E. Afr. Wildl. J. 7: *67-72* (*1969*)

RELATIONS AMONGST VARIOUS LINEAR MEASUREMENTS AND WEIGHT FOR BLACK RHINOCEROSES IN KENYA

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SUMMARY

Records of black rhinoceroses obtained from different areas of Kenya suggest a very close relationship between body weight and length and chest girth. The best regressions are: log weight on log length + log girth, and weight on length × girth^2. The square of the correlation coefficient in both cases is more than 0.98, and the relations appear to be independent of habitat and sex. In contrast the two sexes show marked differences in the relation between front and back horn length with the males tending to grow relatively longer front horns. Attempts to predict the size of the animal and the length of its horns from the spoor were less successful.

INTRODUCTION

Studies of growth rates, general condition, productivity, drug dosage and other aspects of wildlife management require a knowledge of the body weight of the wild animal under observation. This information may be obtained from a sample of the wild animal population that has been shot or dart-immobilized. Many antelopes may be weighed using a gantry and spring balance attached to a Land-Rover (Talbot and Talbot, 1962); larger animals may be suspended from a tripod (Smith and Ledger, 1965a). The largest ungulates are difficult to weigh in one piece and the total weight is often calculated from the dissected hindleg weight (Smith and Ledger, 1965b; Laws, Parker and Archer, 1967). A study of live pachyderms, for example, will therefore be unlikely to provide any information on body weight; nevertheless, if dart-immobilization has been used, it is probable that dosages will be expressed in µg/kg. The dosages will have been estimated from dead weights of different age groups of another population of the same species. In theory this method is open to question since there is often a considerable variation between the weight of animals of the same species from different areas (Sachs, 1967). In practice the weight variation between populations may be less significant than all the other variables involved in dart-immobilization. Nevertheless other methods of calculating the weight from a more easily obtainable measurement are probably preferable. This preference is based on the assumption that the relation of body measurement to body weight within a species is less variable than gross weight differences between populations of the same species.

Information relating weight to more easily obtained measurements is often required from the living organism; unfortunately, it is more readily acquired from the dead. The problem is not confined to wildlife: thus Pearce (1952) estimated the weight of living apple trees from their trunk girth. Further weight estimations based on linear measurements for livestock have received considerable attention and there are many references in the literature. In East Africa work has been done on domestic cattle by Thornton (1960), and by McCulloch and Talbot (1965) on wild animals.

The purpose of this paper is to examine the relation between body weight and various linear measurements in the black rhinoceros (*Diceros bicornis bicornis* (Linnaeus)), and also the inter-relation of some of these linear measurements and others.

MATERIALS AND METHODS

Linear measurements were obtained from 59 black rhinoceroses. Three were shot in self-defence, one was already captive and 55 were dart-immobilized (King, 1969). The measurements used in this study were obtained from the anaesthetized animal in lateral recumbency and were as follows:

vertebral column length L (along the body contours); heart girth G (a semicircle from the vertebral spine to the mid-line of the sternum, measured immediately behind the forelimb and multiplied by two); forefoot D, being larger than hindfoot (lateral diameter of the sole); front F and back B horn length (measured along the anterior curve).

The immobilized rhinoceros was rolled to a sledge, lashed down securely, winched onto a lorry and transported to holding pens using the method developed by Carter (1965). Within 5 h of immobilization, 25 of these animals were weighed on their sledges. The sledge was lashed to a bar slung from 2 × 1,200 lb and 1 × 1,000 kg spring balances (Geo. Salter & Co. Ltd., West Bromwich, England). The balances were hung from another parallel bar suspended by a block and tackle at each end. The whole apparatus was slung from a baobab tree (*Adansonia digitata* L.) because it was too large for the tripod for which it had been originally designed (Smith and Ledger, 1965a). The spring balances were checked for accuracy at the end of the operations (Kenya Scale Co. Ltd., Nairobi) and the necessary small corrections applied.

A further 16 rhinoceroses were weighed in their crates on the lorries an average of 9 d (range 1–25) after capture using Kenya Police Vehicle Inspection weighbridges of ,995 lb capacity with 5 lb divisions (Avery, irmingham, England). There is no reason to believe that the weights obtained from the weighbridges are much less accurate than those from the spring balances but these animals were not remeasured at the time of weighing.

