Plenary Paper One
Options for Aerial Surveys of Elephants

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In most areas where elephants occur, aerial surveys are the only means used to establish their numbers. The most common methodology is that of the systematic reconnaissance flight, sometimes called the transect sample-count (Norton Griffiths (1978), Jolly (1969)).

Sample-counts estimate the total number of animals in an area by counting the actual number in a small sub-area, and extrapolating the density found to the whole area. The sub-area, or sample, is divided into unbiased sampling units, so that the overall estimate will be, on average, a fair reflection of the true number. Though there is obviously error inherent in this approach, its magnitude can be estimated using appropriate statistics.

Despite the usefulness of the transect sample count, it is commonly criticised as being inadequate. There are other methods, which are appropriate under some circumstances. The purpose of this paper is to examine some of the alternatives to all or part of the standard methodology. Admittedly this is done from the standpoint of some commitment to sample counts but it is hoped nevertheless to stimulate further discussion of the most contentious points.

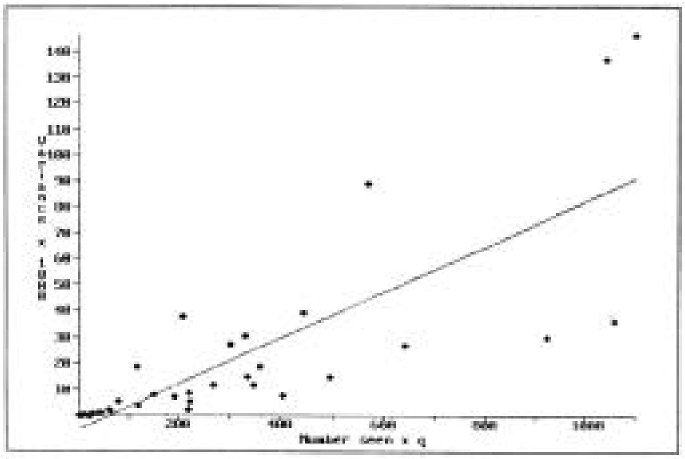

Figure 1 : Relationship between sampling variance of number seen on a survey and the number seen. Data from a 4% sample of an elephant population. Line is y = 87.4 x - 5423

Since many of the arguments revolve around the efficiency or uncertainty of surveys, it is important to start out with some appreciation of the pattern and causes of variation in elephant surveys. A model, based as closely as possible on actual population properties, is needed to serve as a basis for evaluation of the effects of different counting strategies. The following is proposed as such a model.

Sample/Number/Variance Relations in Elephant Surveys

The precision of a survey result predicts the likely spread of results if the survey were repeated many times, i.e. is a measure of confidence in the result. The confidence limits themselves derive from the standard error which is, in turn, the square root of the variance of the estimate. Jolly's (1969) formula for calculating the variance of the estimate for unequal sized sampling units (EQUATION 1) is normally used for sample surveys.

$$s^2_{EST} = \frac{N(N-n)}{n}(s^2_y \quad 2R.COV_{zy} + R^2 . s^2_z). \quad 1$$

The right hand bracket contains the sampling variance, which is the variance among sample units (transects or blocks). This is converted to the variance of the number seen by dividing by n, the number of its units sampled. This in turn gives

the variance of the estimate when multiplied by: N(N-n), where N is the total possible number of units, if all the ground were searched.

For actual elephant surveys, done at a particular sampling intensity, the variance of the number seen is related to the number seen. Figure l shows this for a number of results for blocks in northern Botswana all sampled at about 4%. This gives us two useful pieces of information.

Table 1. Composition of census alternatives

Option	Advantage	Disadvantage
Total count	Results believed by laymen.	Costly, less precise than believed. Encourages low search intensity leading to low accuracy.
Sample count	Cost efficient. Permits highest accuracy. Permits fulfillment of simple assumptions.	Low precision for low sampling intensity
Block sample count	Cost efficient for simple aircraft. Calibration unnecessary. Possible in most places.	High requirement for commuting between blocks. High preparatory work load. Difficult navigation. Returns poor information on distribution and exacerbates the problem of non random distribution.
Transect sample count	Cost efficient in searching vs commuting time. Returns good information on estimates and distribution. Simple navigation and preparation.	Requires high capital and running cost: aircraft and equipment and large crew. Subject to transect width calibration error. Physically impossible in places.
Stratified count	Enhanced precision and cost effectiveness,	Loss of distribution information towards edge of range.
Unstratified count	Not as above	Not as above.
Corrected estimate	Enhanced accuracy.	Correction factors very imprecise. High probability of overestimate.
Uncorrected estimate	Results tend to be conservative,	Always biased, usually toward underestimate.

