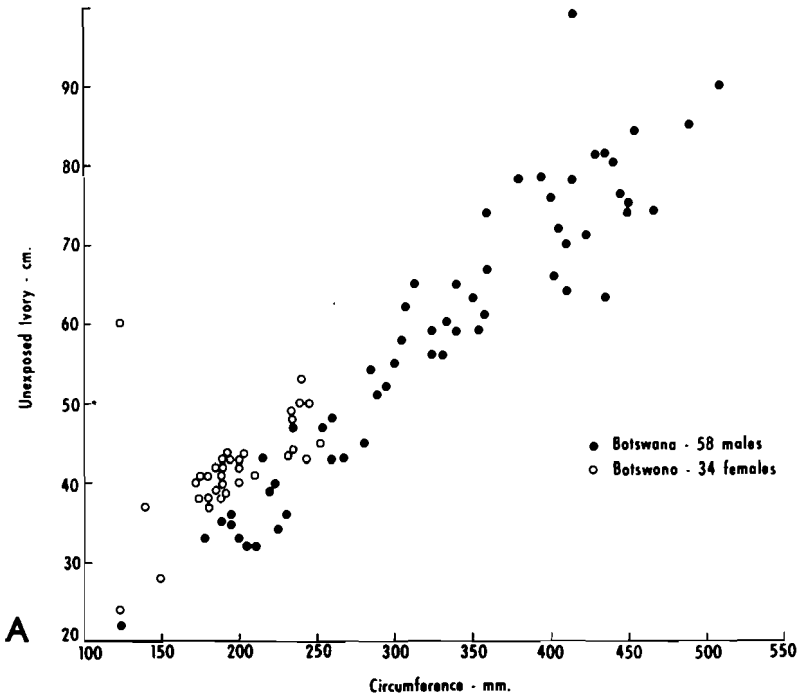
FIGURE 6
A, B, C, The relation of tusk circumference to length of exposed ivory. Curves drawn by inspection.

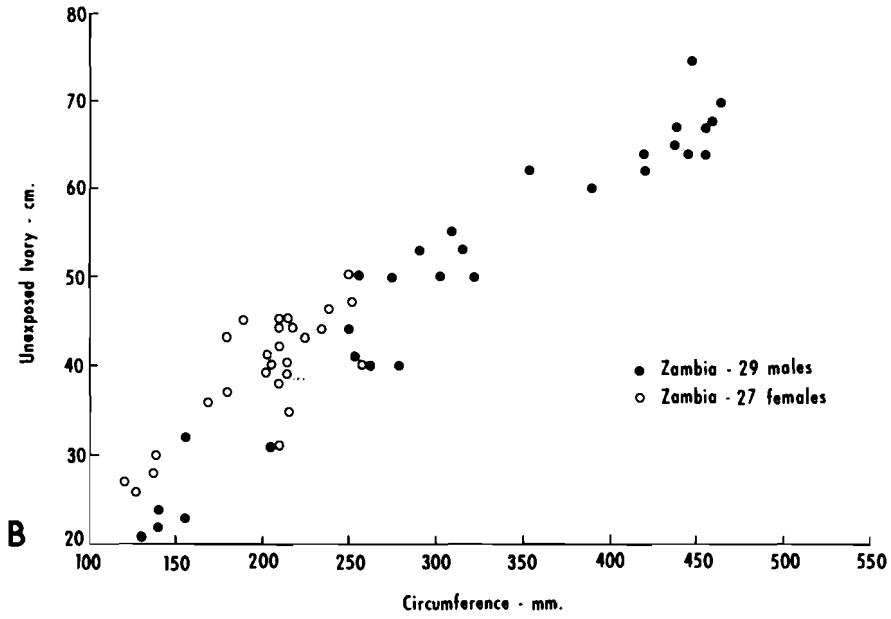
each of the four populations studied. Measurements of circumference were multiplied by 100 to give convenient fractions when this dimension was divided by the total length. The frequency distribution of the resulting ratios were plotted with the sexes shown separately. No distinct separation of the 4 populations was revealed by this procedure. In fact, the extremes are very similar in the three populations represented by sizeable samples. The distribution of the two sexes is clearly different in each sample, with approximately the same amount of overlap in their distribution being found in tusks from each of the four areas.

DISCUSSION

Rates of growth of elephant tusks have seldom been reported but Humphreys (1926) found 16 cm. of growth per year in an Asiatic elephant and Colyer (1957) found 17 cm. growth in an African elephant one year after a known injury had marked the tusk.