The correlation of weight and body measurement has therefore been calculated from 22 animals in which all measurements and spring balance weights were obtained at the time of capture. All of the 59 animals for which the relevant records were available were included in the calculations of the interrelation of various linear measurements.

STATISTICAL ANALYSIS AND RESULTS

For the 22 animals with full weights and linear measurements, various relations were obtained between weight and the other records. Since the purpose was to find relations from these data that could be used for edictions in the future the method of gression analysis seemed appropriate. The results obtained from the most important of the analyses, those relating weight to length and girth, are given in Table 1. For the same animals attempts were made to predict weight from forefoot diameter, and these relations are shown in Table 2. Also shown in Table 2 is the regression that is best for predicting length of front horn from forefoot diameter. Finally, Table 2 also shows the best regression lines, for the two sexes separately, relating lengths of front and back horn. This last is not a predictive relation, so the technique of regression is not strictly appropriate; however, it is the most convenient simple method of showing the difference between the sexes for the relation between these two lengths. The results shown in Table 2 that do not involve weight are based on larger numbers of animals, as indicated in the Table.

It will be seen that the relations shown in Table 1 all give extremely good predictions of weight from linear measurements, the least good still leaving less than 4% of the variation in weight unaccounted for. There is no difference in predictive efficiency between the relations involving length and girth separately, but the double regression involving both of them is better than either of the single regressions. On theoretical grounds one would expect that the partial regression coefficients of log weight on log length and log girth would be in the ratio of 1 to 2, as volume is related to $(\text{length} \times \text{girth}^2)$ and weight may be expected to be related to volume. However, these coefficients are practically equal, and the prediction of log W from $(\log L + \log G)$ is slightly better than that from $(\log L + 2 \log G)$. The regression coefficient of log W on $(\log L + 2 \log G)$ is only slightly greater than one, suggesting that the true relation between weight and volume is nearly linear. Figure 1 shows the regression of log W on $(\log L + \log G)$, and this can be seen to be very closely fitted by the weights determined at the time of capture. Figure 2 shows the same thing for the regression of weight on volume as $(\text{length} \times \text{girth}^2)$, which is almost as good.

The relations shown in Table 2 are much less close than those in Table 1. There might be circumstances in which it is necessary to predict weight from forefoot diameter, but whether the relation in absolute terms or that in logs is used there is still about 28% of the variation not accounted for: this prediction would be better than none at all, but

TABLE 1

Relations between weight in kg(W), girth in m(G) and length in m(L)

Number of Animals	Relationship	(Correlation coefficient)^2
22	$\log W = 3.376 \log G + 1.775$	0.962
22	$\log W = 3.122 \log L + 1.593$	0.966
22	$\log W = 1.665 \log L + 1.650 \log G + 1.653$	0.986
22	$\log W = 1.118(\log L + 2 \log G) + 1.687$	0.982
22	$\log W = 1.658(\log L + \log G) + 1.654$	0.985
22	$W = 69.84\ LG^2 - 46.88$	0.972

TABLE 2

Relations between weight in kg(W), forefoot diameter in cm(D), front horn length in cm(F) and back horn length in cm(B)

Number of Animals	Sex	Relationship	(Correlation coefficient)^2
22	Both	$W = 12169D - 1771$	0.723
22	Both	$\log W = 3.87 \log D + 1.61$	0.726
52	Both	$F = 4.00\ D - 52.48$	0.612
20	Male	$F = 2.00\ B + 7.44$	0.804
24	Female	$F = 0.98\ B + 14.34$	0.655

would be inaccurate. Similarly, the prediction of front horn length from forefoot diameter, though possible, is not good, with 39% of the variation unexplained. There is the additional consideration with both these relations, especially that for front horn length, that a small measurement error in forefoot diameter would have a very big effect on the estimate obtained from regression.

The relations between front and back horn lengths differ significantly ($P<0.001$) for the two sexes. They suggest that for the younger animals the front horn is only slightly longer than the back for either sex, but that the front horn is relatively much longer than the back in the adult male than in the adult female. Thus for every cm of increase in back horn length the front horn length increases by about 1 cm for the female but by about 2 cm for the male.

