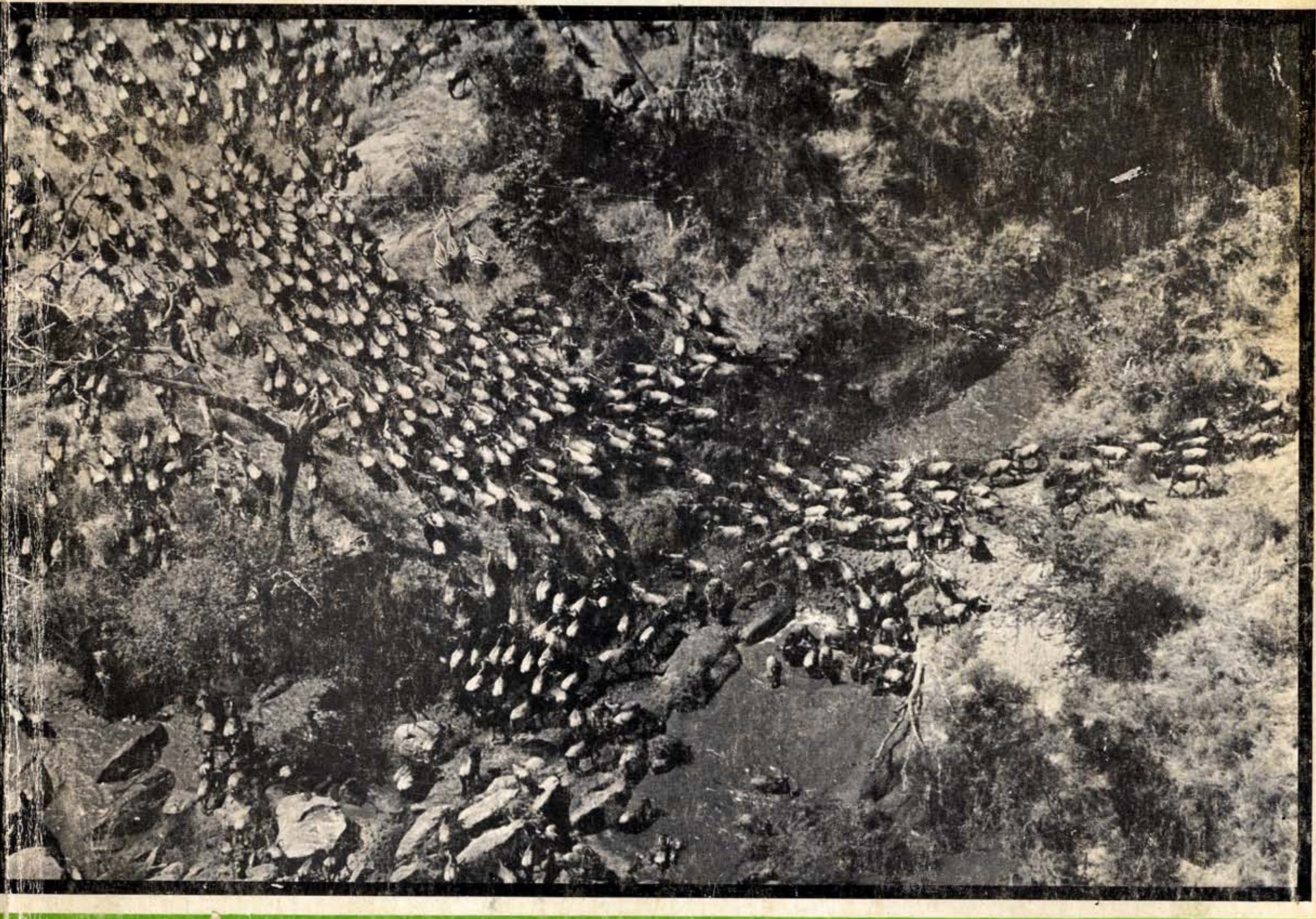
counting animals

by M. Norton-Griffiths

A series of handbooks on techniques in African wildlife ecology
Edited by J.J.R. Grimsdell
of the African Wildlife Leadership Foundation



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COUNTING ANIMALS

by

M. Norton-Griffiths

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Handbook No. 1 in a series of Handbooks on techniques currently used in African wildlife ecology

Edited by J.J.R. Grimsdell

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FOREWORD

The first edition of this Handbook was produced in December 1975. However, during the last two years more information on techniques of counting animals has become available. This revised edition includes some of the more recent research findings on this topic and at the same time various corrections of error and other small changes have been made to the original text. Rather than alter the original text, the extra information is presented as four Appendices which cover the following subjects : (1) the study of movements and distributions, (2) training observers, (3) more about counting bias, and (4) operational procedures and check sheets for censuses. The first and third appendices include further references not given in the main list of references.

Although this Handbook gives special emphasis to methods of aerial census, it must be appreciated that the methods and analyses are similar, if not the same, for ground counts. This is the reason why the section on ground counts is relatively brief.

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SECTION 1 INTRODUCTION TO COUNTING ANIMALS

Any research programme for the management and conservation of large African mammals will require, at some point, information on the number of animals. The type of information falls into three main categories :-

(i) total numbers : estimates of the total numbers of different species within a Park, Reserve or study area forms part of the general ecological description of an area. These estimates are also needed for the study of predator/prey relationships, and for more detailed studies concerning the utilisation of the habitat.

(ii) the size and structure of populations : the study of population dynamics is essential for understanding the ecological status of a particular population within a Park or Reserve, as well as for deciding on management and conservation policies. These studies require periodic estimates of the absolute size of a population, and of its age and sex structure (e.g. male : female ratios; proportions of calves, yearlings and sub-adults).

(iii) distribution and movements : data on the seasonal patterns of movement and vegetation type utilisation are necessary to identify key grazing and watering areas, as well as basic migratory routes and areas of high species density and diversity. This information is used to define the boundaries of new Parks, or to define alterations to existing boundaries. The development of tourist areas is also based on this information. Also, detailed studies of habitat utilisation, overlap and competition require very precise information of this type.

No form of wildlife management, whether it is the establishment of cropping or hunting quotas, the development of tourism or the demarcation of boundaries, is possible without reliable information on the numbers, population dynamics and movements of the animals concerned. This account deals with many of the practical problems that are met with when designing and carrying out a wildlife census. The emphasis has been placed on the problems of estimating the total number of animals within a defined area - for the principles involved and the problems to be solved, apply equally well to other types of census. Emphasis is also placed on methods of aerial censuses, for these methods are becoming very widely used, and the principles involved also apply equally well to vehicle and foot methods. Some Sections are devoted to ground counting methods, especially for those situations when ground methods give better results than aerial methods.

The first important point to remember when designing a census is to decide in advance exactly what the objectives of the census are. It may sound obvious to say that no two censuses are the same, that a census aimed at providing data on distribution will be different from one aimed at estimating total numbers, but many investigators have come to grief through trying to do too much in one census. In general it is best to design a census for one main objective only. For example, a census of total numbers can yield some information on distribution, and this can then be used when designing a separate census aimed specifically at describing distribution.

Once the main objective has been decided upon, many other factors must then be taken into account. Some of these are listed below, although in no particular order of importance :-

(i) resources : men on foot, cross country vehicles, regular use of a light aircraft and qualified crews.

(ii) the size of the area : a small study area (say 200 km^2), a medium sized area (say 1,000 km^2), or a very large area (say 25,000 km^2).

(iii) the nature of the vegetation : open plains, wooded grasslands, thick bush or closed canopy forest.

(iv) the nature of the country : flat and accessible, mountainous and inaccessible; good road systems or no road systems.

(v) the animals concerned : large migratory species, large resident species or small resident species who lurk.

The light aircraft is now very widely used for wildlife censuses and surveys. Reliable and consistent results can be obtained so long as some straightforward precautions are taken and so long as the census is carried out by qualified crews. It can cover large areas of country quickly and economically, and it is the only method for censusing in areas where access on the ground is difficult or impossible. Its use only becomes limited when the vegetation is so thick that the animals cannot be seen from the air, or if the animals concerned are very small.

For example, in Tanzania's Serengeti National Park, censuses of the proportions of calves, yearlings, sub-adults and adults are made throughout the year on the buffalo population (large resident herds) and the wildebeest population (massive migratory herds). Although ground access is possible throughout most of the Park, the buffalo react to vehicles in such a way that ground counts are extremely difficult, while the wildebeest are spread over such a huge area that a representative sample would be difficult to obtain. These censuses are instead obtained cheaply and efficiently from a light aircraft. Similarly, it would be impossible to estimate the size of these populations using ground methods, while from the air it is quite a straightforward matter[37,49]. Another example is given by a recent census in Ruaha National Park, Tanzania, an area of some 10,000 km^2 with almost no road system and with country largely impassable for vehicles. An aerial survey that cost some EA Sh 6,000.00 gave data on the sizes of the large mammal populations as well as density distribution maps for each species. Species diversity and density were also mapped, and areas for future tourist development located[38]. It would have been impossible to obtain this information from ground counts.

Nonetheless, ground counts from vehicles are practicable and give excellent and consistent results in small to medium sized areas where the country can be traversed by vehicles, and where the vegetation is reasonably open and the animals tame to vehicles. Some animals, e.g. very small resident species, can only be studied from vehicles. Ground counts are also excellent for obtaining data on the seasonal patterns of distribution within different vegetation types, and much additional information can be obtained on the behaviour and condition of the animals that cannot be obtained from aircraft. Counts from vehicles are therefore ideal for detailed studies in small study areas, their use being only limited when ground access is difficult or when the area to be covered is very large. In this latter case, representative data can always be obtained by scattering a number of small study areas throughout the whole area of interest.

Road counts are an adaptation from vehicle ground counts that are quite widely used, especially when access off the existing road system is difficult. The data obtained from road counts must, however, be treated cautiously, for the method is open to many types of bias. For example, the edges of roads tend to be 'habitat' for some species, and this leads to a consistent overestimate of numbers or density. In addition, roads are rarely distributed randomly across an area. They tend to pass through 'good game viewing areas', and they tend to be placed along contours rather than across contours. However, the inherent biases in road counts can be corrected for, and so long as this is done the method will give good results.

Foot counts are not often used nowadays and are only necessary if other methods are impracticable. It would, for example, be difficult to count West African forest elephant in any other way except on foot. The same applies to thick *Brachystegia* woodlands. Information from foot patrols can always be used to help design a census using some other method, and foot methods could certainly be used to get ideas of the density of small resident species, and to get information on the proportions of different age/sex classes in a population. Their limitation is that the area covered will of necessity be small, and it is thus difficult to ensure that the data are representative of the whole area, or of the whole population.

There are, in fact, only two ways of censusing animals. In the first, known as the Total Count, the whole of a designated area is searched and all the animals in it are counted. The assumptions are made that the whole area is indeed searched, that all groups of animals are located, and that all groups are counted accurately. The second method - which has many different forms - is known as the Sample Count. As the name implies, only part, or a sample, of the designated area is searched and counted, and the number of animals in the whole area is then <u>estimated</u> from the number counted in the sampled area. The same three assumptions are made about searching, locating and counting all the animals in the sampled part, and an additional assumption is made that if, for example, 25% of the total area is counted then it will contain exactly 25% of the animals.

At first sight the Total Count seems to offer the most straightforward approach and indeed there are some circumstances when this method is the best. In general, however, the Sample Count has so many advantages that it is by now the most widely used method.

The first consideration is one of costs. Sample Counts tend to be cheaper than Total Counts simply because only part of the area has to be searched instead of the whole area. A good example of this is from an aerial census of migratory wildebeest in the Serengeti in 1971 where in the same week both a Total Count and a Sample Count were carried out[37,49]. Comparisons of the costs of the two methods showed that the Sample Count required 5 hours flying while the Total Count required 17 hours flying. The results were very similar : 754,000 animals from the Sample Count and 721,000 animals from the Total Count. Of course, saving money is not the main objective of a census, but it is a major consideration when deciding what sort of census to carry out.

Another disadvantage of a Total Count lies with the difficulties of ensuring that the whole area is in fact searched. This is only possible when very good maps are available, for then the path of the aircraft (or vehicle) can be mapped as well as the location of every group of animals seen. Gaps in the searching pattern can be located while there is still time to make corrections, thus minimising double counting of groups. Most usually the investigators concerned in Total Counts have relied on the assumption that those areas and those animals that are missed are balanced by those counted twice. This is an unsatisfactory state of affairs, and it is the main reason why Total Count estimates are often of dubious reliability. In a Sample Count, on the other hand, it is usually possible to define the areas to be searched so specifically that errors of this sort are minimised. This is especially true in Sample Counts using the line transect technique.

One great drawback to Sample Counting - although on closer inspection this drawback is more imaginary than real - is known as random sampling error. The basic assumption of a Sample Count (namely, that if 25% of an area is searched it will contain exactly 25% of the animals) is patently false, and it could only be true if animals were completely evenly distributed across the whole area. Instead, animals tend to occur in groups, and the groups themselves are more common in some parts than in others. This means that if a different 25% of the area had been counted then it would have contained a different number of animals, and therefore the estimate of the total number of animals would have been different - irrespective of how accurately the animals had been counted and how diligently the area had been searched. The central paradox of Sample Counting is that you can never tell how close a sample estimate might be to the true number of animals, even if it is exactly the same as the true number. What is possible, however, is to measure the size of the random sampling error, and this tells you how much faith you can put on the sample estimate.

The greatest problem with Total Counts is concerned with the problems of actually counting animals, for this is not as simple as it may at first appear. If you are sitting quietly in a car observing a group of impala you would be able to come to a very accurate idea of the number of animals in the group. 'Accurate' here means that the figure you eventually arrive at will be very close to, or perhaps even the same as, the 'real' number of animals in the group. Suppose instead that you flew over this same group of impala at 120 mph at three hundred feet above the ground, and that you had only 8 seconds when the group was in view in order to count them. Your accuracy is likely to be less. This loss of accuracy has to do with counting rate, which is the number of animals to be counted per unit time. If the counting rate is low then accuracy is likely to be high, and *vice versa*. This loss of accuracy can take two forms. Firstly, observers may on some occasions undercount and on other occasions overcount. Any one observation may be inaccurate, but on average they will balance out. This is known as counting error, and it has been shown that counting error increases with counting rate - in other words, counting becomes less precise the faster you have to count. The second form of loss of accuracy is known as counting bias. Most observers consistently tend to undercount, and this undercounting gets worse the more animals there are to count and the faster they have to be counted. This is known as a bias because the error in counting is always in the same direction, in this case downwards. Bias is also connected to counting rate, and it increases with counting rate in the same way as counting error does. Further complications come from the difficulties experienced in spotting individual animals or groups of animals. Under some conditions (thick bush) animals are much more difficult to see, let alone count, than they are, say, on open grassland. The more difficult it is to spot animals, the less time is available for counting them, and subsequently the greater are the counting errors and biases. Similarly, herd size will also affect the counting rate.

It is entirely possible to organise things so that both the difficulties in spotting animals and the counting rates are made as easy as possible for the given conditions. For example, observers for an aerial census can be trained to count by showing them colour slides of different sized groups of animals. In thicker country the observers can scan a narrower strip on either side of the aircraft or vehicle than in more open country. Photography can be used on all groups above some specified minimum size, the number of animals being counted at some later time from the photographs. An aircraft can be flown more slowly over thicker country than over more open country, more slowly over areas of high density than over areas of low density. Similarly, vehicles can be driven more slowly, and stop for longer periods. One result of all these precautions is that the amount of ground that can be covered per unit time becomes quite small, and it is this factor that is the most important in deciding between a Total Count and a Sample Count.

The decision, therefore, between using a Total Count or a Sample Count is not really one of choosing the 'best' method but rather one of avoiding the 'worst'. Under most circumstances the rate at which thr ground can be covered in order to maintain counting accuracy and to minimise counting bias is such that it becomes inordinately expensive and time consuming to attempt a Total Count. A Total Count can, of course, still be attempted, but only by covering the ground less intensively and therefore losing accuracy while increasing bias to a degree that it is usually impossible to gauge. The alternative is to maintain accuracy but only sample a small part of the total area. The penalty for doing this is the effect of random sampling error, but at least the magnitude of the sample error can be estimated, and thus the usefulness of the sample estimate can be judged.

The recent census of Ruaha National Park, already referred to[38], can be used as an example here. In the wet season, the vegetation was so thick that a strip of only 125 metres could be counted on either side of the aircraft, allowing a Sample Count of 5% of the total area to be carried out in twelve hours flying. A Total Count of the whole area would thus have taken some 240 hours flying, a completely impracticable proposition. One should add here, for the unconvinced, that this was not concerned with unobtrusive animals but was an elephant census.

SECTION 2 THE PRINCIPLES OF A SAMPLE COUNT

2.1 Introduction

Sample Counting is surrounded by an abstruse terminology that often gives the impression that it is all very complicated and that a degree of higher mathematics is required to understand it. Nothing could be further from the truth. The principles of Sample Counting are very simple, and the mathematical treatment of the data is purely mechanical.

The census zone is defined as the whole area (e.g. National Park, Game Reserve, cattle ranch or study area) in which the number of animals is to be estimated. The sample zone is defined as that portion of the census zone which is searched and counted. The objective of a Sample Count is to estimate the number of animals in the census zone from the number counted in the sample zone.

All the problems that have to be overcome stem from the fact that animals are not distributed evenly. If they were then any part of a census zone would be representative of the whole area, and the sample zone could be located in any convenient place. However, animals tend to occur in groups or herds, the herds themselves usually being more common in some parts than in others, causing variation in animal density across a census zone. Unless the sample zone can be made to reflect this variation some very curious results will occur.

The census zone is therefore divided up into a number of discrete units known as sample units, a number of which are chosen at random to be searched. The sample zone is thus distributed randomly in different parts of the census zone, ensuring that it will be representative of the variations in density. For example, a census zone could be divided into fifty equal sized blocks twenty of which could be chosen at random. The sample zone would then consist of twenty blocks distributed randomly across the census zone, and the number of animals in each of those twenty blocks would be counted.

By dividing up the census zone in this way a population of sample units is created. The population total is defined as the total number of animals in this population of sample units. The objective of a Sample Count can therefore be restated to be 'to estimate this population total by counting the number of animals in a random selection, or sample, of units from the whole population of units'.

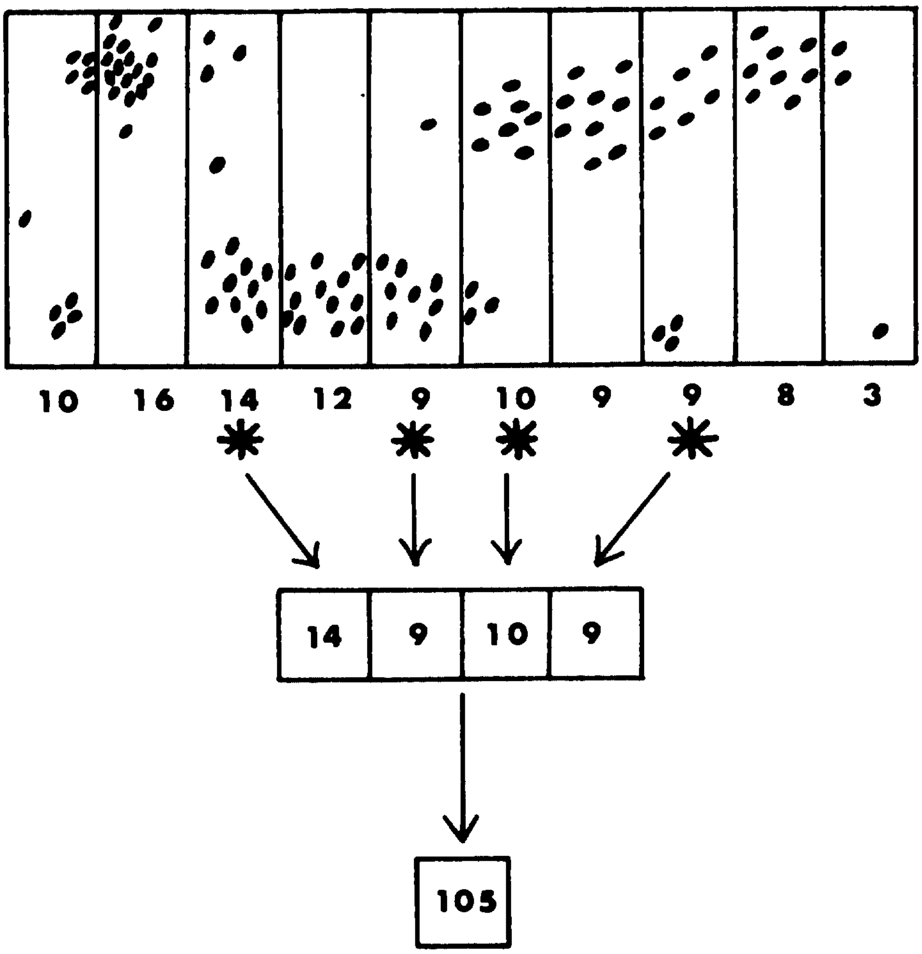
The estimate of this population total, known as the <u>sample estimate</u>, is simple to understand. The assumption is made that since the sample of units is selected at random, then the average number of animals per unit in the sample will correspond to the average number of animals in the whole population of sample units. The sample estimate is therefore found by multiplying the <u>sample mean</u> by the total number of units in the population from which the sample was drawn.

This procedure is shown in Fig. 1 which shows a census zone divided up into ten equal sized strips, or transects. Each dot represents the location of an animal. A random sample of four transects has been chosen, and the number of animals in each has been counted. The sample mean is 10.5 animals, which multiplied by 10 gives an estimate for the population total (i.e. a sample estimate) of 105 animals.

As animals are never distributed evenly within a census zone each sample unit in the population of units will vary in the number of animals that it contains, so that some units will have many animals in them while others will have but a few, or perhaps none at all. This means that the estimate of the population total will depend upon which individual sample units happen to be chosen into the sample, for different random selections will give different results. In other words there are large numbers of alternative estimates that can be obtained from samples of the same size.