It is general knowledge that female elephants do not grow tusks to the size achieved by males (Roberts 1954, 234). However, several authors state that growth rates are similar in the two sexes during early life but change at puberty. Perry (1954) says of the tusks, "Those of the female appear to cease growing soon after puberty, about the time when growth of the body as a whole is slowed down." and Boulière and Verschuren (1960, 94), when writing





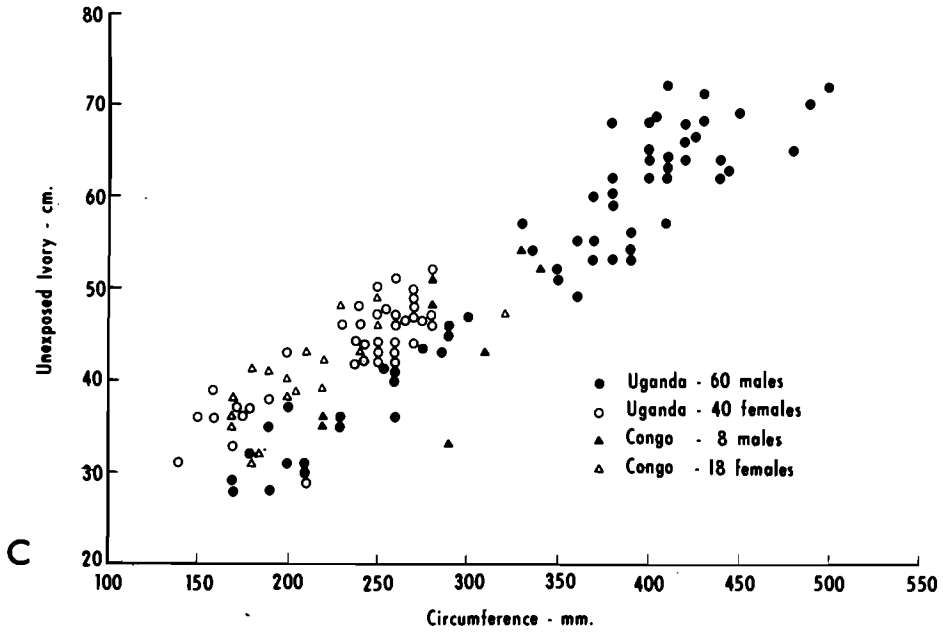


FIGURE 7
A, B, C, The relation of tusk circumference to length of unexposed ivory.

of captives they studied, say, "this confirms Perry's conclusions that the growth of the tusks is almost the same in the two sexes until puberty, after which those of the female generally stop growing." However, Laws (1966) does not agree, stating, " . . . tusk growth in females is continuous and can be represented by a straight line; there is no cessation at puberty as suggested by Perry (1954) nor any suggestion of a change in the rate of growth."

In the present study it has become clear that the growth of tusk external to the face, as commonly viewed in the live animal, continues, while the lengthening of the tusk hidden in the face slows with age and ceases altogether when it reaches about 45 cm. in the female (Fig. 5). This probably corresponds with puberty. It is at this time that the pulp cavity in female tusks begins to fill in and becomes progressively more shallow (Fig. 4). Likewise the tusk of the female ceases to increase in thickness (Fig. 5 and 6).

In contrast, tusks of males continue to increase in all growth parameters. The pulp cavity continues to lengthen as long as the alveolus is still lengthening—apparently until one third larger than in the female. During this period the tusk thickness, as shown by measurement of the circumference, progresses in a nearly straight line relationship with alveolus depth (Fig. 7) and seems to increase at an accelerated rate when compared with length of exposed