The first of these is a prediction of how the number of animals in a population will affect the precision of any estimate from a 4% sample. The equation which results from Figure l is y = 87x - 54000. This predicts that an estimate of 60000 elephants will have a *95%* confidence interval of± *35%*.

The second is the insight that variance, being proportional to number, is analogous to the situation with a binomial distribution, where the variance of the number in a sample is related to the total number and the sample size. i.e. the variance is Np(l - p) where N is the number in the population and p is the proportion sampled. If individual elephants were randomly distributed the variance of a 4% sample of 60000 elephants would be 60000 x .04 x .96 = 2304. This means that the confidence interval on the 60000 would be ± 4%. The reason that it is larger in reality is because elephants are not randomly distributed but clumped into herds and larger concentrations.

Figure 2. Proposed relationship between precision and sampling intensity

The above suggest that a model assuming a binomial relationship of variance with sample size, corrected to give the expected amount of variance from an actual population, might be a model that would adequately represent precision of an elephant survey in relation to size of the population being surveyed and to the proportion sampled.

It is hoped that this is true at least as far as is necessary to draw conclusions about different sampling strategies and this model is used here for that purpose.

Evaluation of Alternatives

The cases for various alternatives, discussed under separate headings below, are summarised in Table 1.

Total Counts

Many people, even professional wildlife managers, have a difficulty with sample counts, and ask the obvious question: why not count all the animals so that we can be certain of the number?

At one time, of course, all counts were total counts, or attempts, statistics and uncertainty being an even more general anathema then. Total counts were rejected in Zimbabwe when the first attempts at sample-counting elephants yielded results which consistently suggested that populations had previously been greatly underestimated. This was seen to be due to the fact that the smaller areas being searched on a sample-count were able to be searched more intensively than had previously been thought necessary.

This alone does not rule out a total count, provided searching intensity is raised to the level prevailing on sample counts. It is clear from Equation l that when n (the number of units sampled) = N (the total number of sampling units in the area), as would be the case for a total count, that the variance of the estimate becomes zero. Although a total count appears there fore, to be the extreme case of a sample count, there are other reasons for rejecting it on most occasions.

As sample size increases, there is a diminishing return in terms of an increase in precision of the result. This is illustrated by Figure 2 which models decrease in the confidence interval as sample size increases. It can be seen that with over 20% sampling there is very little improvement in precision for a very large increase in effort.

The assumption that variance becomes zero for a total count is actually unjustified except where very small areas are concerned. Equation l assumes that all animals within a sample area are seen and that none are seen more than once. In practice this assumption cannot be fulfilled except for small samples. With large samples of large areas it might be better to assume more independence of individual sampling units which would imply replacing N(N - n) with N^2. This would mean that total counts do not give absolute certainty of numbers. This aspect has been incorporated into Figure 2 by assuming some independence of sampling units for samples over 20%.

Large sample counts may be useful in areas that are small enough that time and cost are not problems. Total counts could be considered reasonable in situations where the conditions are such that the above assumptions are fulfilled.

Block or Transect Sample Counts

Block sample counts differ from transect counts basically in the shape of the sampling unit. Transects are delimited by markers on the aircraft and boundary decisions are made in relation to those markers. Blocks are delimited on maps in advance of the survey, and boundary decisions are made by navigation. There is little to choose between the methods statistically.

There are advantages to both methods (see Table 1). The main disadvantages of block counts are that they are inefficient in terms of ground covered per unit effort (see Figure 3) and that they give poor in formation on animal distribution. They are useful where transect counts are not feasible, as in mountainous country.