It is this that is known as random sampling error, the effect of which is shown in Fig. 1. The sample estimate calculated from the sample of four units was 105 animals, which is slightly larger than the true population total of 100 animals (this can be found by adding up the number of dots in Fig. 1). Also shown in Fig. 1 are the sample estimates from a further nineteen random samples of four units each. The theory of random sampling shows that although any single sample estimate may be higher or lower than the 'true' population total, these errors will on average balance out. This is why it is

Fig. 1 The principles of a sample count. The area represents a census zone that has been divided up into ten equal sized strips, or transects. These ten transects are the sample units. Each dot represents the location of an animal.



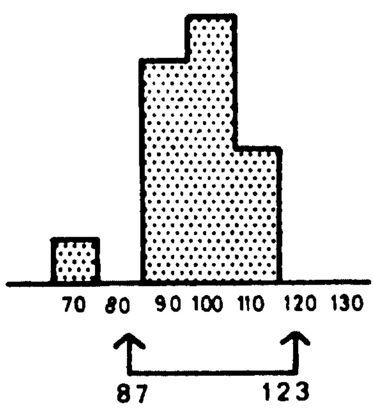
the census zone divided into ten sample units

the number of animals in each unit is shown beneath

a random sample of four units (*) is made, and the number of animals in each counted

The sample mean in this sample of four units is 10.5 animals

The sample estimate calculated from the sample is therefore 105 animals.



Results from twenty samples of four units from this same population of sample units. The average of these twenty sample estimates is 100.2 animals, which is not that far removed from the true population total of 100 animals.

The range of the 95% confidence limits of the sample estimate of 105 animals is from 87 - 123 animals.

called sample error rather than sample bias, for the average value of a large number of sample estimates will correspond very closely indeed to the true population total, while the average of all possible sample estimates will exactly equal the true population total. Fig. 1 shows that this is so, for the average value of the twenty sample estimates is 100.2 animals, and this is not very far removed from the true population total of 100 animals.

The potential magnitude of sampling error can be found from a single sample by examining the variation between the number of animals counted in each of the units selected into the sample. If this sample variance is large it means that there is also much variation between the number of animals contained in the whole population of sample units, and therefore the range of alternative estimates will also be large. If, on the other hand, the sample variance is small, then there must be less variation within the population of units, and therefore the range of alternative estimates will be small.

This range of alternative estimates is given by calculating the 95% confidence limits of the sample estimate, which is in effect a measure of its repeatability and therefore of its precision. An example of 95% confidence limits would be "four hundred animals with 95% limits of ±100 animals". This signifies that the range of 95% of the alternative estimates will lie between 300 and 500 animals. Since the average value of these alternative estimates will equal the true population total the confidence limits can also be interpreted to mean that "there is a 95% certainty that the true number of animals lies in the stated range". Fig. 1 shows the range of the 95% confidence limits calculated from the sample of four units. This range is 87 - 123 animals, and it can be seen that only one out of the twenty estimates (i.e. 5%) lies outside this range. It can also be seen that the true population total of 100 animals lies within the range. These confidence limits therefore describe the precision of the sample estimate very well.

In practical terms this means that a sample estimate with large confidence limits is an imprecise one, for the range in which the true population total might be found is large. In contrast, an estimate with narrow confidence limits is precise, for the true population total will lie in a very narrow range. Confidence limits are often expressed as a percentage of the sample estimate. For instance, a sample estimate of 1,000 animals with 95% limits of ±50% means that the true population total has a 95% chance of lying anywhere between 500 and 1,500 animals. By anyone's standards this is an unsatisfactory result. If, however, this same estimate had 95% limits of ±10% then it would be a much more precise result, and one that a wildlife manager of Park Warden would feel justified in using when planning management or conservation policies.

2.2 Calculating the Sample Mean and the Sample Estimate $\hat{Y}$

Table 1 shows the number of animals in each of the sample units in the population shown in Fig. 1. A random sample of four units has been chosen, and this will be used to make a sample estimate.

The random sample of four units consist of sample unit numbers 3, 5, 6 and 8, which contain respectively 14, 9, 10 and 9 animals. There are two steps in the calculation :-

(i) the <u>sample</u> <u>mean</u> is the average number of animals counted in each unit selected into the sample. It is found by summing the number of animals counted in each unit and then dividing by the number of units in the sample, These calculations are shown in Table 1 where the sample mean is found to be 10.5 animals.

(ii) the sample mean is then used as an <u>estimate</u> of the population mean, and an <u>estimate</u> of the population total, i.e. the sample estimate, is found by multiplying the sample mean by the total number of units in the population. The sample estimate is always referred to as $\hat{Y}$, the $\hat{}$ always indicating an estimate. From Table 1 it is seen that

$$\hat{Y} = \bar{y} \cdot N$$

therefore $\quad \hat{Y} = 10.5 \times 10 = 105$ animals

TABLE 1

Calculating the sample mean and the sample estimate, $\hat{Y}$, from a random sample of four units from the population shown in Fig. 1

(English equivalents of symbols are in brackets)

Sample unit number	1	2	3	4	5	6	7	8	9	10
Number of animals in each unit	10	16	14	12	9	10	9	9	8	3
Units chosen into the sample			*		*	*		*		

Calculations :-

Step 1. The sample mean

Total number of sample units in the population (big-N)	$= N = 10$
Number of units in the sample (little-n)	$= n = 4$
Number of animals counted in any individual unit in the sample (little-y)	$= y$
Sum of y	$= \Sigma y = 14 + 9 + 10 + 9 = 42$
Sample mean (little-y-bar)	$= \bar{y} = \frac{\Sigma y}{n} = \frac{42}{4} = 10.5$

Step 2. The sample estimate

Sample estimate, or estimated population total (big-Y-hat)	$= \hat{Y} = \bar{y} \, . \, N = 10.5 \times 10$ $= \underline{105 \text{ animals}}$

Note : The $\hat{}$ is always used to indicate an estimate. Thus, $\hat{Y}$ is an estimate of Y.

The symbol Σ means summation, or add together.

2.3 Calculating the 95% Confidence Limits of $\hat{Y}$

The calculation of the 95% confidence limits of $\hat{Y}$ is shown in Table 2. Although the calculations may at first sight appear complex, they are in fact very straightforward. There are four steps to go through :-

(i) the first step is to calculate the <u>sample variance</u> which is the expression of the variation between the numbers of animals counted in each of the units selected into the sample.

(ii) from this is calculated the <u>population variance</u> which is an estimate of the variation between all the possible sample estimates that could be made with samples of four units from this population of 10 units.

(iii) the square root of this population variance gives the <u>population standard error</u>, which is an estimate of the standard error of the mean value of all the possible sample estimates.

(iv) this population standard error is then multiplied by 1.96 to give the 95% confidence limits, i.e. the range within which 95% of the possible sample estimates will lie. The use of 1.96 is fully explained in elementary statistical texts[1] and it is considered again in Section 8.

From Table 2 the 95% confidence limits of the sample estimate $\hat{Y}$ is calculated to be ± 18 animals. This means that 95% of the possible sample estimates from this population will lie in the range

$$\hat{Y}_{higher} = \hat{Y} + 18 = 123 \text{ animals}$$

$$\hat{Y}_{lower} = \hat{Y} - 18 = 87 \text{ animals}$$

The confidence limits therefore also give the range within which there is a 95% certainty that the true value of the population total lies. The confidence limits are therefore interpreted to mean

<u>there is a 95% certainty that the true value of Y lies in the range between $\hat{Y} \pm 18$ animals, i.e. between 87 and 123 animals.</u>

TABLE 2

Calculating the sample variance, the population variance and the 95% confidence limits of the sample estimate in Table 1.

(English equivalents of symbols are in brackets)

From Table 1 :

Total number of sample units in the population (big-N) $= N = 10$

Number of units in the sample (little-n) $= n = 4$

Sample estimate (big-Y-hat) $= \hat{Y} = 105$

Step 1. The sample variance

Sum of y $= \Sigma y = 14 + 9 + 10 + 9 = 42$

Sum of y, all squared $= (\Sigma y)^2 = 42^2 = 1764$

Sum of y-squared $= \Sigma y^2 = 14^2 + 9^2 + 10^2 + 9^2 = 458$

Sample variance (s-y-squared) $= s_y^2 = \frac{1}{n-1}\{\Sigma y^2 - \frac{(\Sigma y)^2}{n}\} = \frac{1}{3}\{458 - \frac{1764}{4}\} = 5.67$

Step 2. The population variance

Population variance (Var-Y-hat) $= \mathrm{Var}(\hat{Y}) = \frac{N(N-n)}{n}{}^{*} \cdot s_y^2 = \frac{10(10-4)}{4} \times 5.67 = 84.99$

Step 3. The population standard error

Population standard error (S-E-Y-hat) $= \mathrm{SE}(\hat{Y}) = \sqrt{\mathrm{Var}(\hat{Y})} = \sqrt{84.99} = 9.22$

Step 4. The 95% confidence limits

95% confidence limits of $\hat{Y}$ $= \pm 1.96 \times \mathrm{SE}(\hat{Y}) = 1.96 \times 9.22 = \pm 18$ animals

Note : ± means "plus or minus"

$^{*}\frac{N(N-n)}{n}$ is a term that expresses the intensity of sampling, being a form of weighting; the higher the sampling intensity, the smaller this term becomes, so that if all possible units were sampled, it would become zero.

In this example the 95% confidence limits represent 17% of the sample estimate of 105 animals. The precision of this single estimate can thus be expressed as

$$\hat{Y} = 105 \pm 17\% \text{ animals.}$$

SECTION 3 RANDOM NUMBERS, RANDOM SAMPLES AND MAPS

3.1 Random Number Tables

A random number table is a list of single digits from 0 to 9 that occur in a totally unco-ordinated and random order. The two basic properties of random number tables are (i) each digit occurs with the same overall frequency, and (ii) there is no connection between the occurrence of one digit and the occurrence of a neighbouring one. From this it follows that the digits may be combined into sets of any length to give random numbers of any size.

Tables of random numbers occur in many different shapes and sizes. To use the random number tables, first choose any starting point (e.g. page three, row four, column 2) and then decide whether to go down a column or along a row. These two decisions must be made before looking at the numbers. Then, write down the numbers from the table in the order in which they occur. These rules must be followed quite mechanically.

For example :-

(i) to choose ten random numbers between 00 and 99
choose a starting point in the way described and write down the first ten numbers in the order in which they occur.

(ii) to choose five random numbers in the range 35 to 73
choose a starting point and write down the numbers as they occur, but disregard any that are less than 35 or more than 73.

(iii) three digit numbers.
If three digit numbers are required, e.g. in the range 00 to 120, then follow the same procedures only write down the digits in groups of three. If going down a column, the pair of digits in the column would be grouped with the first digit in the neighbouring column, while if going along a row the digits are simply written down in groups of three. Larger numbers, e.g. with four or five digits, can be found in the same way.

3.2 Simple Random Samples

Most sampling is carried out using a simple random sample without replacement. The requirements for such a sample are

(i) each sample unit in the population has an equal chance of being chosen

(ii) all possible combinations of sample units in a sample of a given size are equally likely to occur

(iii) any individual sample unit may occur only once in a sample.

This type of sample is often referred to as equal probability sampling without replacement, and the requirements are met by first numbering each of the sample units in the population, then using tables of random numbers to select the required number of units into the sample. Each number, and therefore each unit, has an equal chance of being chosen (requirement (i)), and all possible combinations of numbers, and therefore of units, are equally likely to occur (requirement (ii)). The third requirement, no replacement, is met by simply discarding a random number if it turns up on a second or subsequent occasion.

3.3 Choosing Random Points along a Line

An example here would be to locate ten points at random along a transect line of 6 km drawn in on a map. It is usually impossible to locate a point along a line with an accuracy greater than about 100 metres, so consider the transect line to be made up from 60 units of 100 metres in length. There are therefore 60 points (counting the starting point as 00) on this line, and ten of these have to be chosen at random. This problem is the same as choosing ten random numbers in the range 00 to 60. The procedures outlined are followed, any number greater than 60 being discarded, and any number in the range being discarded if it turns up on a second or subsequent occasion. One end of the transect must be designated as point 00, and the numbers chosen are then located along the transect line, each being in multiples of 100 metres. For example, if random number 13 had been chosen, the point would be located 1300 metres along the line from point 00.

3.4 Choosing Random Points in Space

Fig. 2 shows an oddly shaped area in which it is required to locate a number of random points. The first step is to set up a pair of axes at right angles to each other and long enough so that each covers the whole of the area. These lines form the x-axis (horizontal) and y-axis (vertical) of a grid co-ordinate system. The two axes must then be divided into convenient intervals, for example intervals of 100 metres as in the last example. Tables of random numbers are now used to choose pairs of random numbers. The first of a pair gives the location of the point along the x-axis while the second gives the location along the y-axis (Fig. 2). Each point is plotted on a map by locating it along the two axes, being discarded if it falls outside the area. Pairs of random numbers are drawn until the required number of points have been located within the area.

3.5 Maps

Maps are necessary for any census work and it is important to become well acquainted with the meaning of different map scales. This is especially important when locating sample units and when measuring areas. If an area measured on a 1 : 50,000 scale map is treated as if it were from a 1 : 250,000 map, an error of times 5 would result, which would lead to some very curious sample estimates.

The scale of a map relates a distance on the map to a distance on the ground. A scale of 1 : 250,000 means that one unit measured on the map will represent 250,000 units on the ground. Thus, a transect of 2 cm measured on a 1 : 250,000 map represents 2 times 250,000 = 500,000 cm on the ground, i.e. 5 km. Similarly, a line of 1 km on the ground will be 1/250,000 km = 0.04 km = 4 mm on a map of this scale.

In many Sample Counts the area of a census zone, or sometimes the area of each sample unit, has to be known, and this can only be measured from a map. The best way of doing this is to use an instrument known as a planimeter which measures area directly when the 'arm' of the instrument is run around a boundary. An area of known size must first be marked in on the map by drawing it to scale (e.g. a circle with a known radius, or a square with carefully measured sides). A number of measurements are then made with the planimeter of this known area, giving a calibration of the instrument for that map. A number of measurements are then made of the census zone, the average reading from the known area being subsequently used to calculate the area of the census zone.

The procedure for measuring the area of a census zone on a 1 : 250,000 map would therefore be as follows :-

(a) carefully draw a square with sides of 2 cm. This therefore represents an area of 5 x 5 km = 25 km^2 on this scale of map.

(b) make a number of measurements of the sides of this square with the planimeter, recording each measurement as it is taken. Take the average of these measurements and call it A.

(c) similarly make a number of measurements of the census zone with the planimeter, take their average, and call it a'.

(d) since A units measured on the planimeter represent 25 km^2, the area of the census zone is found by

$$\text{area} = \frac{25}{A} \cdot a' km^2$$

(e) repeat steps (a) through (d) two more times, and average all the results.

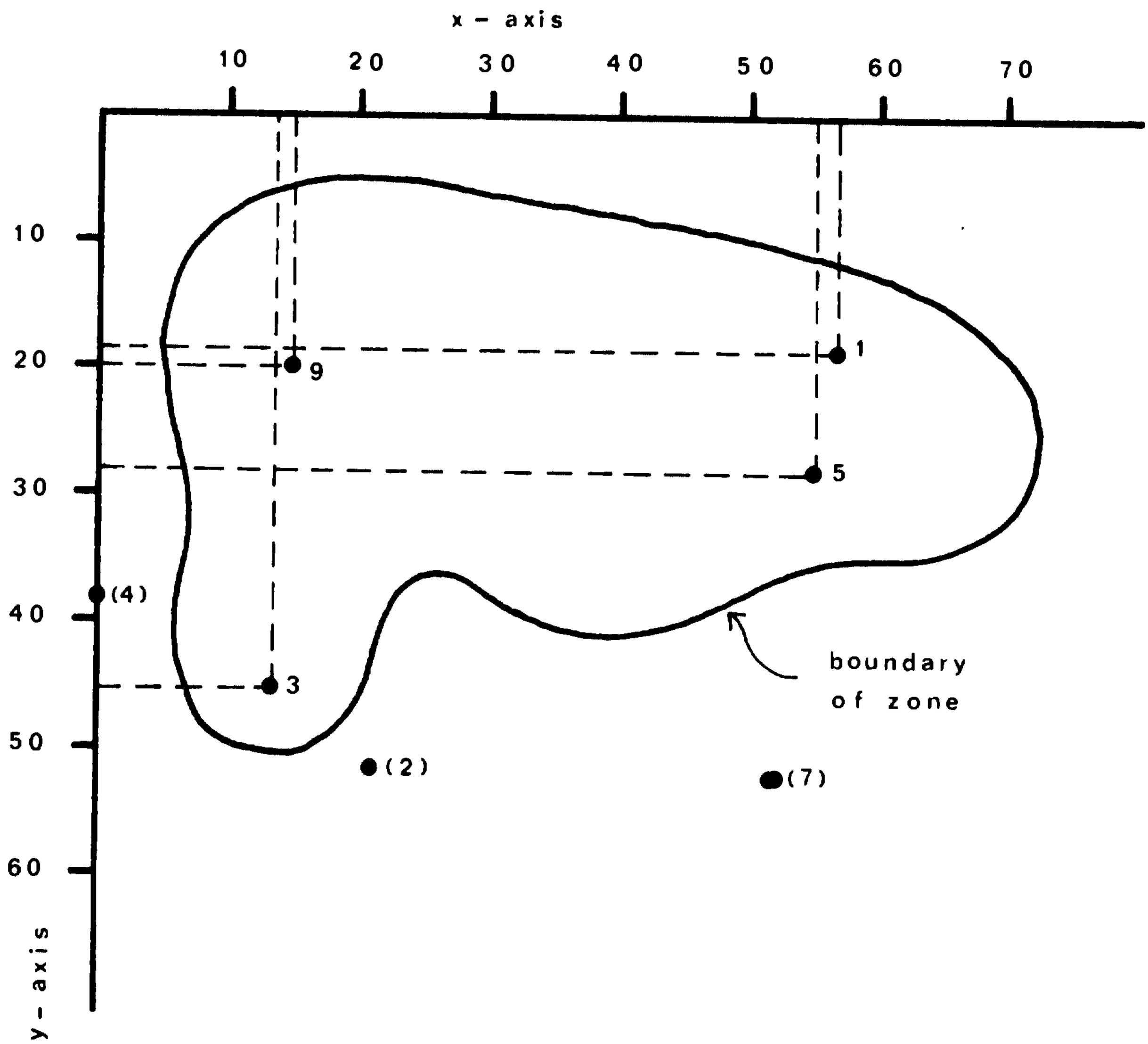
If a planimeter is not available there are a number of more or less accurate alternatives. One method is to make a number of tracings of the census zone on paper of the same thickness. Alongside each tracing a square of known area is drawn in. This square, and the census zone, are then very carefully cut out and weighed on a fine balance. The area of the census zone can then be found from the average weights of the square of known area. Thus :

let W be the average weight of a square of known area, A km^2

w' be the average weight of the census zone

then, area of census zone = $\frac{A}{W} \cdot w' km^2$

Fig. 2 Choosing random points in space



The x-axis and y-axis have been divided into units of 100 metres. The two axes are at right angles to each other and cover the whole of the census zone (solid boundary). Pairs of random numbers are chosen and the points are located along the two axes.

Point	random numbers x-axis	random numbers y-axis		
1	56	19	falls inside the zone and is	included
2	21	52	outside	excluded
3	13	45	inside	included
4	00	38	outside	excluded
5	55	28	inside	included
6	03	75	outside	excluded
7	49	52	outside	excluded
8	56	86	outside	excluded
9	14	20	inside	included

Another method is to use an 'area calculator' or 'dot grid'. This is a transparent sheet with a regular array of small black dots upon it. A square of known area is marked on the map and the dot grid is placed over it. The number of dots falling within this area is counted, and a number of such counts are made. The same process is then carried out on the census zone. The area of the census zone is then found by

let D be the average number of dots counted within a known area of $A\ km^2$

d' be the average number of dots falling within the census zone

then, area of census zone = $\frac{A}{\bar{D}} . d' km^2$

SECTION 4 METHODS OF AERIAL SAMPLE COUNTING

4.1 Introduction

Aerial sample counting is now a very frequently used method of counting large mammals. The next six Sections are devoted to various aspects of the methodology. It is however, important to realise that the principles outlined here apply equally well to other methods of sample counting, either from vehicles, on foot, or by indirect methods (e.g. spoor counts, pellet counts, capture-recapture methods).

4.2 Aerial Transect Sampling

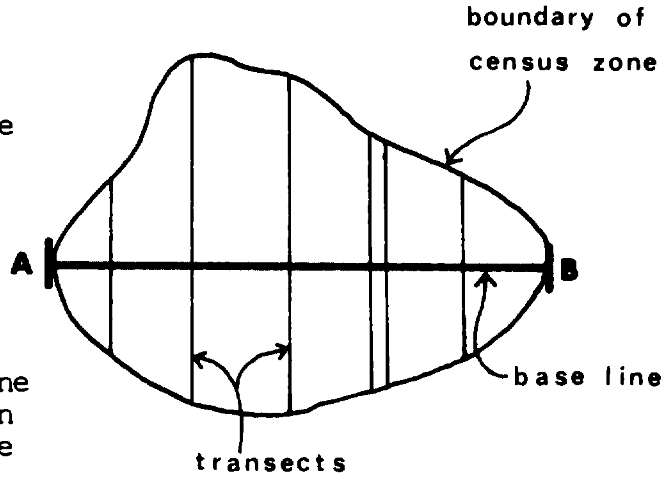
The aerial transect method is the most popular type of sampling method employed. The principle is that the aircraft flies in a straight line from one side of the census zone to the other at a fixed height above the ground. Streamers are attached to the wing struts of the aircraft so that the observer sees a strip demarcated on the ground. The width of the strip can be decided in advance and the streamers positioned so that the desired width is obtained (Section 5). The transects are the sample units, and the observer counts all the animals that he sees between the streamers.

The sample units are located by drawing in a base-line on a map of the census zone (Fig. 3). This base-line is divided into sections of the same length as the width of the chosen transect strip. If, for example, a 300 metre strip is being used, then a 60 km base-line would be divided into 60/0.3 = 200 units. The required number of transects are then located by choosing random numbers in the range 00 to 200 and locating these points along the base-line. The transects are then run through these points at right angles to the base-line, the line of each transect being drawn in on the map to aid navigation.