DISCUSSION AND CONCLUSIONS

The animals used for these studies came from several distinct populations from different habitats but there is no suggestion that these differences influenced the relations between the various linear records and weight. There were, however, differences in horn length: the rhinoceroses from the stony areas of the Kapiti plains had worn down their horns on the rocks. This meant that their front horn length would have been overestimated by forefoot diameter; in fact these animals all tended to lie below the corresponding regression line.

There were no differences between the sexes except for the relation between lengths of front and back horn. The front horn of a male rhinoceros lengthens twice as fast as the back horn while the increases of both horns are similar in the female. A plot of the points for the relation between front horn length and forefoot diameter suggested a possible difference between the sexes, but the statistical analysis lent no support to this suggestion whatever; it must be remembered that this relation, though highly significant, still left considerable variation unexplained. Similarly, the prediction of body weight from forefoot diameter is not good. In practice this means that one cannot estimate with any confidence the size or horn length of an unseen quarry when tracking for dart-immobilization or trophy hunting.

All the regressions involving weight were obtained excluding the small animal shown at the bottom left-hand corner of Figures 1 and 2. There is no reason to believe from these Figures, or from a plot of the other relations shown in Table 1, that this point is seriously off the regression line. The limited evidence provided by this animal tends to suggest that the relations may well hold for young rhinoceroses as well as adults.

The relations between weight and linear measurements given here for rhinoceroses are all very much closer than those reported by McCulloch and Talbot (1965) for other East African animals. The most efficient prediction formula suggests that weight can