Stratified or Non-Stratified Sampling

Stratification involves breaking up the area to be surveyed into separate areas (strata) which may be sampled at different intensities, hopefully in such a way as to improve the precision without expending greater effort. The common criticism that when a stratum which contains more elephants is surveyed more intensively, the overall result must therefore be biased towards obtaining an overall higher result, is of course wrong. A stratum containing l 0000 elephants will, on average, be estimated to contain 1000 elephants regardless of how intensively it is sampled. There is some question of how effort should be allocated to obtain optimal precision. Gasaway *et al* (1986) calculated the allocation of sampling effort using a quantity called the relative variation factor for each stratum. If the relative variation factor for stratum i is R and the total area to be sampled in all strata is A, then the area S_i to be sampled in stratum i is given by

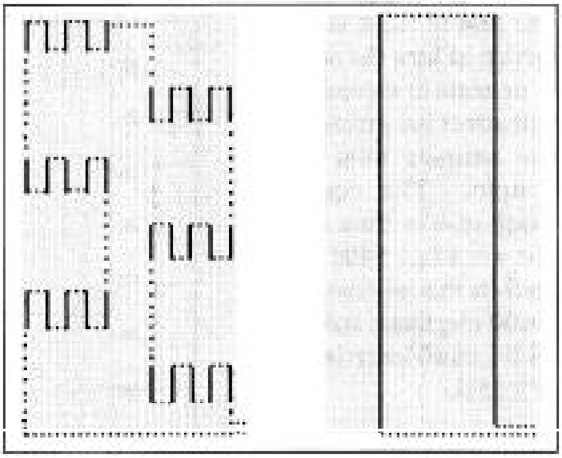

Figure 3. Comparison of block count (left area) with strip count at same overall sampling intensity (right area). Dotted lines represent commuting flights

$$S_1 = \frac{AR_i}{\sum R_j} \qquad 2$$

There are alternatives for R. which give different results. Gasaway *et al.* (1986) use:

$$R_i = N s_I \qquad 3$$

where N. is the total number of possible sampling units in stratum i, and 0 is the square root of the sampling variance in that stratum. This is known as the Neyman allocation (Cochran, 1977).

Norton-Griffiths (1978) uses:

$$R_i = d_i \qquad 4$$

where d_1 is the density of animals in the ith stratum .

Zimbabwe Department of National Parks (eg. Gibson, 1989) use

$$R_i = a_i\sqrt{di} \qquad 5$$

where a is the area of the ith stratum. Note that only Norton-Griffiths method takes no account of the size of a stratum.

To model the effects of these stratification techniques on an elephant survey, some real data are required. Figure. 4 shows the cumulative frequency distribution of elephant numbers by density for the l 989 dry season survey of Northern Botswana as mapped in Craig (1990). The available area has been divided into three strata according to the root cumulative frequency rule (Cochran, 1977). These strata are summarised in Table 2.

Table 3 shows the allocation of sampling effort to these three strata according to the three methods above i.e. Norton-Griffiths (N.G.), Gasaway (Gas.) and Zimbabwe (Zimb.). Allocation of the same sampling effort per unit area through all strata (null) is also simulated. Precision was calculated from the total predicted variance worked out on the above binomial model.

The Zimbabwe and Gasaway type allocations give almost identical results although they are not precisely mathematically identical. They also result in some increase in precision, unlike the Norton-Griffiths method which results in a decrease in precision. The latter method is clearly wrong in its failure to allow for size of stratum as well as density in the allocation of sampling effort. It must be noted, however, that this does not mean that the estimates using that method would be wrong, just that the level of precision might be less than could otherwise be expected.

Table 2. Summary of high, and low density sampling strata proposed for the elephant population of Figure 4.

Stratum	Area (km^2)	No.elephants	Density (km^2)
High (H)	7073	*34515*	4.8800
Mediurn(M)	13437	19016	1.4150
Low (L)	63776	5469	0.0858

Table 3. Allocation of sampling effort to the three density strata of Table 2 by four different methods, and predicted precision of each method.

	% sampling allocation				predicted
Method	basis	H	M	L	precision
Null	area	5	5	5	± 30%
N.G.	dens	45.6	6.95	0.089	± 72%
Gas.	No	18.5	9.97	2.460	± 21%
Zimb.	a√dens	18.5	9.97	2.454	± 21%

An even more important point demonstrated by Table 3 is that the gain in precision from the two acceptable methods over no stratification at all is not great, at least for these three strata. It should be noted that to obtain the improvement in precision predicted, there would have to be very precise a *priori* information on the distribution of elephants. A rough prior idea of their distribution would result in a lesser gain. This tends to call the value of stratified sampling effort into question. When good distribution information is required, an unstratified sampling might be a better approach because the latter would require less sampling effort in the peripheral low density areas, resulting in less information about the elephant range.