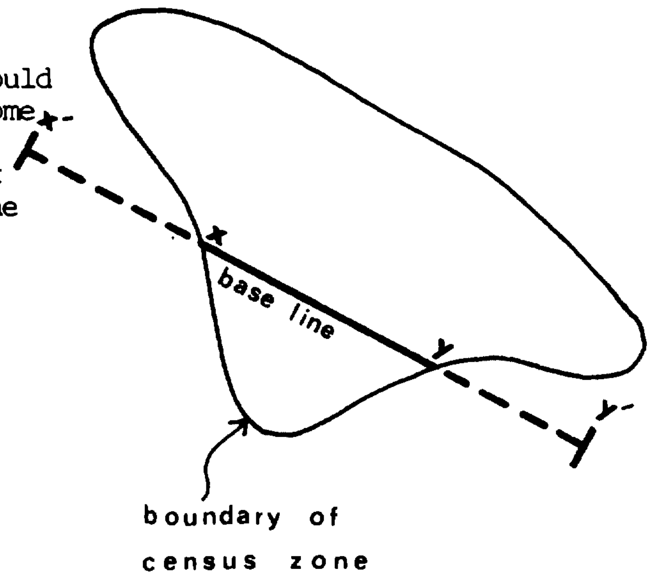
The base-line must be made long enough so that transects passing through it can 'cover' all parts of the census zone. The x---y base-line in Fig. 3 could not be used, for large portions of the census zone could not be crossed by transects. If it was necessary to have the transects in this particular orientation then the base-line would have to be extended to x' --- y'. Of course, only

Fig. 3 Locating the transects along a base-line for aerial transect sampling.

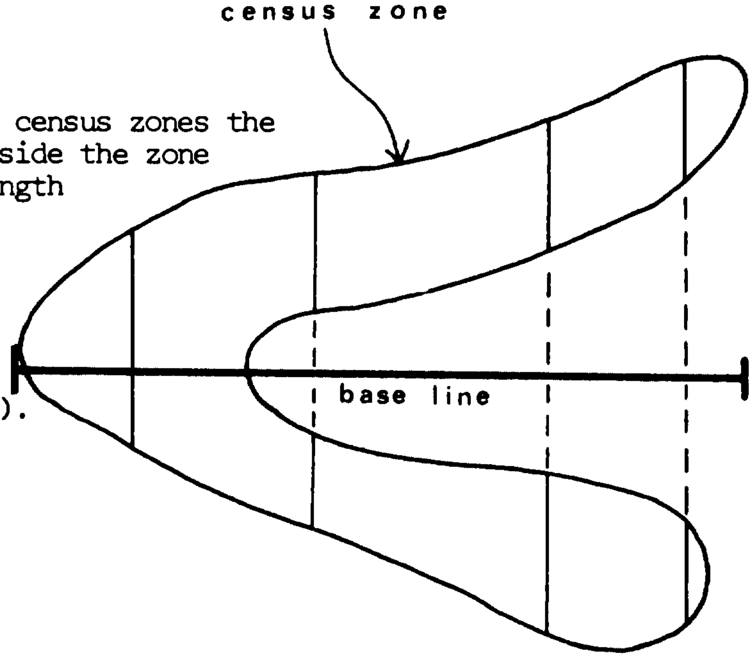
a) the base-line A - - - B is made long enough so that it covers the whole area of the census zone. Random points are located along it, and the transects pass through these points at right angles to the base-line. The transects pass from one side of the census zone to the other. All animals seen within the demarcated strip are counted.



b) this base-line x --- y would not be long enough for some areas of the census zone could not have a transect passing through them. The extended line x' --- y' would be long enough.



c) in very oddly shaped census zones the transects may be outside the zone for some of their length (dotted portions). Animals are only counted along those parts of the transects that lie within the census zone (solid portions).



those portions of the transects passing through the census zone would be flown along. Similarly, the base-line must not be so long that transects can pass outside the census zone.

The transects can all be of different lengths if necessary, and it is in fact rare to find a census zone that does not dictate transects of different lengths. In the oddly shaped census zones (e.g. Fig. 3) the transects may even pass out of the zone and then into it again. In this case the aircraft has to fly along the whole length of the transect, but animals are only counted within the census zone.

The two main characteristics of aerial transect sampling are therefore (i) the transects are parallel to each other and cross the census zone at random points along a base-line, and (ii) the aircraft flies once down each transect line and the observers count all animals seen between the streamers. Examples of transect counts are given in various publications[3,38,41,49].

4.3 Aerial Quadrat Sampling

Quadrat sampling is much used in the United States of America but does not seem to have received much attention in Africa. The sampling units are quadrats, e.g. rectangles, that are located in some suitably random fashion within the census zone. Most usually the quadrats are square in shape[4,18,50], although rectangular shaped quadrats have been used[22]. The procedure used by most authors is to divide the whole census zone into grid squares of appropriate size (e.g. 2 x 2 miles, or 1 x 1 mile) and select some of these grid squares to search. The selection is most simply done by numbering the squares from 01 to N, then choosing the necessary number of random numbers in this range. A slightly different method has been employed whereby quadrats have been constructed from random points located in space[22].

Once the selected quadrats are marked in on a map of the census zone, the aircraft visits each one in turn and locates and counts every animal within them. The aircraft can spend as long as is necessary in counting each quadrat.

4.4 Aerial Block Sampling

Block sampling is very similar to quadrat sampling except that the sample units are blocks that are demarcated by physical features present on the ground (e.g. rivers and streams, roads and tracks, hills, ridge tops, edges of woods etc.). A sample of blocks is chosen by locating random points in space, then counting those blocks in which a random point falls. Alternatively, the blocks can be numbered from 01 to N and the required number of random numbers drawn.

Although the use of blocks as sampling units is sometimes mentioned in passing[27] it is surprising to find that they have never been used in practice for an aerial sample count. They are often used in total aerial counts (Section 9), and they are often used in ground sample counts (Section 10), and they are sometimes used as a method of checking the accuracy of transect counts[38]. This is surprising, for blocks have many advantages over quadrats as sampling units (see below).

4.5 Comparisons Between the Three Methods

(i) Costs

Transects have the great advantage over blocks or quadrats in that the aircraft is operating at maximum efficiency when flying in a straight line. This shows in two ways (Table 3). Firstly, the aircraft never retraces its track or backtracks and consequently the rate at which the ground is covered is higher than for blocks or quadrats. Secondly, as the transects are parallel to each other, and as the transects usually tend to be near to each other, the proportion of "dead time' (i.e. the time spent by the aircraft in travelling from one sample unit to another) is low.

(ii) Navigation

Navigation is considerably easier with transects, for the pilot has only to follow a straight line on a map and then need only locate the starting point of the next straight line. Both blocks and quadrats have to be searched for and the boundaries identified precisely. This is often extremely difficult to do, especially with quadrats located in featureless country. With no physical mark on the ground, it is often impossible to decide exactly where the quadrat should be[18] and this can only lead to errors that are

TABLE 3

Comparisons between the efficiency of transect, block and quadrat sampling.

Animal(s) counted	Method used	Rate of covering the ground (km^2/hr)	Percentage of flying time in transit between sample units
caribou[50]	quadrats	18	86%
moose[18]	quadrats	10	42%
moose[4]	quadrats	4	not given
rhinoceros[22]	quadrats	13	not given
elephant and others[38]	blocks	58	30%
	transects	78	12%
multi species[48]	transects	67	17%
multi species[61]	transects	58	12%
multi species[60]	transects	117	not given
lechwe[3]	transects	29	c.10%
multi species in Kenya, 1972	transects	102	20%

impossible to gauge.

(iii) Boundary effects

All three methods suffer from boundary effects to some extent in that it is always difficult to decide whether or not an animal is inside or outside the sample unit. In transect counting the rule is that the observers count any animals seen within the streamers whatever the aircraft happens to be doing. It is immediately apparent that the width of the demarcated strip depends upon the pilot maintaining strict height control and strict bank control. In Section 6 methods for doing this are discussed in some detail. Nonetheless, the observer does have a physical mark in the form of the streamer to indicate whether or not an animal should be counted. In quadrat sampling this problem is very acute for there is no physical mark of any kind by which the observer can make this decision. This again can only lead to errors whose magnitude it is impossible to gauge. The situation is better with block counting for the boundaries of the blocks are made up from physical features, ensuring simplicity in deciding whether or not an animal is inside the block. However, many 'natural' boundaries (e.g. rivers and streams) tend also to be habitat edges across which there is often considerable movement.

(iv) Counting

The great disadvantage of the transect method is that the observers have only one chance to locate and count groups or individuals because the aircraft makes only a single pass along each transect line. In block or quadrat sampling the aircraft can make as many passes as required in order to locate and count all groups. There are disadvantages in that great care must be taken to avoid double counting and to ensure that all the area is indeed searched. These problems are also considered in Section 6.

Unfortunately there are no well controlled experiments in which block or quadrat sampling have been tested against transect sampling. Some authors have attempted it but in such a way that the results appear meaningless. For example, in one study a comparison was made between the density of moose counted in intensively searched 1 x 1 mile quadrats with the density found when counting a transect strip of ½ mile. As a strip width greater than ½ mile is normally far too wide for effective counting (but see pp. 30 and 40), it was not surprising to find that the transect densities were considerably lower than the quadrat densities. In one study where block counts were used as a check against transect counts, the results were not found to be statistically different, even though the blocks were being searched more intensively[38]. In this case both counts were being carried out in a sensible fashion.

There are certain conditions under which the transect method does not work at all well. For example, when the ground is very broken and when there are many gullies and rocky outcrops; or, of course, when the vegetation becomes very thick; or when the country is very mountainous. In the first two cases animals can only be located by intensive criss-crossing and 'buzzing' with the aircraft. In the last case (very mountainous country) the problems of height control make the transect method ineffective.

(v) Sample error

Sample error, as has already been pointed out, is caused by animals clumping together instead of spreading out uniformly. Transects tend to reduce the effect of this clumping while blocks or quadrats tend to accentuate it. The reasons for this are rather obscure and technical, although a simple explanation is given in Fig. 4 (Section 5). In practical terms this means that for the same effort (either cost or amount of ground covered) transects will give a more precise estimate than either blocks or quadrats.

(vi) Fatigue

Flying along in a straight line is much less tiring than constantly criss-crossing, backtracking, making steep turns etc. This may seem to be a relatively minor point, but it should be remembered that tired pilots do not concentrate or fly very well, and tired and/or airsick observers do not count very well.

In general, therefore, the transect method is superior to quadrat or block sampling in terms of cost, navigation, boundary effects, sample error and fatigue of crews. All three methods have problems with counting animals, with none of them appearing to be any better or worse than the others. The transect method becomes ineffective in very broken country, when the vegetation is very thick and/or patchy, and when the country is very mountainous. In these cases some form of block sampling would be preferable to quadrat sampling because of the advantages over boundary effects.

SECTION 5 DESIGNING AN AERIAL SAMPLE COUNT

5.1 Introduction

Although there are theoretically many different ways to design an aerial sample count, practical considerations fortunately limit the options to a few well tried and trusted methods. This Section considers some of the more important factors in a reasonably logical sequence from a very practical viewpoint. First, the census zone must be defined, which in some situations is not particularly easy to do; then the 'best' method must be chosen; next sample error must be considered, and it will be seen that there are some simple techniques for reducing sample error at the design stage without increasing the costs of the census; then, the sources of bias and errors must be identified and steps taken to minimise them; finally costs must be taken into account. It is not possible to say which of these is the most important, for this will vary from area to area, from animal to animal, and will also depend upon resources. For example, a biologist might be given unlimited funds to obtain an estimate with 95% confidence limits of not more than 10% of the estimate. His approach, in this fortunate position, would be very different from that in which he had been allocated a certain amount of money and told to do 'the best he could'.

5.2 Defining the Census Zone

The census zone, already defined on page 9, is the area within which you wish to estimate the number of animals. If this happens to be a defined area such as a National Park, a Game Reserve or a study area then the boundaries of the census zone are simply those of the particular area. If, on the other hand, the objective is to estimate the number of animals in a certain population, then the census zone must be defined by the area occupied by that population at the time that the census is carried out. This requires quite detailed knowledge of the movements and distribution of the population concerned, otherwise serious errors could result. Examples of how to use this type of information to define the census zone are available[3,37,49]. In Serengeti, for example, the problem was to estimate the number of animals in the migratory wildebeest population[37]. This population moves over a vast area in the course of a year but at any one time occupies only a small fraction of the total area. Systematic surveys were used to locate the population on the basis of which information it was possible to define a census zone that contained all the animals.

The size of the census zone must be kept within reasonable limits otherwise the census becomes unmanageable. It has been our experience that 10,000 km^2 is about the largest area that can be reasonably treated as a single zone, and areas larger than this should be split up in some way and sampled as separate entities. This is one application of what is known as stratification, which will be dealt with in more detail in Section 5.4.

5.3 Choosing a Sampling Method

The decision to be made here is between transect sampling and block sampling, quadrats being ignored because of the difficulties of locating the boundaries on the ground. The relative advantages of these two methods have already been discussed in the previous Section. For the reasons given there, and for additional reasons given later in this Section, transect sampling should always be used except in the following situations :-

(a) If the animals occur in very large and conspicuous herds (e.g. buffalo) block sampling - or perhaps even total counting - is preferable because a very wide searching strip can be used. For example, in block counts of buffalo in open savannah woodlands, the ground can be covered at a rate of 240 km^2 per hour using a strip of about 1.5 km in width. This is a much higher rate of ground coverage than with transect sampling, and it is only possible because the observers have to search for and locate large herds rather than individual animals. Once a herd is located the aircraft can divert to the herd in order to count it.

(b) If the country is very broken (e.g. with many rocky outcrops or ravines) or if the vegetation is very thick and/or patchy, block counting is preferable because these difficult areas can be searched particularly intensively.

(c) If the country is really mountainous, with precipitous valleys and high mountain walls, transect sampling is downright dangerous. It is sheer madness to try to fly a light aircraft in a straight line close to the ground under these conditions. In addition, the inevitable massive variations in flying height over this sort of country would produce unacceptably large biases that would be difficult to correct for. Block counting would have to be used instead.

5.4 Reducing Sample Error

The main cause of sampling error is related to animals not being evenly distributed over an area. This means that the sample units will tend to have different numbers of animals in them, chance thus selecting a set of units into a sample that will give one population estimate out of a whole range of possible population estimates. Sampling error is more aggravated the more bunched - or aggravated - the animals are, for this leads to a bigger variance between the numbers found in each unit. Sampling error can only be reduced by minimising the effect of this clumping. The strategy, therefore, is to create at the outset - i.e. at the census design stage - a population of sample units that has as low a variance as possible. All the points mentioned below are discussed in great detail in general texts[13,66].

(i) the shape and size of sampling unit

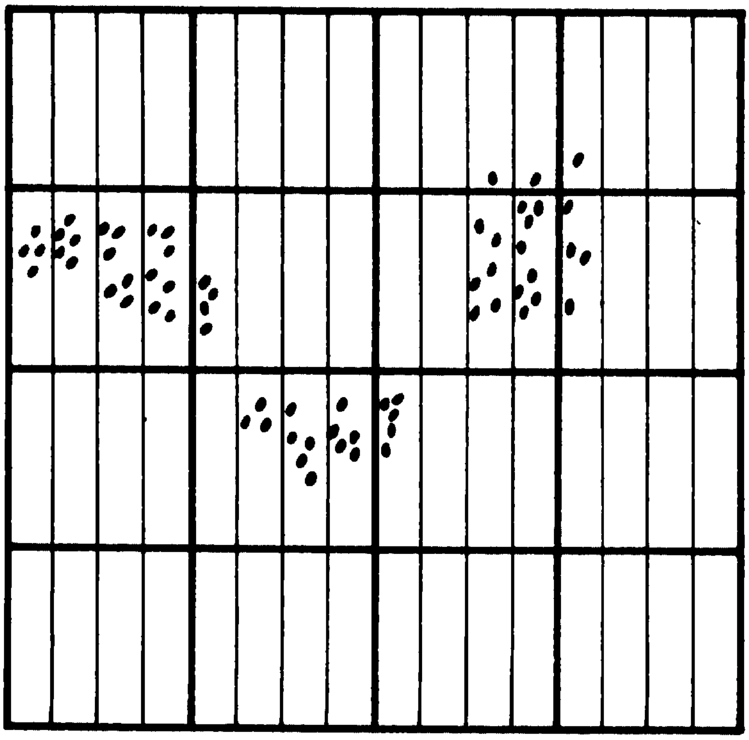
Some types of sampling units will always give a higher variance, and therefore higher sampling error, than others. Fig. 4 shows a census zone which has been divided up into sixteen transects and sixteen quadrats each of the same size. Each dot in Fig. 4 represents the location of an animal, and it is immediately obvious that the quadrats have an 'all-or-nothing' effect, i.e. they either contain many animals or none, while the transects all tend to have roughly the same number of animals in them. The population of quadrats is therefore more variable than the population of transects, and sample error will therefore be higher with the quadrats than with the transects. This is also shown in Fig. 4. The variance of the quadrats (43) is very much higher than the variance of the transects (8), and the effect of this on sample error is demonstrated by the results of three random samples of 25%, 50% and 75% of the sample units. The 95% confidence limits of the transects are always less than those of the quadrats.

A population of blocks will, if anything, intensify the aggregations of animals, blocks thus tending to have an even higher variance than quadrats. This demonstrates the great advantage of the transect method of sampling, for transects have an inherently low sampling error.

The reason for this is slightly obscure but can be explained as follows. Each of the quadrats in Fig. 4 only collects 'information' about the density of animals in a small, localised part of the census zone. In contrast, each of the transects collects 'information' across the whole census zone. It is obvious that the more information you have about a census zone the less room there is for error. Accordingly, since transects collect more information than quadrats, they must lead to a smaller sampling error.

One general rule of sample theory is that for a fixed amount of material to be sampled, a lower sampling error will be achieved if many small units are counted rather than a few larger ones. In other words, 50 blocks of one square kilometre each will give lower confidence limits than will 25 blocks of two square kilometres. This follows from the previous paragraph, for the fifty small blocks will collect much more information than the twenty-five larger ones, and therefore sample error can but only be smaller. Unfortunately it is not always possible to follow this advice because many small sample units are inordinately expensive to count while fewer and larger units cost much less. For fixed costs, therefore, a lower sample error will be achieved by counting larger units than smaller units. Although this may seem to contradict the first statement in this paragraph, on close examination it will be seen to be a logical consequence of it. Some compromise must therefore be reached between the size of unit, the number to count, and the costs of counting each one. Publications are available which indicate ways and means of doing this[13,66]. However, in aerial sampling, practical considerations in terms of maximising the efficiency of the aircraft

Fig. 4 The effect of different shapes of sampling unit on sample error. A census zone has been divided up into 16 equal sized sampling units, either transects or quadrats.



95% confidence limits from samples of different sizes

	s_y^2	size of sample 25%	50%	75%
transects	8	59%	48%	34%
quadrats	43	136%	112%	78%

and the observers outweigh statistical considerations leaving relatively little room for manoeuvre.

With block or quadrat sampling it is most efficient to have the unit of a size that can be counted in one flight of two to three hours duration. Reducing the size of the unit has a very dramatic effect on costs. The amount of dead time, i.e. time spent flying from one unit to the next, becomes very high, and the amount of time spent locating the boundaries is proportionally higher with smaller units than with larger ones. An extreme case of the expense of counting very small units is given by an unsuccessful census of gazelle in the Serengeti. The idea was to take a large number of photographs of gazelle at random locations across the Serengeti Plains. Some 600 photographs were taken, in about ten hours flying. Since each exposure was taken at a 1/1000 sec., the aircraft was collecting information for about half of one second during the entire ten hours flying. This is not an efficient method of using an aircraft.

In transect sampling there is more freedom of choice. Theoretically, the size of the unit can be altered by altering the strip width, but here considerations of counting bias are more important, and the strip width should always be chosen to minimise this source of bias (see 5.5 below). However, the size of the unit can be altered by altering the length of the transect. In a rectangular census zone, a lower sample error will be achieved for the same amount of flying by running the transects across the shorter dimension. In this way the same amount of material will be sampled in many small units rather than fewer larger ones. Of interest here is the fact that the costs will be exactly the same, another advantage of transect sampling. Sample error can also be reduced by paying attention to the orientation of the transects. Fig. 5 shows a census zone with a river running north-south and the animals distributed along the river line. Transects running east-west, i.e. across the density gradient, will give a lower sample error than transects running north-south, for the east-west transects will all tend to contain the same number of animals. In practical terms this means that transects should always be oriented at right angles to the major drainage systems within a census zone, for animals tend to be distributed along such systems.

To summarise what has just been discussed we can say the following :-

* a population of transects will have a lower variance than a population of blocks or quadrats, and will therefore lead to lower sampling error.
* the transects should be oriented across the shorter dimension of a census zone, and should also run at right angles to the major drainage systems.
* when block counting, avoid really small blocks (because of expense) and really large ones. The most efficient size is one that can be counted in two to three hours flying.

(ii) sample size

In general terms the larger the sample size, i.e. the more units that are counted, the lower will be the sample error. This is a fairly obvious statement for as more of the population is sampled so more information is gained about the census zone, therefore there is less room for error. However, sample error is not reduced proportionally with increasing sample size. The general form of the relationship is shown in Fig. 6 in which the 95% confidence limits of $\hat{Y}$ (expressed as a % of $\hat{Y}$) are plotted against increasing sample size. At first there is a rapid decrease in sample error with an increase in sample size, but after a point the decrease falls off until very large increases in sample size produce negligible reductions in sample error. Also shown in Fig. 6 are the confidence limits for different numbers of hours flying, in other words for different costs, and this shows perhaps more clearly how the increase in precision of the estimate falls off with increase in sampling effort.

Curves of the sort shown in Fig. 6 can be used in different ways. Firstly, they can show the most efficient sample size in terms of cost. This is defined as the point on the curve where any further increase in effort is not repaid by even a proportional increase in precision. Although this point can be calculated exactly, it is simplest just to look at the curve and note the point where it begins

Fig. 5 A census zone with a river running through it. The animals are distributed along the river edge. Sample error will be less if the transects are oriented west-east than north-south.