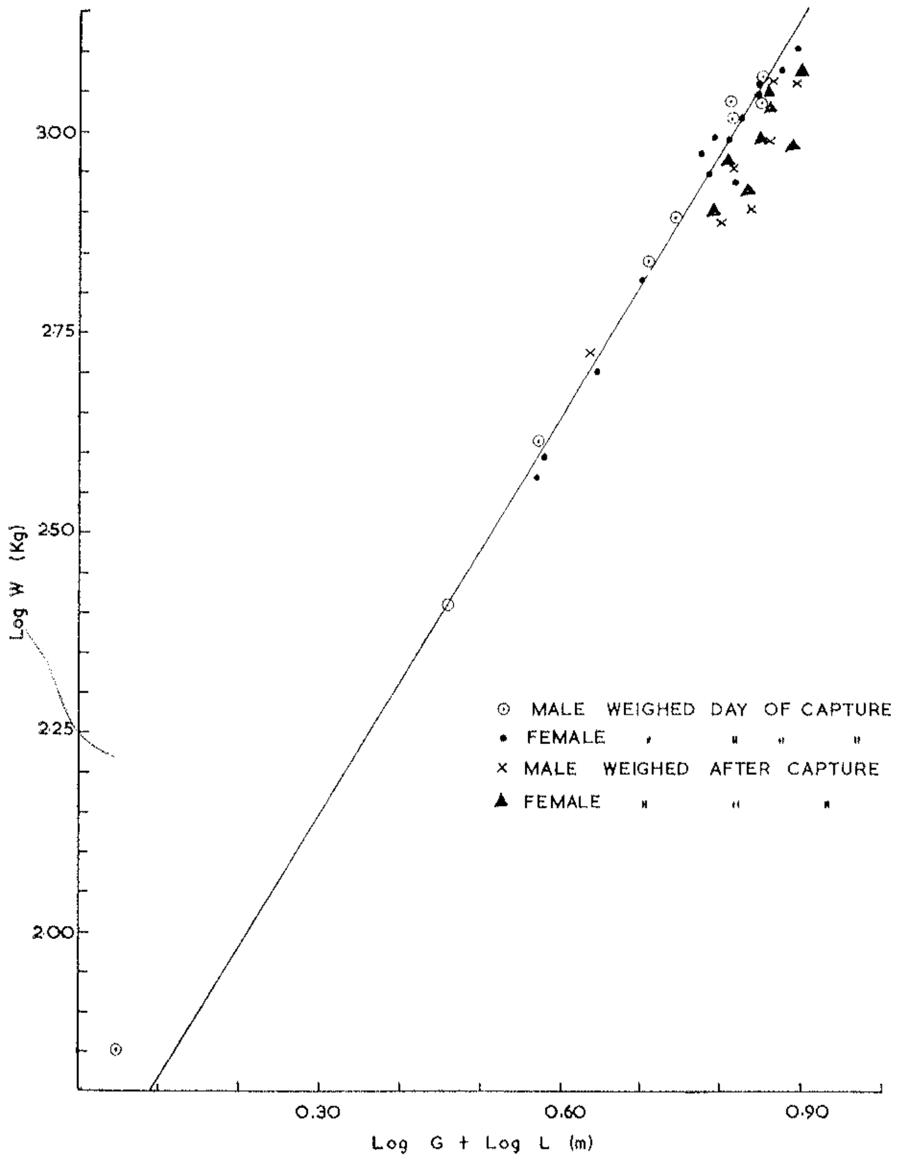

Figure 1
Regression of log weight W in kg on (log length L in m + log girth G in m).

most nearly be represented as a function of (length × girth) raised to the power of about 1.66. This, though statistically useful, is biologically meaningless. The relation of weight to volume suggests a density for the rhinoceros of about 70 kg/m^3, and this at least has a biological interpretation, even if not one of direct practical use.

There are many purposes for which it may be important to predict the weight of a large animal from fairly easily-obtained linear measurements. The black rhinoceros is so large and unwieldy that conventional weighing equipment is frequently difficult to use in the conditions in which the animals are captured, but this is the time when an accurate