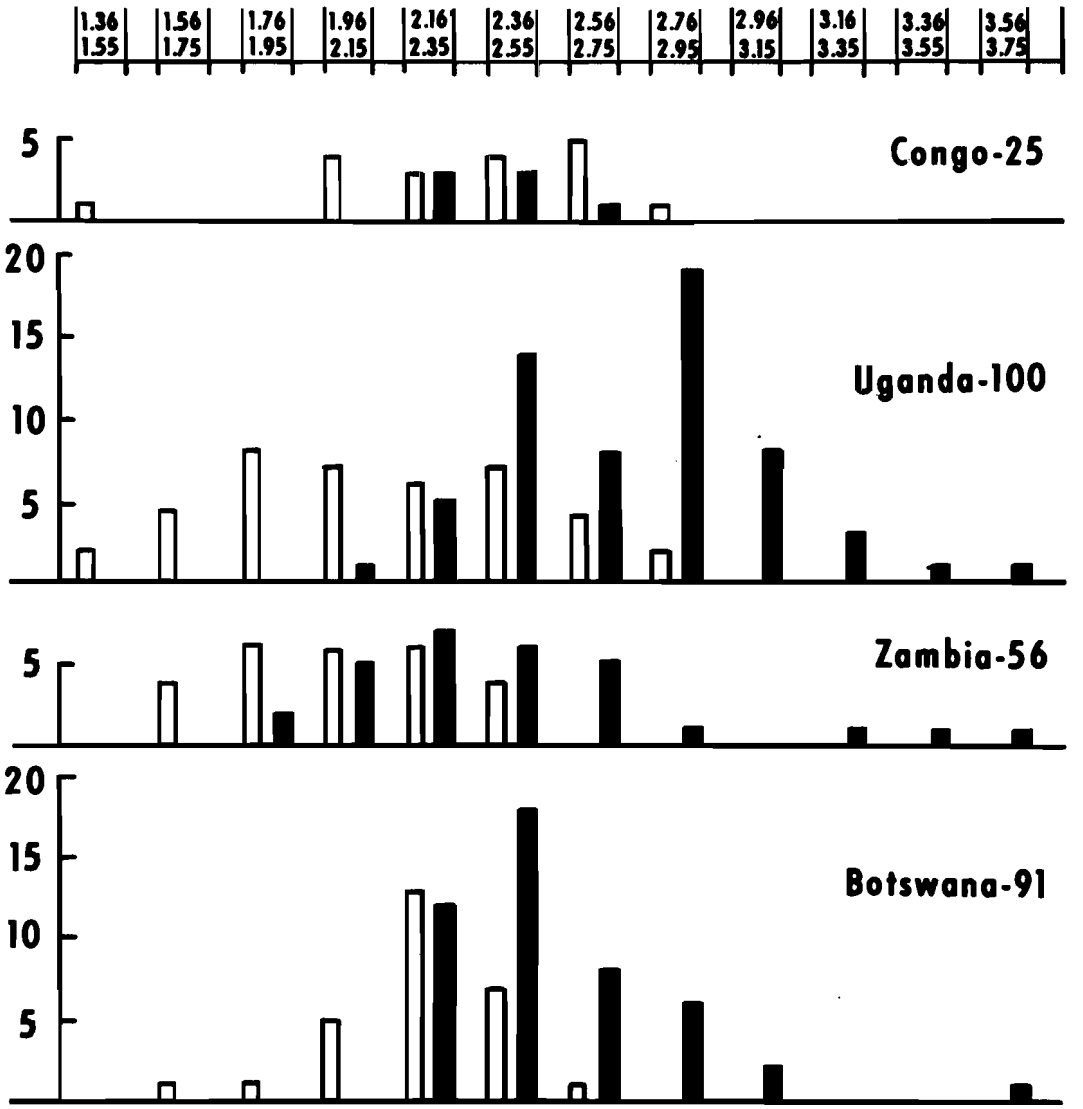


FIGURE 8

Frequency distribution polygons showing the relation of tusk circumference to total length in four populations of elephants as determined by the formula $\frac{\text{Circumference (cm.)} \times 100}{\text{Total length (cm.)}}$. Solid bars = males, open bars = females.

ivory. Figure 6A and C show a flattening of this curve when there is 60–80 cm. of exposed tusk showing. This again probably corresponds with puberty.

Factors slowing tusk growth rate in the female African elephant—whether genetic or endocrine—seem to operate throughout life but in the Asiatic elephant, *Elaphus maximus* their influence is expressed very early so that tusks in females of this species seldom extend beyond the lip. Complete tusklessness is the ultimate expression of tusk growth inhibition and has been reported in both sexes of the African and Asian elephants, although much more frequently among females. (Deraniyagala 1963, Foran 1960, Nicholson 1955).

Concern over the possible spread of a supposed gene for tusklessness, inadvertently following hunter selection for big ivory, has been expressed by several authors (Buss 1959, Owen-Smith 1966). One could postulate an alternative hypothesis in which an endocrine upset could account for this condition. It is possible that unusually high levels of estrogens could inhibit tusk development for it seems that tusks of females cease to increase in diameter and depth of alveolus stops elongating as the females become sexually mature, i.e. when circulating levels of estrogens increase. Very probably a multi-factorial control mechanism exists.

The growth of a tusk is a complex phenomenon and involves continuous osteoblastic activity depositing new dentine (ivory) in a circle at the base of the alveolus which comes to be located just below the orbit of the skull. Deposition at this point pushes the tusk outward and more and more ivory is extruded from the face. Simultaneously there must also be deposition of dentine along the entire inner surface of the tusk's pulp canal (over the outer surface of the pulp). In all tusks this internal deposition and filling is continuous with tusk elongation, only in males the two processes are equal in rate and thus the pulp cavity continues to extend beyond the lip line while in the female after puberty, tusk filling exceeds rate of elongation and hence buyers see that female tusks have a shallower "nerve" or pulp cavity than do males.