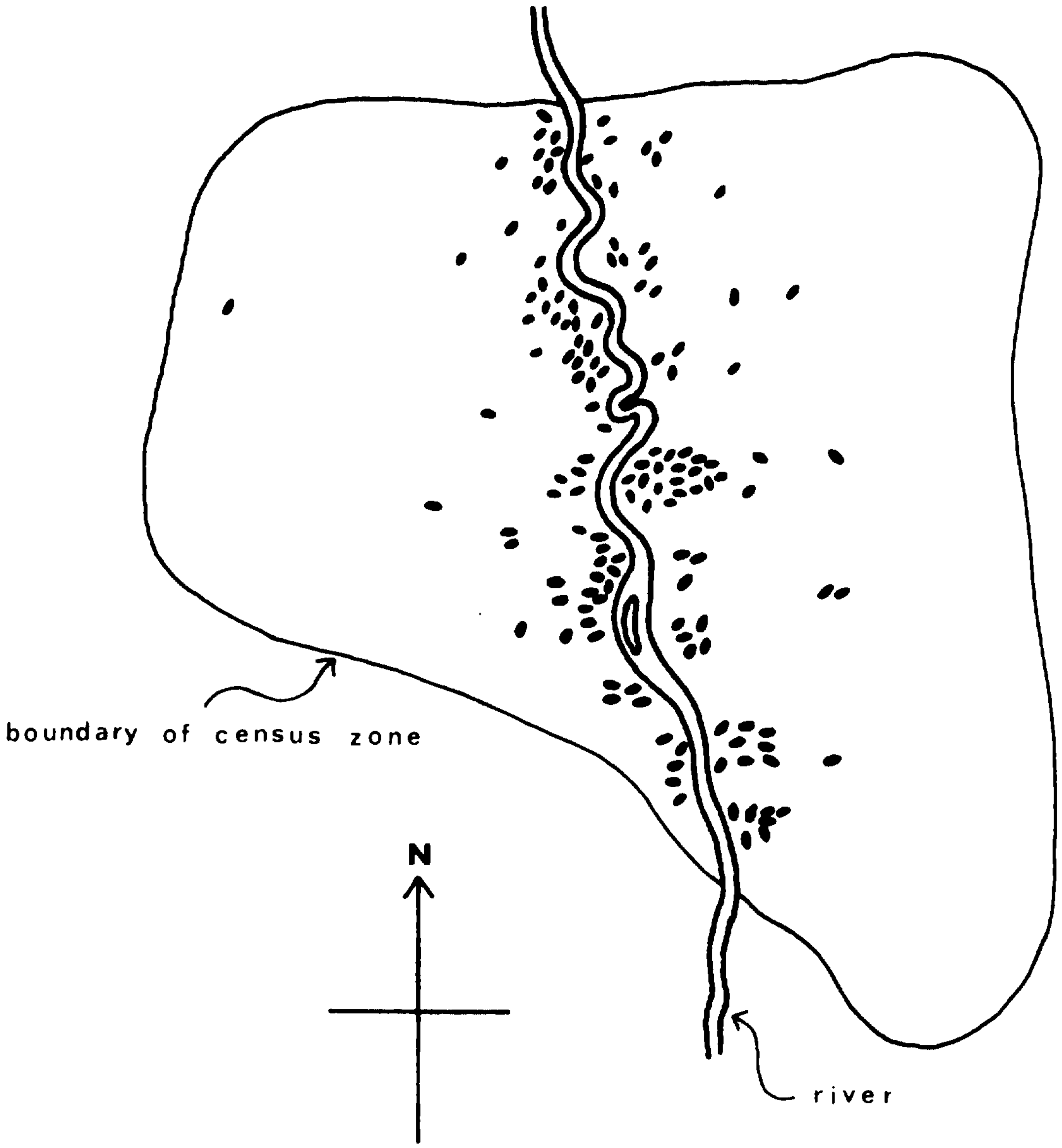
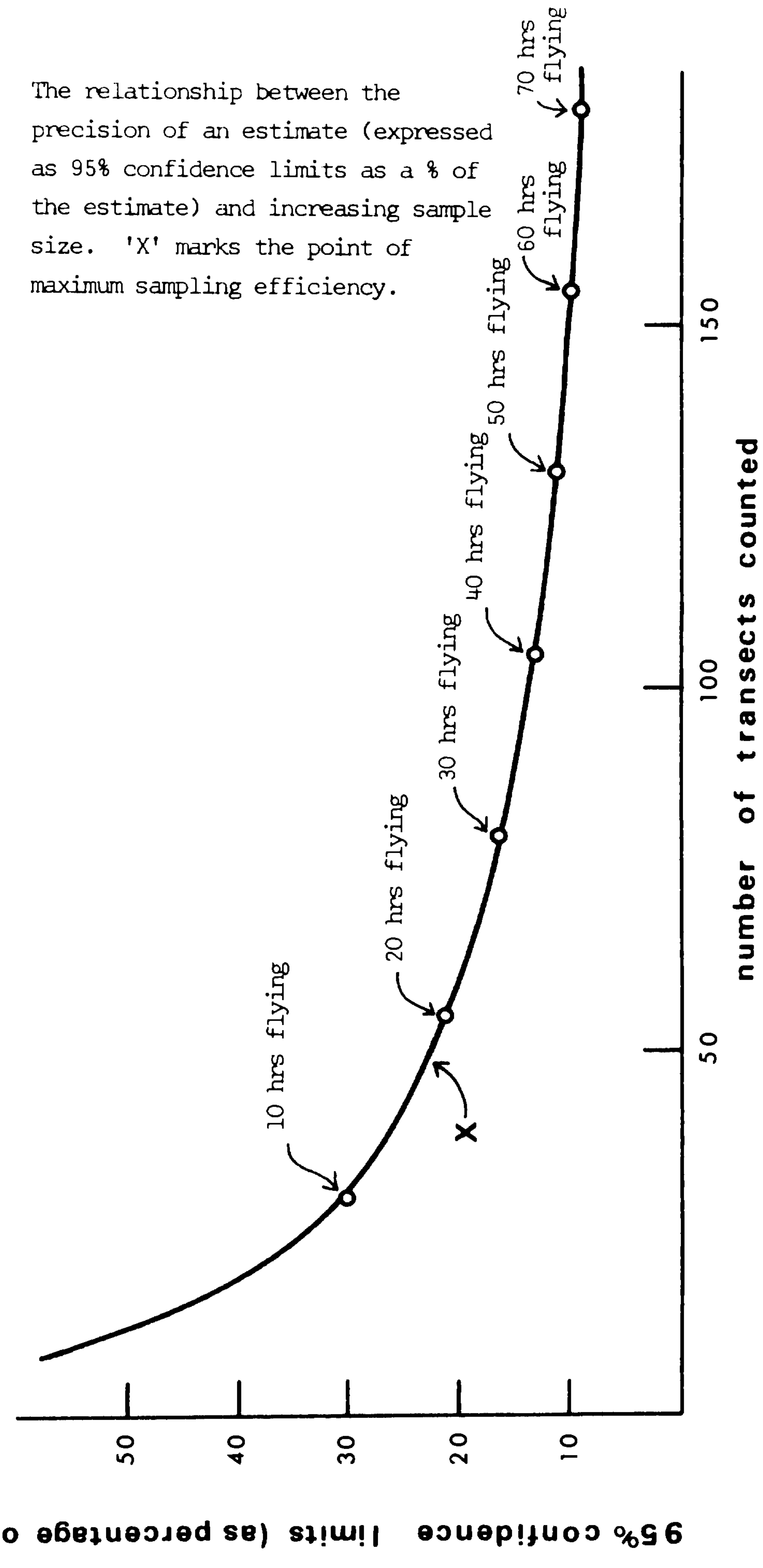


Fig. 6 The relationship between the precision of an estimate (expressed as 95% confidence limits as a % of the estimate) and increasing sample size. 'X' marks the point of maximum sampling efficiency.



to 'flatten out'. In Fig. 6 this point is marked by 'X', representing about 52 transects costing some 19 hours flying, which will give an estimate with a precision of about 21%. Alternatively, Fig. 6 could be used to find out how many transects, and how much cost, will be required for any stated precision, or conversely what the precision is likely to be for any given cost. Curves like this are really very useful.

Fig. 6 was constructed from data obtained during an aerial transect count of elephant in Ruaha National Park, Tanzania. It was used to decide how many transects to fly in a subsequent census being constructed in the following way. From Table 2 we see that

$$\begin{aligned} \text{95\% confidence limits of } \hat{Y} &= 1.96 \times SE(\hat{Y}) \\ &= 1.96 \times \sqrt{Var(\hat{Y})} \\ &= 1.96 \times \frac{N(N-n)}{n} \cdot s_y^2 \end{aligned}$$

Knowing N and s_y^2, the curve is calculated by substituting different values of n in the equation, and then plotting the 95% confidence limits (expressed as a % of $\hat{Y}$) against n. This is fine so long as you have an estimate of s_y^2, but it becomes slightly tricky if you do not. Two ways around this are to (a) go out and count a few transects in order to get a rough estimate of s_y^2 (this could be done as part of an observer training programme), or (b) use data published from different areas where the density of animals is roughly the same as in your area. N is simple to calculate. For transect counting it is found by dividing the length of the base-line by the strip width, while with block counting it is simply the number of blocks into which the census zone has been divided.

The actual shape of the curve will depend upon s_y^2. If this is small then the increase in the precision of the estimate increases very rapidly with increasing sample size, then falls off very rapidly. If s_y^2 is large, then the increase in precision is less marked, and there is a less marked fall off.

If absolutely no information can be obtained about an area before a census, then as a general rule of thumb avoid very small samples (less than ten) and very large samples (more than fifty).

It is always important to remember that sample error is not reduced by the percentage of units that are sampled but by the number of units that are sampled. It is often instructive to carry out the calculations mentioned above on data given in published accounts of censuses. In one recent, and nameless, paper the authors were obviously extremely proud at having put in a great deal of effort and expense to count a large number of transects. I calculated that with exactly one half of the effort the precision of their final estimate would have been only 3% less. To my mind they wasted a lot of money.

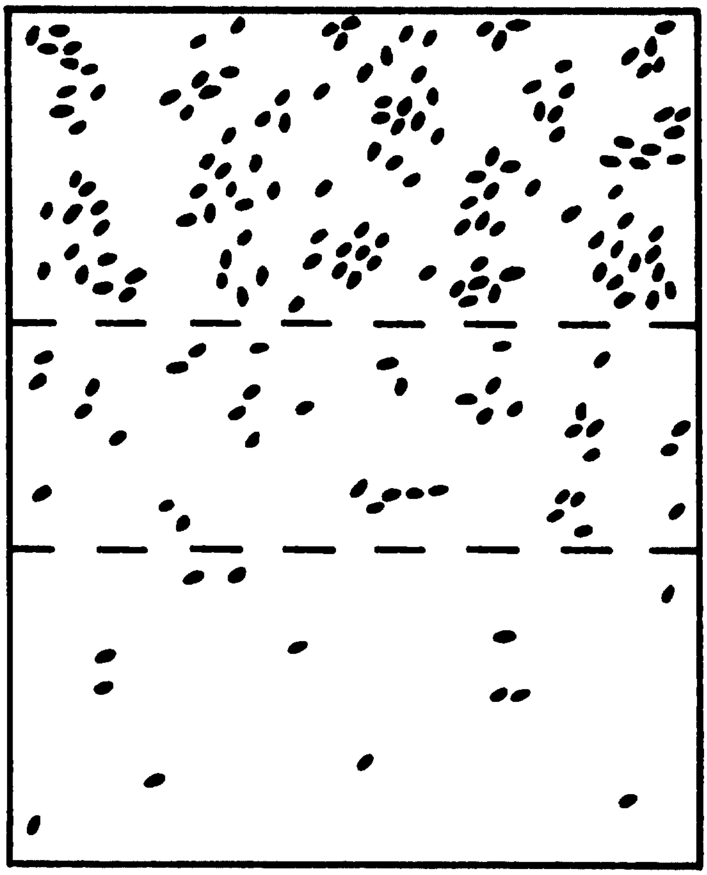
(iii) stratification

The principle of stratification is to divide a census zone into sub-zones, or strata, in which the density of animals is approximately uniform. Independent samples are then taken within each of the strata, the results being combined later. In Fig. 7 a census zone is shown in which there are very obvious differences in animal density. If sampled as a single zone the population of sample units would have a very high variance and therefore sample error would also be high. By dividing it, as shown, into three strata on the basis of density, each stratum is more uniform within itself than is the whole census zone. The population of sample units within each stratum will therefore have a low variance, and the overall sampling error will be reduced.

The problem now is to allocate the sampling effort between the strata. In general terms a stratum with a high variance should receive more sampling effort than a stratum with a low variance. Since the variance within a stratum will be directly proportional to the density of the animals in the stratum, sampling effort should be allocated on the basis of animal density. This procedure is shown in Fig. 7 where the densities in each stratum are taken to be 10, 5 and $1/km^2$ respectively. Sampling effort would thus be allocated in the ratios 10/16, 5/16 and 1/16, i.e. 62.5%, 31.25% and 6.25% respectively.

Once the sampling effort has been allocated then completely independent samples must be drawn within each of the strata. When transect sampling, this will entail constructing a different base-line within each stratum, while with block sampling different sets of

Fig. 7   The principle of stratification on the basis of differences in animal densities



Stratum A
density circa $10/km^2$

Stratum B
density circa $5/km^2$

Stratum C
density circa $1/km^2$

If 20 hours flying were available for a census, it would be allocated between the three strata as follows :

Stratum A	would be allocated	20 x 10/16	=	12.5 hours
Stratum B	" " "	20 x 5/16	=	6.25 "
Stratum C	" " "	20 x 1/16	=	1.25 "

random numbers would be used to choose the blocks in each stratum.

Examples of stratification can be found in several publications[3,22,48,50,60,61]. It is a very useful method for reducing sampling error at the design stage of a census. However, good information must be available on the distribution and density of animals before the stratification can be made, for sample error can be greatly increased if a mistake is made in drawing the stratum boundaries. Stratification should be used with caution until some experience with census work has been obtained.

Stratification may also have to be used in order to divide a census zone into units of manageable size. In this case there may be no reason to suppose that there are major differences in animal density between the strata, and accordingly the sampling effort is allocated in proportion to the area of each stratum. Thus, a stratum that represented 38% of the original census zone would be allocated 38% of the sampling effort.

A stratum may itself be split up into two or more pieces. In Fig. 8 the high density stratum lies on either side of the low density stratum. The allocation of sampling effort would now be in two parts. First, sampling effort is allocated on the basis of density, the high density having 10/15ths and the low density 5/15ths of the sampling effort. Secondly, the sampling effort allocated to the high density stratum is now apportioned to each piece of it in proportion to its area.

5.5 Avoiding Biases and Errors

If a pilot is maintaining height control by reference to a radar altimeter he will sometimes be a bit too high, and sometimes a bit too low, but on average he will be at the required height. This is known as an error, for the times he is too high are compensated for by the times he is too low. The same applies to animals moving around in a census zone. The number moving into a transect strip will be balanced, on average, by those moving out. A bias, on the other hand, is an error in a constant direction. If the radar altimeter was overreading, so the pilot was always lower than he thought, then although he would be oscillating around the indicated height he would always be too low. Here, there would be a negative, or downwards, bias in his height control. Similarly, if animals are flushed out of the transect strip by the approach of the aircraft there will also be a negative bias in the number of animals counted. In both these examples the total numbers of animals would be underestimated.

The importance of a bias is that it produces a consistent inaccuracy irrespective of the sampling design and how much care is taken over the census. If the radar altimeter, unknown to the pilot, is reading wrongly, the results of the census will be biased, however much trouble is taken over navigation and counting.

There are three common-sense rules that apply to biases :

(a) be aware of the potential sources of bias and take all precautions to minimise them

(b) design the census in such a way that the most potent sources of bias can be measured and then corrected

(c) do everything possible to keep the biases constant from count to count.

(i) biases from the sample design

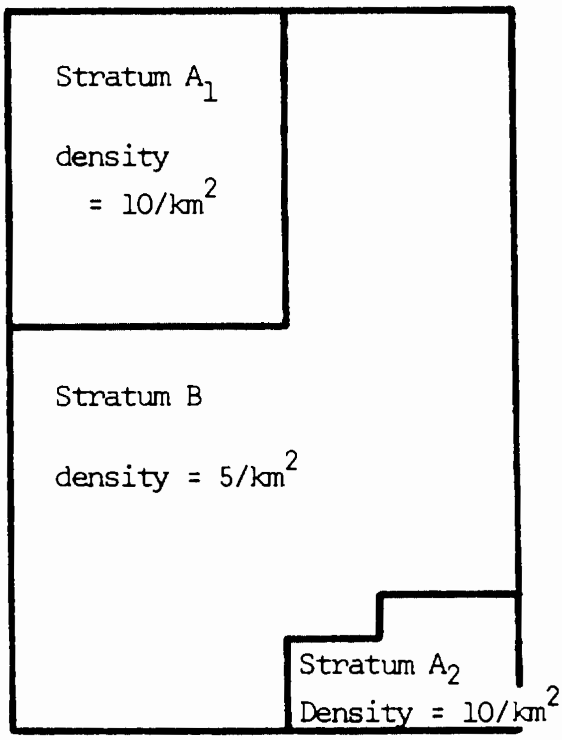
So long as the sample units are set up in the ways described, and the sample is drawn completely randomly, no biases should occur from the sample design.

(ii) biases from the census design

Before the census: The time of year that the census is carried out must be carefully considered. Animals may move in or out of the census zone at different seasons. Some species are also more conspicuous at some times of the year than others. Some species aggregate into larger groups at certain times of the year, thus increasing sample error. The time of day is also important, for animals tend to seek shade around midday making them difficult to count.

Biases from boundary effects should also be considered here. One difficult aspect of any aerial counting is to decide whether an individual or a group of individuals is in or out of the sample unit. It is likely that observers will tend to give the animals the benefit of the doubt and to include them where possible. With some types of units (blocks or quadrats) this decision is much harder to make than

Fig. 8 Allocation of sampling effort on basis of density and area for a split stratum



The allocation of 20 hours flying would be as follows :

(i) on basis of density

stratum A is allocated 20 x 10/15 = 13.33 hours
stratum B is allocated 20 x 5/15 = 6.67 hours

(ii) within stratum A on basis of area

area of stratum A_1 = 420 km^2)
area of stratum A_2 = 130 km^2) total area of stratum A = 550 km^2

stratum A_1 is allocated 13.33 x 420/550 = 10.18 hours
stratum A_2 is allocated 13.33 x 130/550 = 3.15 hours

with others (transects). This has already been discussed in Section 4 and will be treated again in the next Section. However, the size of the unit is important here, for the smaller the unit the larger will be the proportion of animals falling on the boundary. Larger units therefore tend to reduce this source of bias. A slightly different example comes from a census of black rhinoceros[22] The sample units were rectangular quadrats defined by a fixed strip width and a fixed length. The length of each quadrat was 'measured' by flying the aircraft in a straight line for twelve minutes, assuming a ground speed of 90 mph. There is obviously a potentially large source of bias here. Firstly, no 'Super Cub' (the aircraft used in this census) that I have ever met has ever managed to fly with a ground speed of 90 mph, at least not consistently. Secondly, no precautions were apparently taken to check the ground speed, or even to check the direction and strength of the wind during the census. It is therefore very probable that there was an underestimation.

During the Census : Errors in navigation are unlikely to produce biases unless, for example, the pilot mistakes one river for another - or something like that - and consistently stops counting in the wrong place. In block or quadrat sampling there is a large potential for bias in that the crew may not count the whole area - although methods for avoiding this are discussed in the next Section. In aerial transect sampling height control is the most potent source of bias, but fortunately precautions can also be taken to correct it.

After the Census : Biases could be caused by consistent inaccuracies in measuring distances and areas (through getting the map scale wrong), but common-sense, and repeating all measurements a number of times, should keep this to the minimum.

(iii) counting bias

This is the most potent source of bias in any form of aerial census[10]. Methods for minimising it are discussed in the next Section, but at the census design stage much can also be done. To start with, the observers should be thoroughly trained in all aspects of census work, including spotting and counting animals. Secondly, photography should be used whenever large numbers of animals are encountered.

In block or quadrat sampling the observers should also be thoroughly familiar with the methods of assuring that all parts of the sample unit are searched and that none are searched twice (see next Section).

In aerial transect sampling the most important considerations are those of flying height, strip width and flying speed, for these all affect the ability of observers to count animals.

Flying Height : More animals are missed the higher the aircraft is above the ground[41]. Lower heights are therefore preferable unless there is some good reason for flying higher, e.g. if the animals run away from the aircraft. The most useful height for transect flying has been found to be about 300 ft. above the ground. A lower height should be used when the vegetation is very thick or when the animals are small and difficult to see. A greater height can be used in more open country and for very conspicuous animals.

Strip Width : More animals are missed in wide strips than narrow ones[41]. In a recent study, strip width was found to be the most important variable in affecting counting bias, more important than either flying height or flying speed[9].

As a general rule a strip width of 200 metres is satisfactory for fairly open savannah country when more than one species is being counted. The strip width must be varied for different species. Thus impala would require a narrower strip than, say, buffalo. Similarly, a narrower strip is required when the vegetation is thick than when it is more open. In a recent census of elephant in Ruaha National Park[38] the strip width was reduced from 225 metres in the dry season to 125 metres in the wet season. Very wide strips of up to 500 metres can only be used for highly conspicuous animals.

Speed of the Aircraft : No detailed analysis of the effect of the speed of the aircraft on counting bias has been carried out to date.* Nonetheless, it stands to reason that the slower the aircraft flies the more time the observers have to spot, count and photograph animals. Much will depend upon the size of the animals and the experience of the observers, but speeds of more than 120 mph should never be attempted. Most census work is done at speeds between 80 mph and 120 mph.

As a general rule of thumb, therefore, a height of 300 feet, a strip of 200 metres and a speed of around 100 mph will be adequate for most purposes and will keep counting bias within reasonable bounds. However, if continuous work is to be carried out in an area test flights should be made to find out the best combination of height, width and speed for that area. A number of different study areas should be covered a number of times using different combinations[41].

It is one thing to choose the 'best' strip width and quite another to ensure that you maintain this width during the census. In Section 6 methods are described whereby the flying height can be recorded during the census so that the actual strip width can be worked out afterwards. This is obviously important to do, for if a strip width of 200 metres is chosen and the pilot always flies too high, then the actual strip width during the census would be wider. Unless this was corrected for, the estimate would be biased.