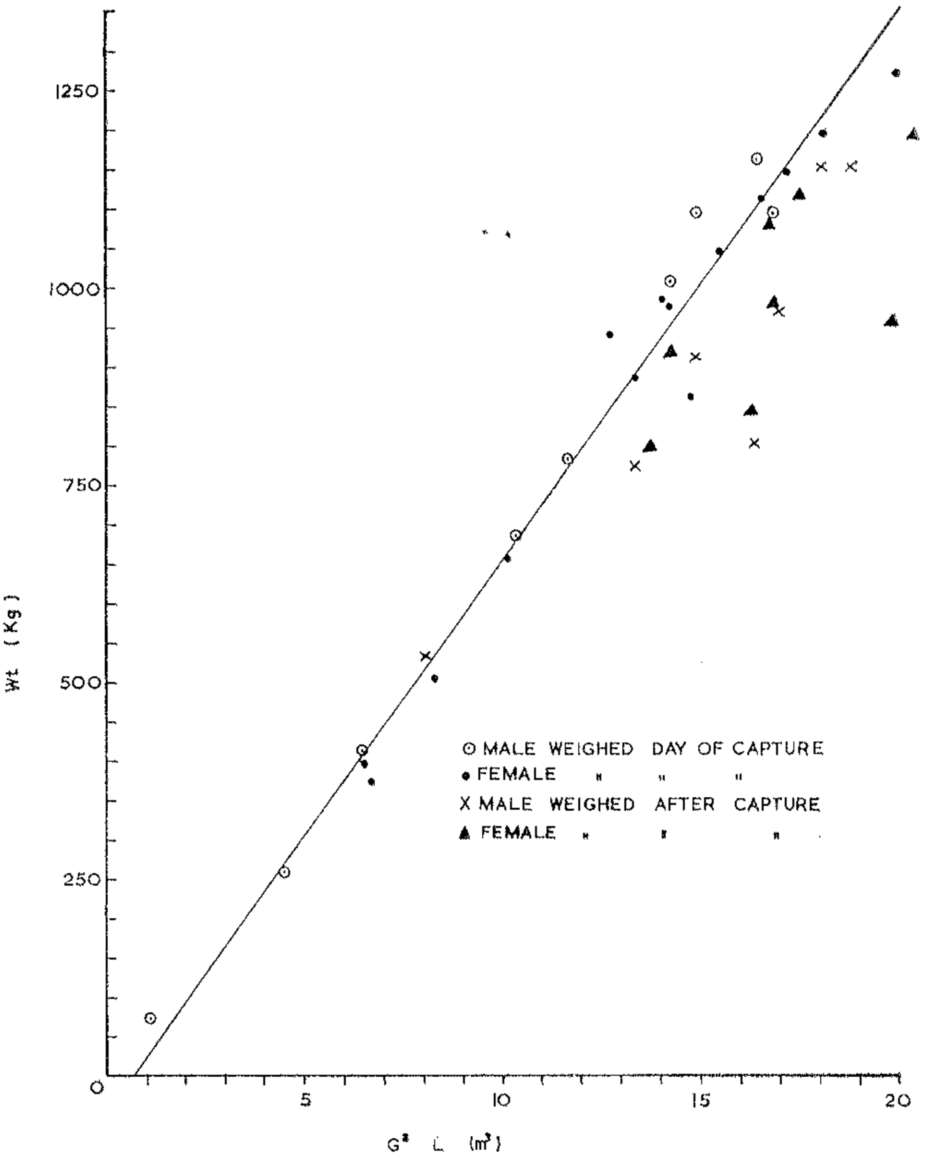

Figure 2

Regression of weight, Wt, in kg on (length L×girth G^2) in m^3.

estimate of weight is needed. All the relations shown in Table 1 are good enough to use as predictors of weight with considerable confidence, even those using either length or girth separately. Some of the sample of 59 animals had only length or only girth measurements, so the weight would have had to be estimated this way. However, it is more satisfactory if both length and girth are measured, and weight can then be estimated in practice using either of the equations illustrated in Figures 1 and 2. Estimates of weight from both equations were found for 25 animals which were either not weighed at all or weighed some time after capture, and the differences between the two estimates and the mean of the estimates were both calculated. Neither estimate was consistently higher than the other and the greatest difference between the two, expressed in terms of their mean, was 6.2%, the differences being less than 4% in 20 of the 25 animals.

Where weights were obtained after capture these are marked on Figures 1 and 2. One animal was weighed 25 d after capture, but the other 14 were weighed 4–10 d after capture, the mean being just over 7 d. It can be seen that, except for one rather small animal, all the points lie below the regression lines in Figures 1 and 2. The mean weight loss for the 14 animals weighed within 10 d of capture was 132 kg, this figure being obtained from the difference between the estimated weight at capture and the weighbridge weight later. These differences are large enough to be almost certainly real, but only in three cases did the animals show marked loss of condition. This confirms the observation that rhinoceroses, and indeed most wild animals, tend to lose weight during the initial period of captivity.

ACKNOWLEDGEMENTS

We are grateful to the Game Department Fauna Research Unit, the Animal Husbandry Division of the East African Agriculture and Forestry Research Organisation, the East African Wild Life Society and the John Seago Unit for their contributions towards the weighing assembly. We would also like to thank Mr. H. P. Ledger for his advice and Mrs. C. A. King for typing the manuscript.

REFERENCES

CARTER, B. H. (1965). The Arm'd Rhinoceros. *Andre Deutsch Ltd., London.*

KING, J. M. (1969). The capture and translocation of the black rhinoceros. *E. Afr. Wildl. J.*, **7**:115–130.

MCCULLOCH, J. S. G. and TALBOT, L. M. (1965). Comparison of weight estimation methods for wild animals and domestic livestock. *J. appl. Ecol.*, **2**: 59–69.

LAWS, R. M., PARKER, I. S. C. and ARCHER, A. L. (1967). Estimating live weights of elephants from hind leg weights. *E. Afr. Wildl. J.*, **5**: 106–111.

PEARCE, S. C. (1952). Studies in the measurement of apple trees 1. The use of trunk girths to estimate tree size. *Rep. E. Malling Res. Stn for* 1951: 101–104.

SACHS, R. (1967). Live weights and body measurements of Serengeti animals. *E. Afr. Wildl. J.*, **5**: 24–27.

SMITH, N. S. and LEDGER, H. P. (1965a). A portable tripod and weighing assembly for large animals. *J. Wildl. Mgmt*, **29**: 208–209.

SMITH, N. S. and LEDGER, H. P. (1965b). A method of predicting live weight from dissected leg weight. *J. Wildl. Mgmt*, **29**: 504–511.

TALBOT, L. M. and TALBOT, M. H. (1962). A hoisting apparatus for weighing and loading large animals in the field. *J. Wildl. Mgmt*, **26**: 217–218.

THORNTON, D. D. (1960). The estimation of Ankole and Zebu cattle weights by girth measurement. *E. Afr. agric. For. J.*, **26**: 140–141.

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(Received for publication February, 1969)