Extremes of filling may be found in both sexes and may reflect great age and accompany slowing in elongation, as shown by the longest male tusks from Botswana (Fig. 4-A) and the single cases of females from Zambia and Botswana (Fig. 4A and B). It was surprising that one of these females had a very short alveolus—only 30 cm.—and the other a very long alveolus—60 cm. Rarely one finds a female tusk with pulp cavity extending well beyond the lip line. It is tempting to postulate that these animals matured late, for Perry (1954), Buss and Smith (1966) have shown there is much variation in the age at which females reach sexual maturity. Extreme filling in a male tusk was found by Adrian Lind in Rhodesia (pers. comm.); a very large tusk being solid nearly to its butt. Again this may indicate that the bull was impotent.

Population differences in elephant tusks were difficult to demonstrate with the present data. Tusks of all shapes and curvatures were found in each population. Tusks from the Congo can usually be spotted at once by their yellow colour and shiny patina, their great length and slenderness, and the comparatively straight profile. Dealers have told me that Botswana tusks are usually massive and stubby due to extreme wear and are usually much whiter than tusks from surrounding countries. In the present study we have established the reason for

tusks from Botswana being heavier than can be predicted by observation of the living animal. Why there is extreme wear or breakage resulting in thick stubby tusks in many cases, is a matter of conjecture. Some believe that these elephants lead a much harder life in the extreme aridity of Botswana and may be forced to use their tusks more frequently in barking trees and digging for underground roots and tubers. In addition they may be older on the average because they are not hunted as intensively.

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SUMMARY

Measurements of specific gravity failed to reveal differences in density of ivory from young and old elephants or from animals in widely separated geographic areas.

When shape alone was used to classify tusks as to sex of animal, a very high correlation was found with depth of pulp cavity and with the distribution of tusk lengths. It is concluded that the old trade secrets have a factual basis and that tusks of males not only are bigger but more conical in profile while those of females are more slender, with sides appearing parallel.

The pulp cavity usually extends beyond the lip line in tusks of males and does not reach the lip line in most females. The depth of pulp cavity decreases with tusk size (age) in both sexes but this process sets in much earlier in females, probably at puberty.

The diameter of the tusk increases concomittantly with the lengthening of the alveolus in both sexes but slows greatly when the alveolus depth ceases to increase. This process sets in much earlier in females than in males and thus accounts for the slender tusks characteristic of this sex.

Weights of tusks from Botswana are usually underestimated in the field because elephants of this population have tusks that are deeper rooted and larger in circumference than are tusks from other regions studied.

REFERENCES

BOURLIÈRE, M. P. and VERSCHUREN, J. 1960. Exploration Parc National Albert. Bruxelles. *Introduction a L'ecologie des ongules du Parc National Albert.* 159 pp.

BUSS, I. O. 1959. Elephant census—III. *Uganda Wild Life and Sport* 1 (5): Unpaged reprint.

BUSS, I. O. and SMITH, N. S. 1966. Observations on reproduction and breeding behavior of the African elephant. *J. Wildl. Mgmt.* 30 (2): 375-388.

COLYER, F. and MILES, A. E. W. 1957. Injury to and rate of growth of an elephant tusk. *J. Mammal.* 38 (2): 243-247.

DERANIYAGALA, P. E. P. 1963. Tusk and tail variations in *Elaphus maximus* and in *Loxodonta africana. Spolia Zeylanica* 30 (1): 85-86.

FORAN, W. R. 1960. Single tusked and tuskless elephants. *Wild. Life*, Nairobi 2 (3): 32-33.

HUMPHREYS, H. F. 1926. Particulars relating to the broken tusk of a wild Indian elephant. *Brit. Dent. J.* 47: 1400-1407.

LAWS, R. M. 1966. Age criteria for the African elephant. *East Afr. Wild. J.* 4: 1-37.

MABERLY, C. T. A. 1963. *The game animals of southern Africa*, Johannesburg, Nelson.

NICHOLSON, B. D. 1955. The African elephant. *S. Afr. Wild Life*, 9 (1): 31-40.

OWEN-SMITH, N. 1966. The incidence of tuskless elephants in Mana Pools Game Reserve. *Afr. Wildl.* 20 (1): 69-73.

PERRY, J. S. 1954. Some observations on growth and tusk weight in male and female African elephants. *Proc. zool. Soc. London*, 124: 97-105.

Roberts, A. 1951. *The mammals of South Africa.* Johannesburg, Trustees of "the Mammals of South Africa" book fund.