Two final points are worth mentioning in connection with biases. The first is that some biases are not worth worrying about. For example, errors in the bank of an aircraft (i.e. the wings not being horizontal) produce a small but consistent positive bias on the strip width[41]. Common-sense dictates that this source of bias will be constant from count to count, so long as highly turbulent conditions are avoided. It should also be mentioned that measuring this source of bias is extremely laborious. This leads on to the second point which is that if continuous work is to be carried out in an area, great care must be taken to ensure that biases are kept constant from count to count.

5.6 Accuracy or Precision?

This brings us to the question of whether emphasis should be placed on obtaining either an accurate or a precise population estimate. As has been pointed out[9] the two are not the same. An accurate estimate is one that is near the true total but may have wide confidence limits. Alternatively, a precise estimate has narrow confidence limits but the population estimate itself may be biased, that is, usually on the low side. Whether an accurate or a precise estimate is required depends on the aim of the census. For instance, precise censuses are needed to follow population trends, but the repeatability must be high (i.e. the degree of bias remains constant from census to census). On the other hand, accurate estimates are required, for example, if a population is to be reduced by culling or if biomass estimates are being calculated.

Of course the ideal is an estimate that is both accurate and precise but it is usually impossible to maximise both qualities in one census.

5.7 Costs

There are many different ways of looking at the costs of a census, but the two main considerations are :-

* how many units can be counted for a given cost?
* how much will it cost to count a given number of units?

Once you can answer these questions, you can then calculate the cost of achieving a required precision, or the precision to be expected for a certain cost (see Section 5.4).

The simplest cost model is

total cost = cost of dead time + cost of counting time

where the dead time is the time spent flying to and from the census zone and from unit to unit, and the counting time is the time spent actually counting the units. The cost of counting time is found by multiplying the cost of counting one sample unit by the number of units to be counted, so that the cost equation can be written as

total cost = cost of dead time + (cost of counting one unit x number of units to be counted)

(i) Aerial transect counting

The basic information required here is the cost of the aircraft per hour, the flying speed at full cruise and the flying speed during counting. These speeds may of course be the same. From this information calculate

c_d = cost per kilometre for dead time at full cruise
= cost of aircraft per hour / cruising speed in kph

and c_u = cost per kilometre for counting
= cost of aircraft per hour / flying speed during counting in kph

The cost of dead time is now found by measuring in kilometres the distance from the base airfield to one end of the base-line, down the base-line and back to the airfield, and then multiplying this distance by c_d. Thus

C_d = cost of dead time = distance of dead time . c_d

The cost of counting a unit is now found in the same way by measuring the average length of the transects in kilometres and multiplying this by c_u. Thus

C_u = cost of counting one unit = average length in km . c_u

The amount of dead time in a transect count will be the same however many transects are counted. Thus, using n to denote the number of units to be counted, the total cost C can be written as

$$C = C_d + (C_u \cdot n)$$

If you want to calculate how many units can be counted for a given cost C, then

$$n = (C - C_d) / C_u$$

while the cost of counting n units is given by

$$C = C_d + (C_u \cdot n)$$

(ii) Block or quadrat sampling

As usual everything is more complicated with block or quadrat sampling. The first problem is that the cost of dead time will increase with increasing sample size. The only way to calculate this increase is to choose random samples of increasing size, plot the location of the units on the map, and measure the shortest distance in each case from base airfield through all the units and back to base airfield. These distances can then be converted to cost per sample size by multiplying the distance by c_d and then plotting C_d against n on a graph. C_d can then be read from the graph for any size of n.

The calculation of C_u is also more difficult for there are two components to the cost. The first is the cost of flying around the boundary in order to locate it exactly, and the second is the cost of searching the unit. From the map of the units you must calculate the average boundary length in kilometres and the average size of the units in square kilometres. The cost of flying the boundary is found by multiplying the average length of the boundary by c_u. The cost of counting is more difficult. The best way is to calculate the rate of ground coverage in km^2 / hour from the speed of the aircraft during counting and the width of strip that you think you will be covering. From this calculate the time taken to count a unit by dividing the average area of the unit by the rate of covering the ground, and convert this into cost by multiplying it by the cost per hour of the aircraft. Add these two quantities together to get an estimate of the cost per unit.

The same formula for total cost can be used, only C_d must now be read from your graph.

(iii) Other costs

These calculations will give estimates for the cost of carrying out the census. In addition, one should allow for such items as the cost of personnel, the cost of putting out fuel dumps, or the cost of bringing in an aircraft from outside to do the census. These costs can often be greater than those of the census itself.

SECTION 6 PRACTICAL ASPECTS OF AERIAL SAMPLE COUNTING

6.1 Introduction

Organising and carrying out a sample count requires a common-sense approach to a large number of rather small practical problems. Experience is necessary before things can be expected to go without a hitch. It must always be borne in mind that an entire census can be invalidated, and a great deal of time and money wasted, by inadequate attention to small practical details.

The minimum crew comprises a pilot and an observer. The pilot should never be called upon to count animals or to record data : he has enough to do navigating, avoiding vultures, and maintaining strict height, speed and bank control. The time he spends piloting will be at the expense of the time he can spend observing, and so his observing will be inefficient. If he spends too much time observing then his piloting will become unsafe. Pilots who claim they can do both jobs are fooling themselves as well as everyone else, and census results obtained by a pilot/observer should always be treated with great scepticism.

It is our general experience that censuses go much better if the pilot is also a biologist involved in the census. This ensures that he has a real interest in flying correctly and in concentrating on navigation, height and speed control. Non-biologist pilots sometimes make poor census pilots as they tend not to appreciate the errors and biases that occur through inaccurate piloting.

Pilots require much practice before they can be expected to carry out a census properly. Census work requires the ability to navigate at low level by reference to small ground features, a skill that can only be developed through practice. Practice at speed and height control is also required, especially the ability to react swiftly to changes in ground level. A thorough familiarity with the census area is also important if consistent results are to be obtained. Low level flying also requires experience in judging and allowing for wind drift, and for the effect of winds around hills. Census pilots should take every opportunity to practice these skills.

Similarly it takes much time and experience before an observer becomes skilled at spotting and counting animals, therefore observers should take every opportunity to fly in order to become accustomed to this. Observers can be trained to count accurately by showing them colour slides of different sized groups of animals. The photographs, taken from the normal height and viewing angle, are shown to the observer who is given ten seconds to count the number of animals on each photograph. He is then told the correct number, before the next slide is shown. This results in an extraordinary increase in counting accuracy[49]. It must always be remembered that even highly experienced observers consistently undercount the numbers of animals in a group by as much as 40%. Observers also need much practice at recording data (either writing down or tape recording) and in using a camera and changing films. The more practiced the observer is at doing this, the more time he can spend observing.*

The census organiser should not underestimate the utter confusion which can result from incomplete understanding between different members of the census team. A thorough briefing of pilot and observers is necessary covering the principles of the census, the details of the flying, and the methods of counting and recording the data. It is not enough, for ecample, just to tell an observer to count all the animals seen between the streamers. Exact instructions must be given as to what to do when a streamer cuts through a herd of animals, or when the same group of animals is seen twice in supposedly different strips, or when animals run into or out of the strip as the aircraft passes by. Exact instructions must be given as to how to record the data, how to operate the tape recorder, how to use the camera and what to do with used films.

It follows from this that consistent results will be obtained if a crew of pilot and observer(s) can always work together as a team, for they will then get used to each other's work methods. Nonetheless, it is quite amazing how many silly mistakes are made even by experienced crews. In one recent census an observer turned his tape recorder 'off' when he made an observation, and turned it 'on' when he had finished. In another census an observer held the microphone too close to an open window so that only wind noise was recorded.

* See Appendix 2.

An observer once lost his spectacles out of the window (they should be tied down with string) while another one mixed up the columns on his data sheet so that the elephant and eland observations were randomly recorded in two columns both labelled 'el'. Again, one very experienced observer forget to tape the lens of his camera at infinity and all his photographs came out blurred.

6.2 Choice of Aircraft

As the observer must have an unobstructed downwards view of the ground only aircraft with high wings are suitable for census work. Wing struts are also necessary if transect sampling is to be employed, for the streamers are attached to these struts. Apart from this there is no real constraint on the choice of aircraft. It should not be too fast for otherwise the observer will not have enough time to scan the strip effectively, nor should it be too slow otherwise it will take too long to cover a census zone. Speeds ranging from 80 - 120 mph have been found suitable for aerial census work, while speeds faster than this should be avoided. It is also advantageous if the windows can be opened or removed altogether, for this greatly increases the observer's counting accuracy. Wind can be deflected by fitting small baffles to the window edges. A four seater aircraft is also of advantage because two observers can be carried. This immediately doubles the area that can be searched per unit time. The fourth crew member can always act as a recorder, or help in navigation, or collect other types of information.

The aircraft most commonly used for aerial census work are the high wing Cessna models 180, 182 and 185, and the high wing Piper models PA-12 (Cruiser) and PA-18 (Super Cub).

6.3 Transect Sampling - General Flight Planning

(i) Safety

Aerial census work requires the aircraft to operate over inhospitable and inaccessible country, often quite far from base, in that part of the air space usually reserved for vultures. Safety measures should therefore be taken seriously. Obviously the aircraft must carry adequate first aid equipment, food and especially water, and some form of ground-air communication equipment (flares, signalling mirrors, radio). Further precautions should also be taken. A map of the aircraft's planned flight should always be left at the home base, and this map should also have expected ETAs at different points written on it. If two aircraft are carrying out a census then they should be in radio contact (listening out) the whole time, and they should report 'operations normal' at fixed times. Each aircraft should also have a map showing the other aircraft's planned flight. If an aircraft is landing for fuel at another airfield apart from the base airfield, then it should report back its arrival if radio communication is available. Similarly, that airfield, if manned (e.g. a guard post airfield), should be told when to expect the aircraft, and when to report its non arrival. A back-up aircraft for search and rescue should always be available as well, of course, as suitable ground vehicles.

(ii) Fuel management

It is the pilot's responsibility to ensure he has enough fuel to carry out a census flight, ensuring that he always has a safety margin to allow him to reach an airstrip. Fuel often has to be located on outlying airfields so that the aircraft can refuel without having to return to base. In this case some method of getting the fuel into the aircraft is required, which is sometimes forgotten. A pump and filter are necessary, as well as some method of opening the drums (this is frequently forgotten). If oil is supplied, then some form of oil-can is also necessary.

(iii) Planning the flights

The most usual arrangement for an aerial transect count is for the transects to be flown in order, starting at one end of the census zone and working through to the other. This arrangement works well for small census zones that can be covered in a single flight of 2 - 3 hours, but the flights have to be broken up in some way if the census zone is larger than this. Care must be taken here, especially if the animals move systematically within the area. For example, if the water is at one end and the grazing at the other, serious errors could result from censusing one end in the morning and the other in the afternoon. If more than one flight has to be made to cover a census zone then the best plan is to distribute the flying over the whole area on each flight. For instance, if 24 transects are to be flown in two flights, choose twelve at random for the first flight, and do the second twelve in the second flight. This will in no way increase the costs of the census.

(iv) More than one aircraft

If two, or more, aircraft are carrying out a census then things get a bit more complicated, for each crew will inevitably have slightly different biases and errors in the way they carry out the census. If there are two distinct census zones, or perhaps strata, then one aircraft can be assigned to each. Alternatively, in the case of a single large census zone, one aircraft can be assigned to one part and the other to the remainder. This is in effect the same as dividing the census zone into two separate parts, the results subsequently being worked up separately for each zone. Finally, if the census organiser is very sure of the competence of both pilots, then one aircraft can have assigned to it half of the transects, chosen at random, the rest being assigned to the other aircraft. This entails some safety problems for the aircraft may frequently be operating close to each other. Under these conditions the observations from each aircraft would be pooled in the analysis of the final results. In general, however, it is best to keep the aircraft well apart if possible. If they must operate in the same area then it is wise to have them working in the same direction. For example, it is asking for trouble if one aircraft works from west to east and the other from east to west. Finally, when two or more aircraft are working together it is absolutely essential that all pilots know exactly where the other aircraft will be.

(v) Other factors

Observers should never be required to count for more than three hours at a stretch otherwise they become tired and their counting efficiency falls off. In very long censuses, no crew, however tough they might consider themselves to be, should work for more than two days without a morning's or afternoon's break. Counting should also never be attempted during the heat of the day because animals lie up in shade and are impossible to see, nor should it be attempted when the light is highly directional (e.g. early in the morning and late in the afternoon). In East Africa the best hours for counting are between 8 a.m. and 11 a.m., and between 3 p.m. and 5 p.m. local time. These constraints must be considered when planning the flying.

6.4 Transect Sampling - Piloting

(i) Navigation

Flying a transect count requires following, with a high degree of accuracy, lines marked on a map of the census zone. The only practicable method of navigation is by reference to ground features, which means that an accurate large scale map is essential. It is possible to use a 1 : 250,000 map if it is very detailed but in general a 1 : 100,000 or even a 1 : 50,000 map is better, especially when censusing a small area. If the transects are very long then some compromise must be reached between large scale and a map of manageable size. If no maps are available then vertical aerial photographs can be used, or even photo-mosaics, for these show up most of the drainage lines, small hills and vegetation boundaries that are most useful for navigation. Maps can always be annotated with tracks etc. to make subsequent censuses easier to carry out.

The transects are marked on the map as a single line down which the pilot should attempt to fly straight. Wind drift can be assessed on the first few transects and the appropriate compass headings selected. It is a mistake, however, to rely too heavily on the compass and reference to ground features must always be the primary navigation aid.

In some types of systematic transect counts, or when distribution data are required, each transect has to be subdivided into units at regular intervals along its length, the pilot informing the observer(s) as the aircraft passes from one unit to the next. Although in most cases these subdivisions can be located by ground features, inevitably there will be some featureless areas where they have to be located by time. The pilot should carry a stop watch in this type of survey and should zero it and restart it at each boundary throughout the flight. When flying over really featureless country it is a good idea for the pilot to have written down in advance the time expected to be taken for each transect. A check on elapsed time can prevent really wild errors in navigation.

It is of course the pilot's responsibility to tell the observer(s) when to start counting and when to stop at the end of a transect.

It is inevitable that occasional wild errors in navigation will occur, usually taking the form of ending a transect some kilometres from where you should be. The pilot can do one of two things. Firstly, he can fly the transect again, in which case the data collected on the first attempt are ignored. Alternatively, he can mark on his map the point where he finally finished up, and then go on to the next transect. In this case the error can be corrected for when working up the results. It also sometimes happens that large storms prevent a number of transects from being flown along in their entirety. All the pilot has to do here is to mark on his map where the transects are broken off and where the next ones are started. These errors can also be corrected for later.

(ii) Height control

This is one of the most important aspects of transect piloting for the width of the transect strip as demarcated by the streamers is directly proportional to the aircraft's height above the ground. The higher the aircraft the wider will be the strip, and *vice versa*. Serious biases can thus creep in unless the pilot pays very careful attention to height control. For example, if the pilot always flies too high then the strip will be wider than that calculated, and the sample estimate will be biased in an upwards direction leading to an overestimate of numbers.

The only really satisfactory way to achieve height control is to have a radar altimeter fitted in the aircraft. This instrument gives continuous readings of the actual height above the ground, enabling the pilot to fly more accurately. The real advantage, however, is that the readings from the instrument can be written down (by someone <u>other</u> than the pilot) at regular intervals (e.g. once every minute) so that after the census the actual height flown can be calculated. This actual height can then be used to calculate the actual width of the strip during the census. It is our experience that pilots can maintain very accurate and very precise height control when using a radar altimeter[37,38].

A radar altimeter, like any other instrument, is prone to error and it is essential to calibrate the instrument against the pressure altimeter at the start of each flight in a census. The calibration is carried out as follows. The aircraft is flown a few feet above the ground at full cruising speed while the pressure altimeter is set to a convenient reading (a certain steadiness of hand is required to do this). The aircraft then flies to the desired height as shown on the pressure altimeter and maintains this height for a few minutes to allow the pressure altimeter to settle down and to allow the radar altimeter to warm up. A number of passes are then made over the point where the pressure altimeter was set, and the readings from both altimeters are recorded. The radar altimeter can then be calibrated against the pressure altimeter, and any error corrected for.

An alternative method is to use the 'shadow meter'[42] which is a device whereby the aircraft's height above the ground can be judged by matching the size of its shadow on the ground against marks on the wing strut. If the wings are level then the size of the shadow on the ground is constant, and equal to the wing span. The method of constructing a shadow meter for a desired height is shown in Fig. 9. It is a remarkably effective device. Once it is set up then it must be calibrated against the pressure altimeter in the way described above. After setting the pressure altimeter when close to the ground, the pilot passes a number of times over the same point adjusting his height by the shadow meter and taking readings from the pressure altimeter.

When using a shadow meter during a transect count it is wise to write the pressure altimeter readings on the map at odd points along each transect. These can then be used on successive transects should the sun be temporarily hidden. It is essential to do this in four seater aircraft for the pilot will only be able to use the shadow meter on every other transect. The shadow meter works best at low altitudes being effective at flying heights of up to about 400 ft

Fig. 9 Constructing the Shadowmeter

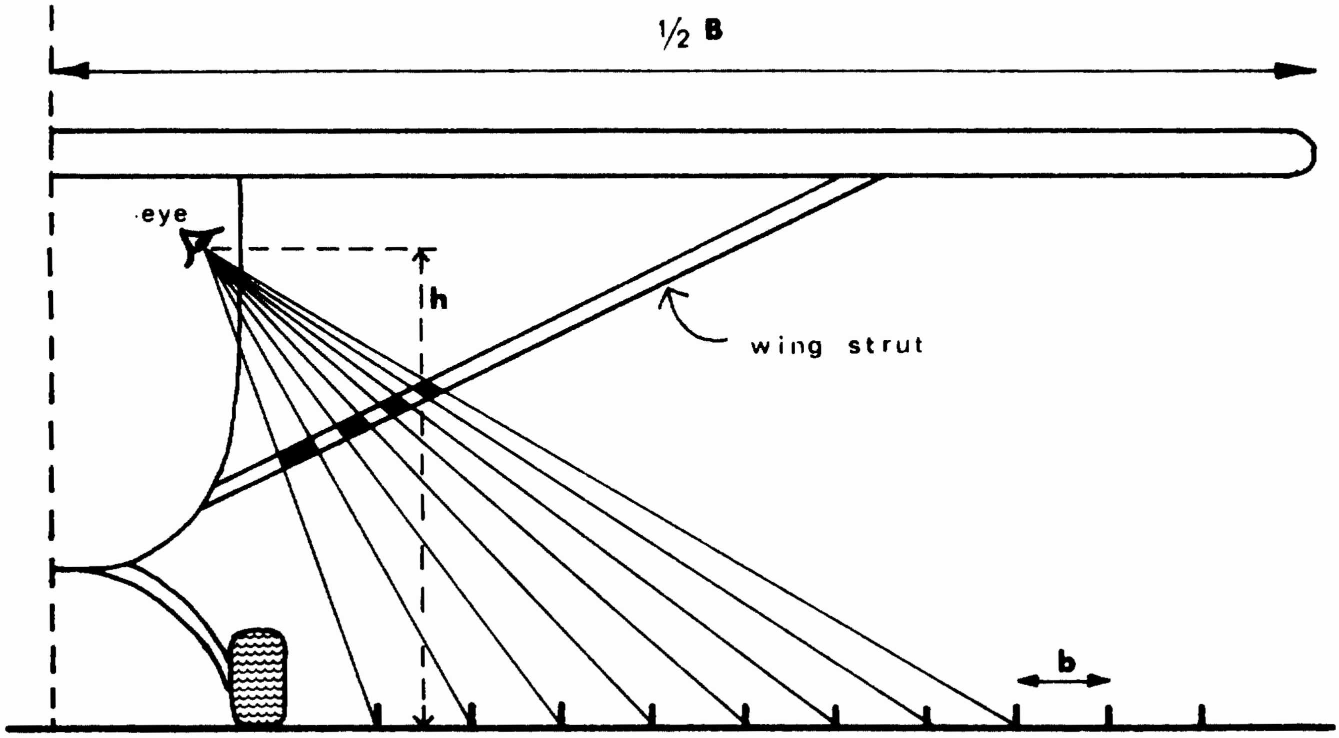


diagram after Pennycuick 1973[42]

a) prop the aircraft in the flying position and measure the height of the pilot's eye above the floor (h)

b) if H is the required flying height

B is the wing span of the aircraft

calculate b = B . h / H

c) mark on the hanger floor intervals of width b

d) mark alternate black and white marks of the strut as shown.

(120 metres) above the ground.

Transect counts can be carried out with no other aid than the pressure altimeter provided that the ground is nearly horizontal, as for instance when the census zone is a flood plain[3] or an old lake bed. If certain parts of the area are raised then the pilot should know their elevations in advance so that he can adjust his height when flying over them.

The pressure altimeter must first be zeroed at the start of the flight by making a low pass over the ground. A progressive altimeter error will develop during the day as a result of change in the ambient barometric pressure, so it is essential to re-set the altimeter every half hour or so. For this purpose a number of flat open places should be selected in advance where ground height at each, relative to the <u>original</u> reference point, must be known. When a check is due, the pilot breaks off at the end of a transect, flies down to ground level over one of these check points, sets the altimeter and informs the observer of any error. The actual height flown, and therefore the actual strip width, can then be calculated for each half hour period.

(iii) Aircraft bank

The overall effect of aircraft banking is to make the strip width, as seen by the observer, larger than calculated[41]. The reason for this is that, for an observer viewing from one side of the aircraft, the errors of inward and outward bank do not cancel each other out. Inward bank reduces the strip width, but an outward bank of the same order increases the strip width to a much greater extent in comparison with the reduction of strip width caused by inward bank. Therefore, banking will cause a positive bias to the results of the census. The pilot must therefore try to maintain the wings in as near a horizontal position as possible.