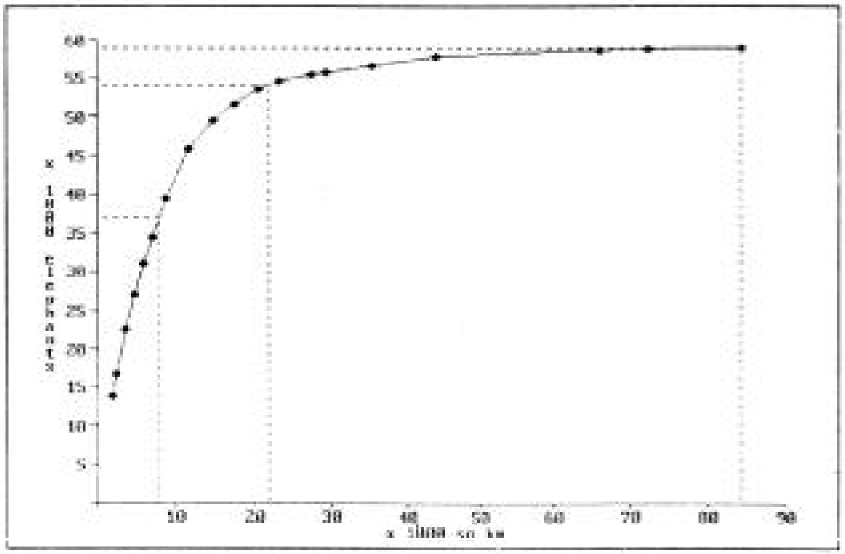

Figure 4. Cumulative number of elephants vs cumulative area of range, starting with high density part of range. packed lines delimit high, medium and low density strata.

Use of Correction Factors

The above discussion has dealt with the problems of precision, the potential variation of survey estimates around a mean result. It has ignored the problem of accuracy which refers to the closeness of the mean result to the true number. It is usually assumed that the true numbers are underestimated by surveys due to animals within the sampling units not being seen. As stated above, one of the successes of sampling is in permitting much more intensive search effort within slumping units. Nevertheless undercounting probably still occurs and the question often arises whether an attempt should be made to apply correction for this. Methods exist (eg. Magnusson *et al* 1978) for calculating such correction factors.

Correction factors of course have their own errors of estimation so they may add some accuracy while decreasing precision considerably. This will tend to lead to a greater number of results being overestimates, bringing with it the danger that bad management decisions could become more likely.

Conclusions

The above deals mostly with problems of maximising the information gain from a particular amount of effort. The question of how much effort has been left open. Although it has been shown that there is a diminishing return for greater levels of effort, high effort might be necessary for some applications.

Necessary effort depends on the requirements of the user of the information to be produced. Does he want to be able to estimate the rate of increase to ± 1% over a period of a year, or is he hoping to detect a large decline, should one occur, over a number of years? The former will require a much greater effort than the latter. The identity of the user and his information requirements will be paramount in this decision.

An effective census should be designed to make the best use of the available human, capital and financial resources. This implies making sufficient effort to obtain the answer to the question, and no more, because in conservation all resources should be used wisely.

Acknowledgments

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References

Cochran, W.G. 1977. *Sampling Techniques.* Wiley. 428pp.

Craig, G.C. 1990. Present population and distribution of elephants in northern Botswana. In: *The Future of Botswana ‘s Elephants* Ed. P. Hancock. Symposium of the Kalahari Conservation Society, Gaborone. 16-18.

Gasaway, W.C., S.D. du Bois, D.J. Reed & S.J. Harbo 1986. Estimating moose population parameters from aerial surveys. *Biological papers of the University of Alaska. No. 22.* 108 pp.

Gibson, D.St.C. 1989. Aerial census of larger mammals in the National Parks Estate of Zimbabwe. Report of the Branch of Terrestrial Ecology, Department of National Parks and Wildlife Management, Zimbabwe. 48 pp.

Jolly, G.M. 1969. Sampling methods for aerial censuses of wildlife populations. *E. Aft. Agricultural & Forestry Journal - special issue.* 46-49.

Magnusson, W.E., G.J. Caughley & G.C. Grigg 1978. A double-survey estimate of population size from incomplete counts. *J. Wildl. Manage.* 42(1): 174-176.

Norton-Griffiths, M. 1978. Counting animals. *Handbook No. 1, African Wildlife Foundation, Nairobi, Kenya.* 139 pp.