6.5 Transect Sampling - Observing

(i) Defining the counting strip

In a transect count the boundaries of the strip within which the observer has to count the animals are defined by streamers attached to the struts of the aircraft. The streamers fly out behind the struts in the airstream, being seen by the observer as tracing two parallel lines on the ground. Having decided upon the required flying height and strip width, the position of the streamers are set up as follows[41] :-

(a) prop the aircraft in the flying attitude on a level surface, trestling the tail in the case of a tail wheel aircraft. Have the observer sit in his place making sure he is comfortable and that he is looking out of the window in a relaxed position. (It is of considerable help if the observer has already made a trip in the aircraft beforehand so that he knows a comfortable position to sit in.) Measure the height (h) of the observer's eye above the floor (Fig. 10).

(b) choose the position of the inner streamer (a in Fig. 10) on the strut so that the observer's line of sight through it is clear of the wheel but still as close to the body of the aircraft as possible. Place a marker A on the ground on this line of sight, and get the observer to make a mark a' on the window so that his line of sight passes from a' through a to A.

(c) place a second market on the ground at B. The distance from A to B is denoted by w, and it is found from the formula

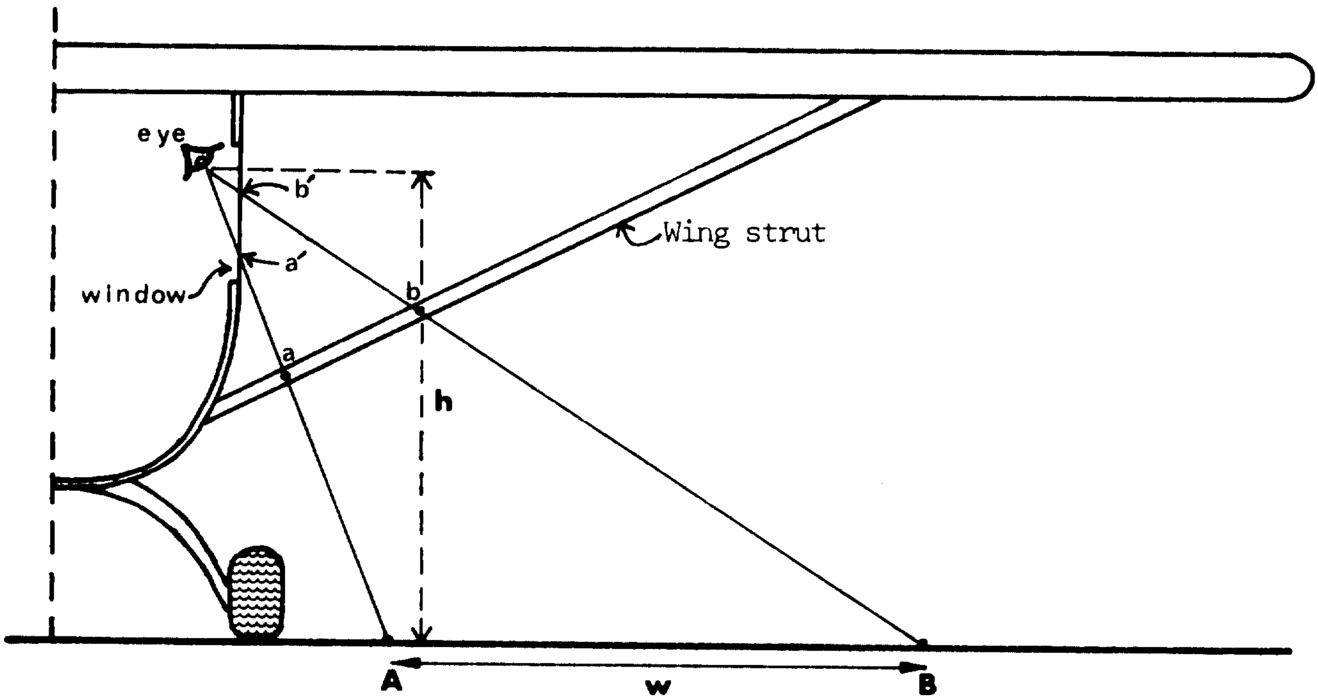
$$w = W \cdot h/H$$

where W is the required strip width and H is the required flying height. The two heights h and H must be expressed in the same units, as also must w and W.

(d) place the second streamer at b on the wing strut in the observer's line of sight to point B. The observer must meanwhile keep his line of sight through a' - a - A, while making a second mark on the window at b' to establish a second line of sight b' - b - B. When all these marks are correctly positioned the observer's two sight lines should be in line when he sits in his comfortable position.

The marks a' and b' on the window ensure that the observer's head will always be in the correct position during flight. These marks must be kept lined up with the marks a and b on the struts, for the strip will appear wider if the observer slumps in his seat, and narrower if he sits upright. If the windows are taken out

Fig. 10 Fixing the position of the Streamers



from text, let h be the height of the observer's eye from the floor

W be the required strip width

H be the required flying height

then w = W . h / H

w is marked out on the hanger floor, and the two lines of sight a' - a - A and b' - b - B established. The streamers are attached to the struts at a and b. a' and b' are the window marks.

during flight then some alternative method of marking must be used, e.g. marks on the window frames.

The width of the strip is also altered by any bank of the aircraft. Both these errors are minimised if the strip is as close to the aircraft as possible, without the wheel being in the way and without the observer having to lean out of the window.

Heavy builder's string is ideal for the streamers. The string must be securely taped to the strut so that it can not slip up or down. The length of the string will be determined by the characteristics of the airflow around the particular aircraft, but in general the streamers should be as long as possible. With some aircraft it is possible to attach small plastic funnels to the end of the streamers. This makes them fly more evenly in the slipstream. Some aircraft have such turbulent airflow around them that thin wooden rods have to be used instead of string. They can be attached to the struts with 'jubilee' clips, being positioned in exactly the same way.

The strip width set up in this way will be approximately correct. A calibration flight must however be carried out to make sure that it is reasonably close to the required width. A line of markers must first be carefully laid out. White blocks, or pieces of cardboard, measuring some 100 x 40 cm are suitable. They should be placed twenty metres apart on a suitably flat piece of ground. The line of markers should be at least twice the intended strip width, and every fifth market should be double or treble in width.

At the start of the calibration flight the pilot makes a low pass over the markers and sets his pressure altimeter before climbing up to the required flying height. He should then make at least twenty passes at right angles across the line, recording his height at each pass. The observer meanwhile counts, or photographs, the number of markers between the streamers. The width of the strip is directly proportional to the height of the aircraft, which is found as follows :-

let h be the average height of the aircraft during, say, 20 passes

w be the average strip width during those 20 passes

H be the selected flying height during the census and W be the nominal strip width at that flying height

then, $$W = w \cdot H / h$$

If this nominal strip width W is widely in error then the streamers can be repositioned and another calibration flight made.

(ii) Counting

The observer must continually scan the strip defined by the streamers, spot groups of animals, decide whether or not they are inside the strip, count them and record the data. The observer can move his head around when spotting for groups of animals but he must always return it to the correct position (i.e. he must line up the window and strut markers) to decide if the animals are in the strip or not. Single animals, or small groups, can be counted individually, but with larger groups the observer may have to count in 'fives' or 'tens'. It is here that previous training given to the observers is valuable. Animals seen within the strip are counted, and those outside the strip are not. If a streamer cuts through a herd so that some animals are in and some are out, only those inside the strip are counted.

There are four very common mistakes made by observers on transect counts :

(a) if the aircraft is too low they count animals just outside the strip.

(b) if the aircraft is too high they ignore animals that are just inside the strip.

(c) if they see the same group of animals twice in two different strips, say because the animals have moved, they ignore them on the second occasion.

(d) if the pilot makes an error in navigation, for example when neighbouring strips are close together, and the observers notice this, they do not count the animals seen in the strip.

These are very bad mistakes to make. In (a) and (b) the observer is trying to compensate for errors in height control, but these errors can be taken care of at a later stage when the results of the census are worked up. In (c) the observers fail to realise that those animals counted twice will on average be compensated for by those missed altogether, so long as the animals are moving independently of the aircraft. Similarly, in (d) the areas counted twice are obviously balanced by those areas missed. Another mistake made by observers is to compensate for any bank of the aircraft, and they tend to count a slightly wider strip when the wing is down and a narrower strip when the wing is up. None of these things must be done, for the excellent reason that errors caused by height control, bank control and navigation can be compensated for at a later stage, but only so long as the observers have always counted everything that they see within the streamers.

The rule that observers must follow absolutely is that if an animal is within the streamers then it must be counted, and if it is outside the streamers then it is ignored.

(iii) Recording data

Data may be recorded either by tape recorder or by writing down, the former always being preferable because the observer does not have to take his eye off the strip. The small cassette tape recorders are best for this purpose because of their compact size. Any model with manual control of recording level (so that it can be adjusted to the engine noise) incorporating an on/off switch on the microphone is ideal. A good supply of spare tapes and batteries must of course be carried. The recorded should be checked before take off, immediately after take off, and at the end of each transect. The recorder need only be switched on when an observation is to be recorded, but it is important to remember to allow the tape to get to full speed before speaking.

When tape recording, the observer should first record the take off time and the date, and must identify each transect by number, noting the start and finish time of each transect. Animal numbers must be recorded in some completely unambiguous form. It is usually best to give the species first, followed by the number in each group; e.g. "zebra 21; elephant 3;" etc. If anything has to be repeated or corrected, say "correction" or "say again" before repeating the item. In this way it is quite clear during transcription that the same item has been recorded twice, and is not two separate items.

Transitions between vegetation types can be recorded, and miscellaneous observations on fire, greenness of grass, water, sub-divisions of transects etc. can be interjected at any time.

If writing down has to be used then an adequate supply of ruled recording sheets, as well as pencils etc., must be made ready beforehand. There must be a separate column for each species, each column clearly labelled, with a spare column on the left for the transect number, the start and finishing times etc. Transitions between vegetation types of sub-divisions of the transects, can be marked in by drawing a line across the data sheet, but if too much is attempted the observer spends more time writing than observing.

The numbers of animals written in the appropriate column, must also be unambiguous. Thus, if three zebra are seen, then two, then six, write them down as 3 / 2 / 6 /; otherwise it may be impossible afterwards to be sure whether you say a three and a twenty-six, a thirty-two and a six, or even a 326. At the end of each transect a horizontal line should be drawn across the data sheet and the next transect number entered below it.

Writing down is on the whole a too time consuming method for a multi-species count, especially if the density of animals is high or if the habitat makes them at all difficult to see. Writing down is also a potent cause of airsickness. In four seater aircraft the fourth crew member sitting alongside the pilot can act as a recorder and write down the observations which the observers call out. In noisy aircraft an intercom system should be fitted, but it must be remembered that at times things can become very hectic with both observers shouting out excitedly. Errors are bound to creep in.

Another very useful task for the recorder is to write down the readings from the radar altimeter.

(iv) Photographing large herds

Experience shows that even experienced observers are unable to count herds of animals numbering more than about twenty individuals with any degree of accuracy. They consistently undercount, sometimes by very large margins[3,49]. Large groups should always be photographed, the number of animaps being counted later from the photographs. A visual estimate of the photographed herds must also be made in the case of photographic failure, or in case the film is lost or destroyed in the developing process. The census organiser must impress upon the observers the importance of getting good photographs, and he must also tell them precisely the minimum group size for photography. The safest method is to photograph any group larger than five individuals, especially if elephant are being counted. On a multi-species count this could well 'overload' the observers, so a minimum size of ten animals should be used.

Any good 35 mm single-lens reflex camera is suitable. A 50 mm or 80 mm lens has been found adequate as it gives good images of the animals while allowing the transect streamers to appear in the photographs. Ideally a zoom lens would be used but these are still very expensive. Colour film gives better results than black and white unless conspicuously monochrome animals such as buffalo and elephant are being counted. A reasonably fast film (e.g. 400 ASA) is required as 1/250th sec. is about the slowest shutter speed which can safely be used. Some colour films can be over-rated to overcome poor light (e.g. High Speed Ektachrome can be rated at 650 ASA with no noticeable loss of quality) but they must then be specially developed.

The photographs must be taken from the fixed head position, e.g. with the window and strut markers lined up as seen through the camera. This requires a lot of practice on the part of the observer. This is, in face, only absolutely necessary if the streamers cut through a portion of the herd, for if the herd is clearly seen to be between the streamers then any convenient photographic angle can be used. It is, incidentally, a good idea to put black marks along the inner streamer so that the inner and outer streamers can be distinguished on photographs.

Certain other precautions must be taken. The camera lens should be taped at the infinity focus position. Each film should be numbered before the census starts, both on the cassette and on the film leader. This number on the leader must be scratched into the emulsion (for otherwise it can vanish during developing) and it must also be underlined (to distinguish later between 6 and 9). The observer must record each film number on his tape or data sheet when he starts a new film, and used films must be put well out of the way. It is a good idea to rewind used films completely into the cassette before unloading. There is then no chance of using the film again by mistake.

A completely unambiguous recording system must be used so that the sequence of photographs can be matched later to the visual estimates and to the different transects. Fig. 11 shows a system that has been found to work well for both tape recording and for writing down. When tape recording it is vital to record the data in the following form : first the species, then the visual estimate, then the number of frames taken. For example, a tape record might be "elephant, six, one frame; elephant, ten, three frames; buffalo, twelve, one frame" etc. If this were muddled up so that it was recorded as "elephant, six, one frame, three frames, elephant, ten, buffalo, twelve, one frame .." etc. it would be impossible to decide during transcription if the three frames referred to the first or second elephant observation. When writing down, a new line must be started after each photograph otherwise it will be impossible to disentangle the sequence of photographs after the census.

Fig. 11 shows the commonest situations encountered.

(a) and (b) are the simplest situations when either a single frame or a number of overlapping frames are taken of the same group.

(c) there are a number of overlapping frames as well as a single frame of a sub-group of the main group. The estimate refers to all the photographs together.

(d) there are a number of independent frames with no overlap, and the estimate again refers to all the photographs.

(e) here two independent frames have been taken of the <u>same</u> group. The estimate therefore refers to only one of the photographs, not to the total number of animals on both. Only one of the photographs would then be used as a count of the group, i.e. the better one.

This convention of x + y distinguishes between independent photographs of the same group when the estimate refers to only one of the sets of photographs. A large group may need many overlapping frames and the observer may lose count. In this case a blank frame should be taken by exposing a frame with the camera held against a knee. This blank must be recorded, e.g. "buffalo, four hundred, many frames, one blank."

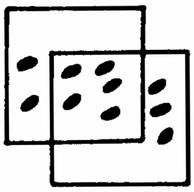
Fig. 11 System for recording frame numbers and estimates when using photography

Tape record | Writing down

a) only one frame

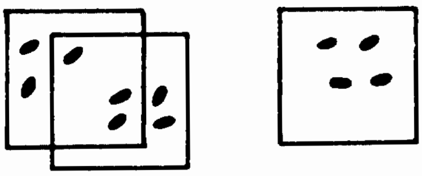
Six, one frame | 6 1 /

b) two overlapping frames



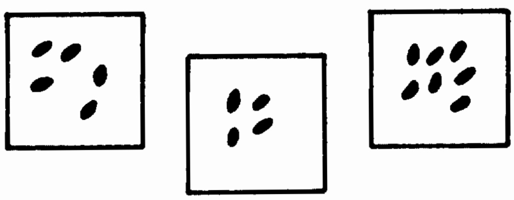
Ten, two frames | 10 2 /

c) two overlapping frames, and a sub-group



Eleven, two frames, one frame | 11 2 1 /

d) many independent frames

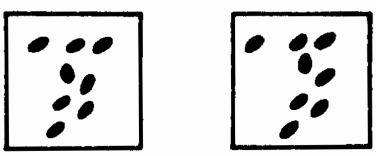


Sixteen, one frame, one frame, one frame | 16 1 1 1 /

OR

Sixteen, three independent frames

e) two independent photographs of the same group



Eight, one plus one | 8 1+1 /

Note : the circle around the number of frames in the written record distinguishes this from the number of animals recorded.

Care must be taken when making overlapping frames. The photograph on the ground is trapezoid in shape, with the side nearest the aircraft smaller than the side away from the aircraft. The overlap must therefore be based on the nearside of the view-finder. The nearer parts of a herd should be photographed before the further parts. Fig. 12 shows the correct procedure to follow.

Prints must always have the film number and the sequence number on them. The first step is to identify the group to which the print(s) belong. Any area of overlap must then be demarcated with a chinagraph pencil before the animals are counted. Each animal should be pinpricked on the print as it is counted, the final number being entered on the data sheet or tape transcript. A hand-held tally counter is a great aid when counting off photographs. The procedure is the same when counting animals on colour transparencies only in this case it is best to count them under a low power binocular microscope. A clear overlay (e.g. clear film strip) can be placed over the slide so that the pin pricking does not spoil the photograph.

6.6 Block/Quadrat Sampling

(i) General flight planning

All the aspects of general flight planning discussed for transect sampling apply equally well to block or quadrat sampling. The only difference is that the blocks/quadrats should be of a size that can be completely covered in a flight of three hours or so. Blocks larger than this should be subdivided into smaller blocks at the time of drawing the block boundaries, i.e. before the blocks are chosen into the sample.

(ii) Defining the boundaries

In a block sample count the boundaries of each sample unit are defined by reference to features on the ground and not by marks on the aircraft. These ground features make it quite easy for both pilot and observer(s) to agree on where the boundaries actually are for both have to have maps of the block (see (iii) below). The situation is more difficult with quadrat counting as there are no marks on the ground to indicate the boundaries. Great care must be taken to ensure that all crew members are absolutely agreed on where the boundaries are. It is best to spend some time flying around the boundaries until agreement is reached. Always play safe by fixing on slightly larger boundaries than those called for. The location of each group of animals has to be marked in on a map anyway (see below) so afterwards a final decision can be made as to which animals are in and which out.

(iii) Flight patterns and counting

The choise of procedure is more flexible than in transect counting because the exact flight path is not laid down in advance, and it is up to the crew to decide exactly where, and at what height to fly. The observer is now required to find and count every animal in the block, and to avoid counting any twice, a problem that does not arise in transect sampling.

A spiral flight pattern is suitable for small blocks where the light is not highly directional. The pilot flies around the boundary of the block and then spirals in towards the middle, with the observer looking inwards towards the centre of the block throughout.

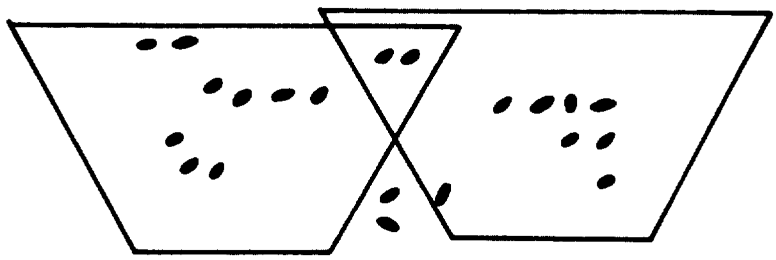
The zig-zag pattern is best for large blocks and in situations where the sun is low in the sky, for the flight pattern can be arranged so that the observer always looks down sun throughout the count, changing sides on each beat. The first beat should always be flown just outside the boundary so that the observer can see the actual boundary as he looks into the first strip.

In block counting the basic flight pattern is only a skeleton on which the details of the flight are based. In hilly country a common variant is to modify the basic zig-zag pattern by following ridges and valleys. In the case of a large block that is divided by a prominent ridge or river it may be best to treat it as two sub-blocks.

The most difficult part of block counting is to ensure that the entire block has been searched but that no animals have been counted more than once, and this becomes quite hard to do with large blocks that may contain many animals. This is basically the observer's responsibility, it being up to him to keep track of the area which has been covered and to tell the pilot to deviate as necessary to fill in any gaps. The observer must keep track of the

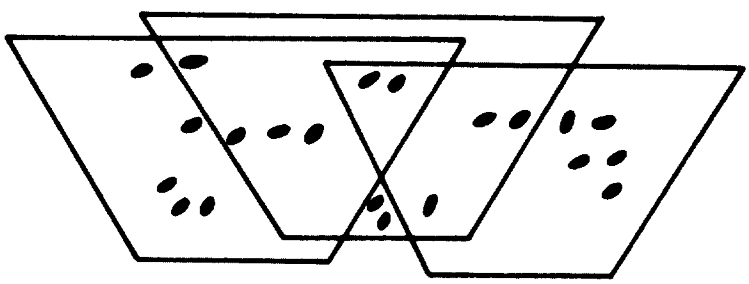
Fig. 12 To ensure overlap on photographs, the nearside of the viewfinder must be used.

a) no overlap on the near side misses some animals



AIRCRAFT

b) correct overlap; all animals are photographed



AIRCRAFT

aircraft's position by marking in the flight line on his map as well as the area scanned (Fig. 13). He must also ensure that there is some overlap between one strip and the next. Each group of animals must be given a serial number which is then marked in on the map in the position where the group was seen. The species and number of individuals is recorded on a separate data sheet or tape, along with the frame numbers of any photographs taken. In this way the map serves as an up-to-date record of the animals seen without becoming unduly cluttered. This procedure keeps the risk of double counting within reasonable bounds, and gaps in coverage become evident while there is still time to rectify them. The observer must also record the start and finish time of each block.

The flying height is variable and will depend upon the species being counted and the thickness of the vegetation. The great difference between block and transect sampling is that in block counting the important thing is to be able to spot groups of animals. The aircraft can then deviate to the group in order to count it. A height of 500 - 700 feet is very suitable for elephant and buffalo in reasonably open country, while a much lower height would be required for impala or gazelle. The distance between successive beats will also depend upon the species concerned as well as the thickness of the vegetation. With elephant and buffalo in fairly open country a distance of 1.5 to 2 km is possible[49], whereas with smaller species a very much narrower strip would be necessary (e.g. 300 - 400 metres). The strip width for a block count can only be discovered by trial and error in the area concerned. The most important thing, however, is that there must be some degree of overlap between successive strips.

Large groups of animals should always be photographed for counting later, but a visual estimate should also be made at the same time. For compact herds of animals a single oblique photograph will suffice. For larger herds, especially buffalo, the pilot must make a straight-line pass along the herd so that the observer can take overlapping photographs. The pilot must not circle the herd otherwise it becomes out of the question for the observer to ensure that he has photographed all the animals, and it becomes totally impossible to sort out the areas of overlap on the photographs (Fig.14).

Block counts become very difficult to carry out if many species are being counted - unless the density of each is low. They are thus best suited to single species counts, and to highly conspicuous species at that.

6.7 An 'Ideal' Aircraft/Crew

Everyone has slightly different ideas of the best aircraft/crew configuration for aerial sample counting. An ideal arrangement, if money were no object, would be the following.

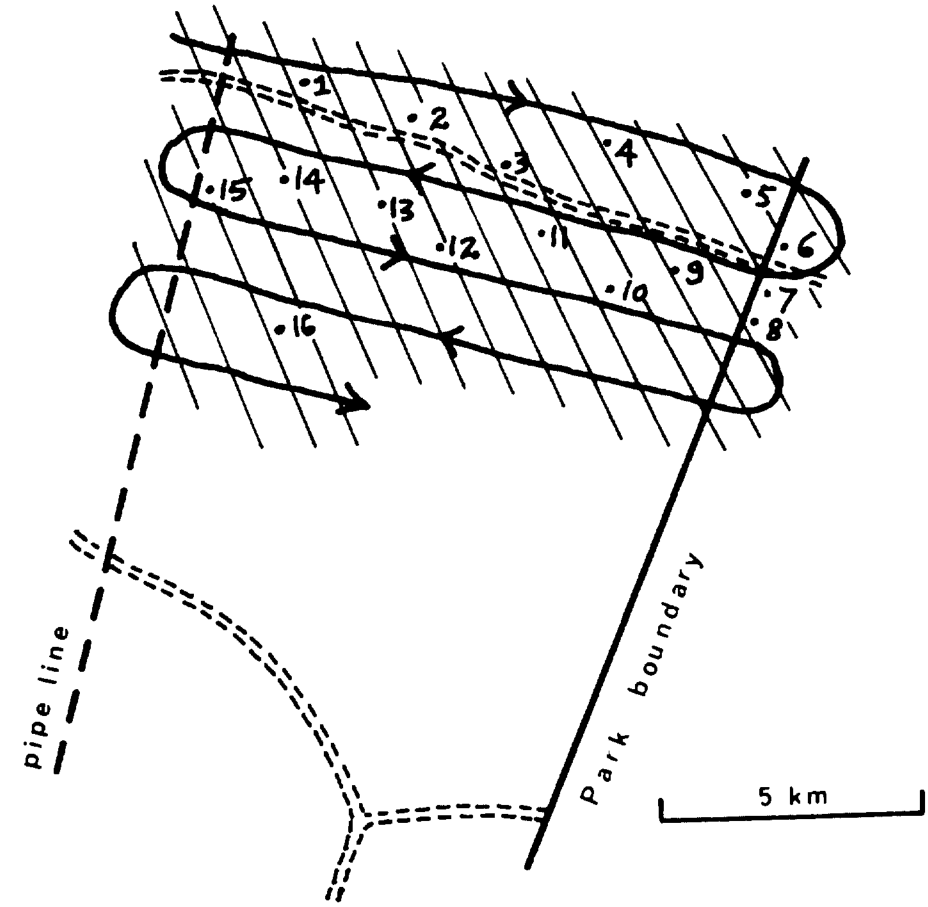
Aircraft : a Cessna 182 (or 180) high-wing monoplane fitted with long range fuel tanks and a radar altimeter. The rear windows would be made removable, and the rear bench seat would be replaced with two separate chair seats, each inclined slightly outboard.

Crew : pilot : concerned with navigation, height and speed control etc.

recorder : sitting alongside the pilot, helping with navigation, timekeeping, recording radar altimeter readings, recording other information (e.g. range conditions, etc.)

2 observers : in the rear seats, equipped with motorised Nikon cameras with 50 - 80 mm zoom lenses and 250 exposure casettes. They would also have tape recorders with throat microphones and earplug playback, with the recorder controls attached to the cameras.

Fig. 13 An example of a block count using the zig-zag flight line. the observer has marked in the aircraft's path (except for odd diversions) and has shaded the searched areas. As each group is seen it is given a number, plotted on the map, and entered on the data sheet.



Example of Data sheet

BLOCK 7
Date 15. 4.72

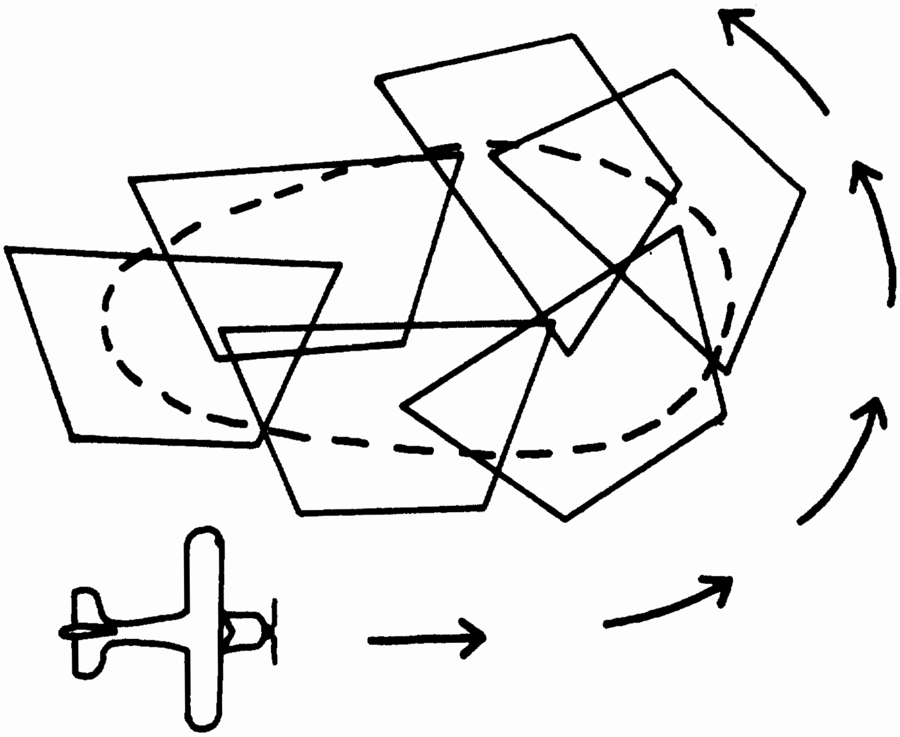
A/c : 5Y KSN
Pilot : X.Y.Z.

Observer : A.B.C ; D.E.F.
Start : 0815
Finish : 1020

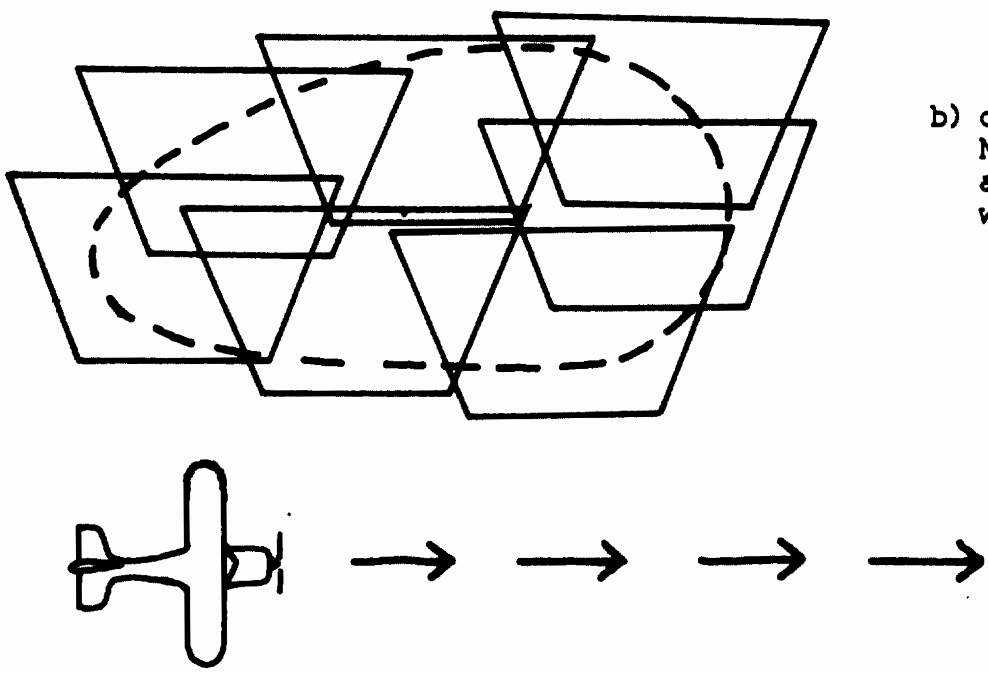
Group	Species	Estimate	Frames	Film No.	Photo count
1	B	4	–	3	–
2	B	460	4		683
3	E	7	–	–	–
4	B	52	1	–	79
5	E	2	–	–	–
6	B	1,500	3+4	–	2,134

Note : B = buffalo, E = elephant

Fig. 14 When photographing a large herd the pilot must make a straight line pass along it. He must not circle.



a) wrong flight path. Some areas have been missed and it will be impossible to work out areas of overlap.



b) correct flight path. No areas are missed and overlap can be worked out.

SECTION 7 WORKING UP THE RESULTS FROM AN AERIAL SAMPLE COUNT

7.1 Introduction

Like everything else to do with aerial sample counting, working up the results is 90% common-sense and 10% rule following. The methods discussed below are based on those of Jolly[27] and the same terminology is used.

It seems sensible to discuss the methods in terms of a worked example from a fairly straightforward type of aerial sample count. The data come from an aerial transect count of a 2829 km^2 census zone (which is here referred to as the 'northern study area'). A base-line of 69 km was constructed, along which twelve random points were chosen. The transects were run through these points at right angles to the base-line, crossing the census zone from one side to the other. The transects varied in length between 15 and 47 km. A four-seater aircraft was used, with the pilot taking care of navigation and height control, the recorder making records of the reading from the radar altimeter once every minute, and two observers in the back who were using tape recorders and cameras. The animals counted were wildebeest, giraffe, topi and impala. Any group larger than ten animals was photographed as well as estimated visually. The observations were split up into successive 5 km intervals along each transect so that distribution data could be obtained, the pilot calling out to the observers when each sub-unit was started. The nominal flying height for the census was three hundred feet. Calibration flights before the census showed that this gave a nominal strip width of 514 metres; 244 metres for the left hand observer, and 270 metres for the right hand observer.

The first point to consider is that the transects are of different length, for this will obviously inflate the sample variance because the longer transects will tend to have more animals in them than the shorter ones. This is taken care of in the analysis by using Jolly's Method 2[27] for unequal sized sampling units. In this method the area of each of the transects has to be known, as well as the area of the whole census zone. The second point is that two observers were used. Unfortunately, it is not possible to treat each observer's observations as though they were independent, so the observations have to be merged once counting bias is corrected for. This simply means that the numbers of animals counted by both observers along the length of each transect are added together. Similarly, the strip width is taken to be the sum of both observers' strips.

7.2 The Stages in the Analysis

There are basically six stages to go through :-

* calculating the actual strip width, and N (the total number of units in the population from which the twelve transects were chosen)
* calculating the area of each transect, and the area of the census zone
* transcribing each observer's observations onto raw data sheets, and counting the photographs
* correcting each observer's counting bias from the photographs
* merging the observations from each observer, and checking for consistency
* preparing the final data sheets, and calculating the population estimates.

Note that the data from each observer are kept 'separate' until the last stage.

(i) Calculating the actual strip width, and N

The nominal strip width for this census was 514 metres at a nominal flying height of 300 feet. This was found in the way described in Section 6.5 (i) (page 53). The actual strip width during the census will of course depend upon the actual flying height, and this is found by averaging all the recordings from the radar altimeter. In this example the actual flying height was found to be 320 feet. The actual strip width is now found by using the same formula for calculating the nominal strip width.

Let h be the nominal flying height (e.g. 300 feet)

w be the nominal strip width (e.g. 514 metres)

H be the actual flying height (e.g. 320 feet)

W be the actual strip width

then, $W = w \cdot H / h = 514 \times 320 / 300 = 548$ metres = 0.548 km.

Thus, at the actual average flying height of 320 feet during the census the actual average strip width was 548 metres.

N is the total number of units in the population from which the sample was drawn, which in an aerial transect sample count is found by dividing the length of the base-line by the actual strip width during the census. In this example the base-line, measured from the map, was found to be 69 km in length. N is therefore given by

$$N = 69 / 0.548 = 126$$

Thus, 12 out of a possible 126 transects were sampled, giving a sample fraction of 12 / 126 x 100 = 9.5%.

It will be realised that most of the bias from inaccurate height control is removed by using the actual strip width in these calculations.

(ii) Calculating the area of each transect, and of the census zone

The area of each transect is found by measuring its length from the map and then multiplying this length by the actual strip width. These calculations are shown in Fig. 18. Thus for transect number 1

$$\text{area} = 15 \text{ km} \times 0.548 \text{ km} = 8.2 \text{ km}^2$$

At this stage gross errors in navigation, of the type mentioned in Section 6.4 (i), can be corrected for.

The area of the census zone is found directly from the map by any of the methods mentioned in Section 3.5. In this example the area of the census zone is 2829 km^2.

(iii) Transcribing the tape record onto data sheets (Fig. 15)

Fig. 15 shows the general lay-out of a data sheet suitable for the initial transcription of the tape record. The first point to note is the full documentation shown at the top of the data sheet in which all the details of the census are recorded, as well as the name of the observer and the side of the aircraft on which he was sitting. The objective of this initial transcription is to write down all the observations in the order in which they were made so that the photographs can be matched to the visual estimates.

The various columns of the data sheet are self explanatory.

TR gives the transect number.

s/u gives the sub-unit number. These sub-units were 'called off' by the pilot during the census, and they allow densities of animals to be plotted at different points along each transect so that a better idea of the distribution of the animals can be gained. Where two sub-units numbers follow each other on the same line (e.g. 1 - 2 in transect 2) this means that no animals were observed in the first of the sub-units. Thus, the observation 'Gir 6' refers to the second sub-unit (e.g. sub-unit 2) and not to sub-unit 1.

s/st the start and stop time of each transect.

film the number of the film in the camera. Note the change of film at the beginning of transect 4.

sp species of animal that was observed. In this example W refers to wildebeest; Gir refers to giraffe; Imp refers to impala; and T refers to topi.

vis the visual estimate of each group of animals.

ph the number(s) of photographs taken of each group, following the convention of Section 6.5 (iv). Note the 'blank frame' recorded in transect 3, sub-unit 3.

ph.c the count of the number of animals off the photograph(s). This is filled in at the next stage.

other other information.

The tape record transcribed onto Fig. 18 would have been somewhat as follows :-

"date eleven three seventy two - northern study area - aircraft Cessna one eighty two - pilot DEF - observer JKL - on left hand side repeat left hand side of aircraft - tape number forty six - take off time zero seven two five - film number fourteen loaded - transect one repeat transect one starting at zero seven five zero - sub-unit one - wildebeest fifteen one frame - wildebeest ten one frame - sub-unit two - two lions - giraffe five - sub-unit three - impala twelve one frame - impala ten one frame - water pools - end of transect at zero seven five eight - transect two repeat transect two - start at zero eight zero zero - sub-unit one - sub-unit two -

Fig. 15 Data Sheet for Tape Transcribing

Date : 11.3.72
Census : Northern study area
Take Off Time : 0725
Landing Time : 1235

a/c : C. 182
Pilot : D.E.F.

Obs. : J.K.L.
Side of a/c : left
Tape No. : 46

TR	s/u	s/st	film	sp	vis	ph	ph.c	Other Information
1	1	0750	14	W	15	1		
				W	10	1		
	2			Gir	5			2 lions
	3			Imp	12	1		
		0758		Imp	10	1		water pools
2	1-2	0800		Gir	6			
	3			Imp	26	1+2		all in transect
	4			W	15	1+1		grassland
				T	6			
	5	0842		T	5			
3	1	0855		W	4			
				W	7			
				W	14	1		
				W	16	2		
	2			T	1			
				T	3			
				W	13	1		
				W	11	1		
	3			T	27	2/1/1+2		last 2 photos unusable
	4					blank		-note blank frame
				W	3			
				T	4			
	5							woodlands - nothing to see
	6			Imp	24	2/1		
				Gir	8			
				Imp	26	1		
	7			Imp	1			
				Imp	46	3		
	8-9			Imp	35	1+2		
				T	1			
	10	0938		T	16	1		
4	1	0950	15	Gir	1			
				W	3			

etc. etc. etc.

giraffe six - sub-unit three - impala twenty six one plus two - all in transect - sub-unit four wildebeest fifteen one plus one - grasslands - topi six - sub-unit five - topi five - end of transect zero eight one two - transect three - start at zero eight one five - sub-unit one - wildebeest four ..." etc.

Once this initial transcription has been made, and checked, then the photographs can be matched to each visual estimate and the photographic counts written in alongside the appropriate observation. The same procedure will of course, be applied to the tape record of the second observer who was sitting on the right hand side of the aircraft.

(iv) Correcting for counting bias by using the photographs (Fig.16)

The objective here is to correct the visual estimates for counting bias by using the counts off the photographs so that you end up with the total number of each species that the observer counted along the length of each transect. Fig. 16 shows a data sheet suitable for this. Note firstly that one of these data sheets is required for <u>each</u> transect, and secondly that full documentation is repeated at the top of each data sheet.

The data shown in Fig. 16 come from transect 3 on Fig. 15, from which it can be seen that the observations for each species are entered in separate columns. The column heading 'vis' refers to the visual estimate, while 'ph.c' refers to the count off the photographs. Everything is very straightforward so long as all photographs can be counted, but unfortunately this is rarely so. Inevitably some photographs will be useless, either because they are blurred, or because the exposure was wrong, or for some other small reason. However, these gaps in the photographic record can be corrected for.

In this example every group of animals larger than 10 was photographed as well as being estimated visually. We can therefore define

x_1 which are those groups less than ten animals for which no photographs were taken

x_2 groups larger than 10 animals which were photographed, but which for some reason a photographic count was not possible (e.g. the wildebeest group of 13 and the impala group of 46 in Fig. 16)

x_3 groups larger than 10 animals, which were photographed, and for which a photographic count was possible

and x_4 the photographic counts of those groups.

We can also define

y' as the total number of each species counted along the length of a transect, corrected for counting bias from the photographs.

If every group of animals larger than 10 was photographed, and if a satisfactory count from those photographs was possible, then y' is given simply by

$$y' = x_1 + x_4$$

which is just the sum of the groups less than 10 animals, and the sum of the photographic counts of groups larger than 10 animals.

This is shown in the lower part of Fig. 16. x_1, x_2, x_3 and x_4 should be self explanatory. In the last line of Fig. 16 there are two expressions for y', and it is the first of these we are here concerned with. In the 'giraffe' columns there was only a single observation of eight animals and therefore no photograph was taken. y' is thus given by x_1, i.e. 8. In the 'topi' columns two groups larger than 10 were photographed, and photographic counts were made for both these groups. Here y' is given by $x_1 + x_4$ as explained above.

In both the 'wildebeest' and 'impala' columns there are gaps in the photographic record, there being one 'missing' photographic count for each of these species. The problem therefore is to estimate y' by correcting for the missing photographs. This is done simply by estimating the counting bias from the groups for which photographs were available and then correcting the visual estimate for the groups for which no photographs are available.

We can define the counting bias as

$$B = x_3 / x_4$$

which can be seen to be 0.82 for wildebeest and 0.79 for impala.

Fig. 16 Correcting counting bias from the photographs

Date : 11.3.72 a/c : C. 182 Obs.: J.K.L
Census : Northern study area Pilot : D.E.F. Side of a/c : left
Transect No. : 3

	wildebeest		giraffe		topi		impala	
	vis	ph.c	vis	ph.c	vis	ph.c	vis	ph.c
	4	–	8	–	1	–	24	31
	7	–			3	–	26	34
	14	17			27	31	1	–
	16	19			4	–	46	missed
	13	missed			1	–	35	43
	11	14			16	19		
	3	–						
Σx_1	14		8		9		1	
Σx_2	13		–		-		46	
Σx_3	41		–		43		85	
Σx_4	50		–		50		108	
$B = \Sigma x_3 / \Sigma x_4$	0.82		–		0.86		0.79	
$\Sigma x_2 / B$	16		–		–		58	
$y' = \Sigma x_1 + \Sigma x_4$			8		59			
$y' = \Sigma x_1 + (\Sigma x_2/B) + \Sigma x_4$	80						167	

The visual estimate of the 'missing' photographs can then be corrected by dividing it by this counting bias. Thus, for the wildebeest group of thirteen animals, the correction is 13 / 0.82 = 16 animals, while for the impala group it is 46 / 0.79 = 58 animals. y' is now given as

$$y' = x_1 + (x_2 / B) + x_4$$

It sometimes happens that B cannot be calculated, for instance when there is only one observation within a transect. In these cases all that can be done is to calculate an 'overall' counting bias by summing all the x_3 and all the x_4 from all the transects, and then applying this bias to these isolated observations. The expression here is $B_{overall} = x_3 / x_4$

The final catastrophe is when whole films, covering a number of transects, are lost or destroyed in the developing process. The way around this is explained later in this Section (7.7).

These methods for correcting counting bias from photographs are explained in more detail in published material[39].

(v) Summarising the data from both observers (Fig. 17)

Once all the counting biases have been corrected for the data from both observers are summarised. This is shown in Fig. 17, where 'left' and 'right' refer to the observations of the two observers. Note again the full documentation at the top of the data sheet, and that the figures from Fig. 16 are entered under 'transect 3, left'. The objective here is to calculate, for each species, the value of y which is the total number of animals counted by both observers along the length of each transect. By laying out the data in the way shown it is also possible to see how consistent the two observers are. Theoretically, each observer should see just about the same number of animals. In Fig. 17 it is seen that these two observers are pretty consistent. If there are marked differences between the observers then things can become a bit complicated, as is explained in Section 7.6.

(vi) The final calculations (Fig. 18)

Fig. 18 shows the final steps in the calculations. The first thing to note is the very full documentation in which all relevant information about the census is pulled together (e.g. total flying time, dead time, area of census zone, actual flying height and strip width, the value of N and n etc.). It is always useful to have this information clearly recorded so that it can be used at a later date to improve the efficiency of your census work, or to design further censuses. Then, for each transect, all relevant information is also recorded; namely the transect number, the flying time along the transect, the length, breadth and area of the transect, and the number of each species counted. Finally, there are the various steps in the calculation of the estimate $\hat{Y}$ and the 95% confidence limits.

The calculations shown in Fig. 18 are those of Jolly's Method 2[27] for unequal sized sampling units, which is specifically designed to eliminate the effect of the difference in size between the sampling units. It is known as the 'ratio method' for it is based on the calculation of the ratio between animals counted and area searched. The estimate is thus based on the density of animals per sample unit rather than on the number of animals per sample unit.

The details of the calculations are shown in Table 4. The parameters that need to be known are

- N the total number of units in the population from which the sample was drawn
- n the number of units selected into the sample
- Z the area of the census zone
- z the area of each sample unit
- y the number of animals counted in each sample unit.

The first step is to calculate $\hat{R}$ which is the ratio of all animals counted to all area searched, i.e. it is an estimate of the overall density of animals per unit area within the sample zone. Thus

$$\hat{R} = \frac{\text{total animals counted}}{\text{total area searched}} = \frac{\Sigma y}{\Sigma z}$$

The population total $\hat{Y}$ is now found by multiplying $\hat{R}$ by Z.

The calculation of the population variance is a little more complicated for there are three terms to be enumerated (Table 4). The first and second terms respectively are the variance between the

Fig. 17 Summarising the data from both observers

Date : 11·3·72 a/c : C. 182 Obs. left : J.K.L.

Census : Northern Study area Pilot : D.E.F. Obs. right : X.Y.Z.

TR	wildebeest lft	wildebeest rt	wildebeest total	giraffe lft	giraffe rt	giraffe total	topi lft	topi rt	topi total	impala lft	impala rt	impala total
1	30	28	58	5	7	12	0	2	2	28	12	40
2	18	26	44	6	11	17	11	15	26	33	18	51
3	80	95	175	8	9	17	59	51	110	167	150	317
4	73	68	141	7	5	12	45	37	82	140	182	322
5	70	81	151	11	5	16	40	49	89	26	31	57
6	74	70	144	6	0	6	35	40	75	15	18	33
7	62	69	131	5	1	6	20	22	42	9	0	9
8	65	70	135	5	6	11	29	21	50	36	28	64
9	59	45	104	4	6	10	27	20	47	2	0	2
10	62	49	111	0	1	1	16	7	23	4	0	4
11	62	68	130	0	0	0	18	12	30	0	0	0
12	66	70	136	1	0	1	23	31	54	1	0	1
Σ	721	739	1460	58	51	109	323	307	630	461	439	900

lft = left rt = right

Fig. 18 The final calculations

Date : 1.3.72
Census : Northern study area
Total flying time : 5 hrs. 10 mins
Dead Time : 1 hr. 26 mins
Counting Time : 3 hrs. 44 mins
Base-line : 69 km N = 126 n = 12

a/c : Cessna 182
Pilot : D.E.F.
Obs. left : J.K.L.
Obs. right : X.Y.Z

Actual height : 320 ft.
Actual strip : 548 m
Left strip : 260 m
Right strip : 288 m

Area of Census zone = 2829 km²

TR	time mins	length km	width km	area z	wildebeest y	giraffe y	topi y	impala y
1	8	15	0.548	8.2	58	12	2	40
2	12	25	"	13.7	44	17	26	51
3	23	47	"	25.8	175	17	110	317
4	25	46	"	25.2	141	12	82	322
5	21	40	"	21.9	151	16	89	57
6	20	38	"	20.8	144	6	75	33
7	22	42	"	23.0	131	6	42	9
8	18	35	"	19.2	135	11	50	64
9	20	39	"	21.4	104	10	47	2
10	17	32	"	17.5	111	1	23	4
11	18	35	"	19.2	130	0	30	0
12	20	38	"	20.8	136	1	54	1
			Σz	237	237	237	237	237
			Σy		1460	109	630	900
			Σz^2 or Σy^2	4931	193262	1417	43868	216910
			$\Sigma z \cdot y$		30547	2149	13820	20824
			$\hat{R} = \Sigma y / \Sigma z$		6.16	0.46	2.66	3.80
			s_y^2		1421	39	981	13583
			s_z^2	23	23	23	23	23
			s_{zy}		156	−0.34	125	277
$\hat{Y} = \hat{R} \cdot Z$					17427	1301	7525	10750
$\mathrm{Var}(\hat{Y}) = \frac{N(N-n)}{n} \cdot (s_y^2 - 2.\hat{R}.s_{zy} + \hat{R}^2.s_z^2)$					445079	52883	573050	14136474
$SE(\hat{Y}) = \sqrt{\mathrm{Var}(\hat{Y})}$					667	230	757	3760
95% confidence limits of $\hat{Y}$ = t.SE($\hat{Y}$) where t = 2.2					± 1468	± 506	± 1665	± 8272
95% confidence limits of $\hat{Y}$ as a percentage of $\hat{Y}$					± 8%	± 39%	± 22%	± 77%

TABLE 4

The calculation of $\hat{Y}$ and 95% confidence limits of $\hat{Y}$ using Jolly's Method 2[27] for unequal sized sampling units

Let N = the number of sample units in the population
n = the number of sample units in the sample
Z = the area of the census zone
z = the area of any one sample unit
y = the number of animals counted in that unit
$\hat{R}$ = the ratio of animals counted to area searched $= \frac{\Sigma y}{\Sigma z}$

(1) s_y^2 = the variance between animals counted in all the units

$$= \frac{1}{n-1} \cdot \{ \Sigma y^2 - \frac{(\Sigma y)^2}{n} \}$$

(2) s_z^2 = the variance between the area of all the sample units

$$= \frac{1}{n-1} \cdot \{ \Sigma z^2 - \frac{(\Sigma z)^2}{n} \}$$

(3) s_{zy} = the covariance between the animals counted and the area of each unit

$$= \frac{1}{n-1} \cdot \{ \Sigma z \cdot y - \frac{(\Sigma z) \cdot (\Sigma y)}{n} \}$$

Then, population total $\hat{Y} = Z \cdot \hat{R}$

population variance $\mathrm{Var}(\hat{Y}) = \frac{N(N-n)}{n} \cdot (s_y^2 - 2 \cdot \hat{R} \cdot s_{zy} + \hat{R}^2 \cdot s_z^2)$

population standard error $\mathrm{SE}(\hat{Y}) = \sqrt{\mathrm{Var}(\hat{Y})}$

95% confidence limits of $\hat{Y}$ = $+/- \; t \cdot \mathrm{SE}(\hat{Y})$

(where t is for n-1 degrees of freedom) number of animals counted in each unit and the variance between the areas of each unit. The third term, is the covariance between the number of animals counted in each unit and the size of that same unit, and it is this term that takes into account the area of each unit. Note that this covariance term has the quantity $\Sigma z \cdot y$ in it. This is the sum of the products of the animals counted and the area of each unit in the sample.

The various stages in the calculations are shown in detail in Fig. 18 with all the correct values shown. The only new thing here is the use of t for calculating the 95% confidence limits. This was glossed over in Section 2 where the 95% confidence limits were found by multiplying the $SE(\hat{Y})$ by 1.96. This value of 1.96 is the value of t that is used only when the number of units in the sample is greater than 30. If n is less than thirty then a different t value must be used. The appropriate t value is given for $n-1$ 'degrees of freedom'. In this example n was 12, so the degrees of freedom are $n-1 = 11$. The t value for 11 degrees of freedom is 2.2, so the 95% confidence limits are found by multiplying the $SE(\hat{Y})$ by 2.2. The reason for all this is a bit obscure but is explained in exhaustive detail in statistical texts[1].

The results of this census show very clearly the effect of sample error of animals clumping together. The number of wildebeest in each transect is roughly the same, therefore the 95% confidence limits are low. The other species are much more clumped, the most extreme being impala where two of the transects had large numbers in them, thus the 95% confidence limits of their estimates are much higher. In fact the estimates for giraffe, topi and impala would be more or less useless for most purposes, except as general "order of magnitude" estimates. However, these data would be useful for designing a better census. For example, you could calculate how many transects would be needed to obtain confidence limits of, say, 15% for all species by the methods shown in Section 5.4. You would use the values of s_y^2 for this. Alternatively, the distribution of the animals in each sub-unit of each transect could be plotted to see whether the transects were oriented in the 'best' direction. In this example, I would expect that much better results would be obtained if the transects were oriented at right angles to their present direction. This would certainly even out the marked clumping shown by the impala.

7.3 Multi-Species Aerial Block Counts

The procedure for block sample counts is exactly the same as that outlined above. The only differences are that N is given by the number of blocks into which the census zone was divided, and both Z and z are measured directly off the map.

7.4 The Method for Equal Sized Sampling Units

With quadrat sampling, and sometimes with transect sampling, the sample units are all of the same size. In this case Jolly's Method 1[27] is used for calculating the estimate $\hat{Y}$ and the 95% confidence limits. The population estimate is calculated from the average number of animals counted in each unit, while the population variance is calculated from the variance between the number of animals counted in each unit. The calculations are shown in Table 5.

With transect sampling N is found in the way described above in 7.2. With quadrat sampling N is given by the total number of quadrats into which the census zone could be divided.

7.5 Stratified Sample Counts

If the census zone has been stratified and separate samples drawn in each of the strata, then the same procedures are applied to <u>each</u> stratum separately. A $\hat{Y}_h$ and a $Var(\hat{Y}_h)$ are calculated for each stratum, and these are then added together (Table 6). The estimate for the whole census zone is thus merely $\Sigma\hat{Y}_h$, the subscript $_h$ denoting a stratum, while the $SE(\hat{Y})$ is given by

$$\sqrt{\Sigma Var(\hat{Y}_h)}$$

7.6 Some Complications

(i) Two aircraft in the same census zone

When two aircraft count in the same census zone the procedures are very much the same with respect to the observers, e.g. correcting each observer's counting biases before merging

TABLE 5

Calculating $\hat{Y}$ and the 95% confidence limits of $\hat{Y}$ using Jolly's Method 1[27] for equal sized sampling units

Let N = the total number of units in the population

n = the number of sample units in the sample

y = the number of animals counted in any one unit

$\bar{y}$ = the sample mean = $\Sigma y / n$

s_y^2 = the sample variance, e.g. the variance between animals counted in all the units

$$= \frac{1}{n-1} \cdot \left\{ \Sigma y^2 - \frac{(\Sigma y)^2}{n} \right\}$$

Then,

population total $\hat{Y} = N \, . \, \bar{y}$

population variance $\mathrm{Var}(\hat{Y}) = \frac{N(N-n)}{n} \cdot s_y^2$

population standard error $\mathrm{SE}(\hat{Y}) = \sqrt{\mathrm{Var}(\hat{Y})}$

95% confidence limits of $\hat{Y} = t \, . \, \mathrm{SE}(\hat{Y})$

(where t is for $n-1$ degrees of freedom)

TABLE 6

Working up the results from a stratified sample count

The procedure is to calculate a $\hat{Y}_h$ and a $Var(\hat{Y}_h)$ for each stratum (subscript h indicating a stratum) and then sum the results. n_h is the number of sample units counted in each of the strata

	$\hat{Y}_h$	$Var(\hat{Y}_h)$	n_h
Stratum 1	4410	492,810	15
Stratum 2	4600	835,440	9
Stratum 3	4590	306,330	21
	13600	1,634,580	45

Thus :

$$\hat{Y} = \Sigma\hat{Y}_h = 13600$$

$$Var(\hat{Y}) = \Sigma Var(\hat{Y}_h) = 1,634,580$$

$$SE(\hat{Y}) = \sqrt{Var(\hat{Y})} = 1279$$

The 95% confidence limits of $\hat{Y}$ would be cound by multiplying $SE(\hat{Y})$ by 1.96, because the value of n (= Σn_h) is greater than 30.

them etc. However, N is a bit more difficult, and it is best to calculate first a mean actual flying height for both aircraft, and from this calculate a mean actual strip width for both aircraft. N is then found by dividing the base-line by this mean strip width.

If, however, the two aircraft had operated in two distinct parts of the census zone, then it is best to keep their results completely separate and to stratify effectively the census zone. Say, for example, one aircraft had counted the western half of a zone and another aircraft the eastern half, then the census zone should be divided into two strata, the division between the strata falling half way between the most eastern transect of the first aircraft and the most western transect of the second.

(ii) Two aircraft in different strata

If two aircraft each count a different stratum then no problems arise for each set of data is treated separately.

(iii) Differences between observers

This is one of the most tricky problems to deal with. If one observer carries out the whole of a census then there is no way of checking his performance, apart from photographic checks. If two or more observers are used in a census then it is wise to check that their performances are about the same. With two observers, each should record about 50% of all the total animals counted. With four observers, each should record about 25% of all animals counted. If two aircraft with two crews are used, then each crew should count roughly the same number of animals. Slight deviations from the expected are in order because there may be real differences in density between the areas where the crews were working, but major differences should be thoroughly investigated.

If, for example, one observer in a crew of two sees 75% of all the animals then something has gone badly wrong. Check first that there was not a marked difference in the strip widths on the two sides of the aircraft. If not, then some other factor must have been responsible. One observer might have been airsick, or always looking into the sun. The other might have slumped in his seat so that his observed strip was always wider than it should have been. He may have been mixing up species and treating two species as one.

The observer with the low count might have been asleep (check the tape record). The cause of the discrepancy must be discovered so that it does not happen again, for aerial counts cost a great deal of money which should not be wasted unnecessarily. If it can be shown that one observer must have been 'wrong' then there is nothing for it but to discard ali his observations from the census.

7.7 Correcting for Total Bias

It may sometimes be necessary to find out how much bias is still present even after all normal precautions have been taken. For instance, if exact cropping quotas are needed, or if metabolic weights or biomass figures are required. This is expensive to do, so the first step is to make a rough estimate of how much bias you might expect to be still present. If it is less than 10% of the standard error of the estimate then it will not affect the accuracy of the estimate[13]. If you still want to go ahead then there are a number of different ways.

(i) Recounting a sub-sample of units

A method is available[28] for correcting total bias by re-counting a sub-sample of the sample units chosen into the initial sample.

(ii) Census the same area using a different method

There are methods[37,38,49] of checking aerial sample counts by aerial censuses of a different type, while another publication[41] compares aerial methods against ground methods. The hypothesis is that if two different methods give the same results then both methods are as accurate/inaccurate as each other. In all these examples the different methods gave the same results, but it would have been illuminating to see the authors' argumentation in choosing one 'accurate' method and one 'inaccurate' method had the results been widely different.

It is usually assumed here that one of the methods is more likely to be more 'accurate' than the other, but great care must be taken over this. For example, a comparison has been made between ground and air counts of rhinoceros[21]. It was found as a result of long and careful counting on the ground, in which known animals were looked for, that there was a population of a certain number of rhinoceros. From all the aerial counts it was found that on average, only 70% or so of the animals were seen. It was therefore assumed that in an aerial census of rhinoceros one only saw 70% of the animals present; so all the aerial census figures were corrected accordingly. Unfortunately, a single aerial census was never compared against a single ground census, for it is quite possible that at any one time there were only 70% of the known animals in the study area anyway.

(iii) Correcting for bias with large gaps in the photographic record

If films are lost after a census then a number of transects will have no photographic record with which the observer counting bias may be corrected. The way around this problem is to use the same method as that proposed[28] for a recount of a sub-sample of sample units. In the photographic example, for some transects you will have both an 'accurate' count in which the counting bias is corrected for as well as an 'inaccurate' count. For those transects for which the photographs are missing you will have only an 'inaccurate' count. This is exactly equivalent to Jolly's example[28], so his method of bias correction can be used.

(iv) Correcting for bias caused by undercounting (see Appendix 3)

Some rather sophisticated mathematical methods for correcting this type of bias have been developed[10,11]. However, since they have yet to be fully tested in practice, they will not be elaborated here.

7.8 Methods for Comparing and Merging Estimates[12]

(i) Testing the difference between two estimates

It is often required to test the difference between two population estimates and to find out if this difference is statistically significant. You may wish to find out whether a population of animals has changed in size, or perhaps whether two different methods give the same results. The statistical test given below only applies if the number of sample units counted is in excess of thirty. With smaller samples than this it becomes increasingly difficult to test the difference between two population estimates. It must also be realised that the test is based on the degree of sample error alone, and it does not take into account any differences in bias between the two estimates. It is also assumed that the two samples were drawn completely independently from each other.

Given that these assumptions are met, then assume you have a $\hat{Y}_1$ with $Var(\hat{Y}_1)$ and $\hat{Y}_2$ with $Var(\hat{Y}_2)$.

then let $$d = \frac{(\hat{Y}_1 - \hat{Y}_2)}{\sqrt{(Var(\hat{Y}_1) + Var(\hat{Y}_2)}}$$

If d is greater than 1.96 then the two estimates are significantly different from each other at the 5% level.

Cochran[12] discusses this in more detail, especially the cases where the sample size is less than thirty.

(ii) Merging two or more independent estimates

If two or more independent estimates are not significantly different from each other it may be advantageous to merge them, for the result will have lower 95% confidence limits than either of the original estimates[3,37,38]. It is done by weighting the estimates inversely to the size of their variance[12].

For example, you have $\hat{Y}_1$ with $Var(\hat{Y}_1)$ and $\hat{Y}_2$ with $Var(\hat{Y}_2)$.

Let $$w_1 = 1 / Var(\hat{Y}_1)$$

$$w_2 = 1 / Var(\hat{Y}_2)$$

Then the merged estimate $$\hat{\hat{Y}} = \frac{(w_1 \cdot \hat{Y}_1) + (w_2 \cdot \hat{Y}_2)}{w_1 + w_2}$$

and $$Var(\hat{\hat{Y}}) = 1 / (w_1 + w_2)$$

$SE(\hat{\hat{Y}})$ and the 95% confidence limits are worked out in the normal way.

(iii) Merging many independent estimates

In some circumstances sample counts are made at regular intervals to study the distribution of animals with respect to vegetation types. In this type of sample count the objective is not to obtain a population estimate as such, but to calculate densities in different vegetation types, or in different areas, at various times during the year, and these censuses therefore tend to give population estimates with very high variances. Nonetheless, it is possible to make use of these estimates and to arrive at a single

SECTION 8 VARIOUS SAMPLING PROBLEMS

8.1 Introduction

The objective of this Section is to demonstrate the flexibility of aerial sample counting by discussing the way in which various investigators have solved difficult problems. Some of the basic principles of sample counting should also be made more clear by these examples.

8.2 Lack of Good Maps

It might be thought that the lack of good maps would create insurmountable problems, but this is not so. Admittedly, the complete absence of maps would necessitate a certain amount of careful thought, but some form of sample count would still be feasible.

The first example[37] comes from a sample count of the Serengeti migratory wildebeest. The problem here was not a lack of good maps, but that it was completely impossible to define a census zone, for the animals would move out of it during the census. Instead, a base-line was set up which was long enough to ensure that the wildebeest were unlikely to move 'off it' at either end. Random points were chosen along this base-line through which transects were flown at right angles to the base-line. Movements of the wildebeest away from the base-line were then taken care of by simply extending the transects until no more wildebeest were encountered. Similarly, a transect was not 'started' until wildebeest were reached. The transects were all of different lengths, but by treating them as if they were of the same length a perfectly valid population estimate and variance was achieved, even though the variance was undoubtedly overinflated.

A similar problem was encountered on the Kafue Flats in Zambia where lechwe were being transect sampled[3]. This was a flood plain, the only map available having merely the main river channel marked on it. This river line was therefore used as a base-line and random points were located along it. Transects were flown through these points at right angles to the river, which were continued along until no more lechwe were located. Again, a perfectly valid estimate was achieved by treating the transects as if they were all of the same size.

Returning now to our hypothetical blank map. It would be quite possible to establish a base-line between two prominent landmarks and to measure its length by flying from one end to the other a number of times (reciprocal flights) whilst recording the time taken together with indicated airspeed. Random points could then be located along this base-line on a flying time basis, and a perfectly valid transect count carried out.

Sophisticated navigational aids are available, such as the Very Low Frequency (VLF) navigation system. This permits transects to be flown over featureless terrain with great accuracy. However, the capital cost of such a system is high and it has to be decided whether the results justify the added expense.

8.3 Stratifying out Large Herds

A research worker was studying topi in the western corridor of the Serengeti National Park, Tanzania, where he carried out routine aerial transect counts in a number of study areas. In some of these the topi were fairly evenly distributed except for a number of large breeding herds. Transect sampling thus gave highly inconsistent results, for on some occasions no transect would pass through these herds (so the estimates were low) whilst on others a number of transects would pass through them (in which case the estimates were ludicrously high). This incidentally, is another example of how clumping affects sample error. His solution to this problem was most elegant. If a transect cut through a large breeding herd then the observers did not count any of the animals but instead marked the location of the herd on the map. Similarly, they marked in the location of any other large herd that they saw. After the census the aircraft visited each of the herds in turn to photograph all the animals in them. This was effectively stratifying out the large herds. Two estimates were thus obtained, one from the transect count, and one from the 'strata of large herds'. The first estimate had a variance attached to it, whilst the second, coming from a total count on photographs, had no variance attached to it. The final estimate was therefore given by adding the two estimates together (i.e. the transect estimate of the scattered animals and the total count of large herds) and the variance was given by the variance of the transect estimate alone.

8.4 Stratifying After the Event

This is a technique of dubious legality that should be used with caution. Cochran[13] in discussing the conditions under which it may be used sets up so many conditions that its use seems limited, but Yates[66] has a much more free and easy outlook towards it, and recommends it wholeheartedly. In any event, it has been used with good effect[3,37,38,48]; one gets the impression that other authors have used it without admitting as much.

The principle is that since a set of transects has been distributed randomly along a base-line, then if neighbouring transects have very similar densities of animals in them this truly represents strata of similar density along the base-line. Sets of neighbouring transects can therefore be grouped into strata on the basis of their density, and a great reduction in sample error will result. The main application of this method is in multi-species counts where different optimal stratifications can be made for each species.

8.5 Completely Photographic Methods

In some instances the density of animals is so high that they can in no way be counted by eye. The Serengeti migratory wildebeest presented this problem, which was solved by using vertical aerial photography from a fixed height along the length of each transect[37]. The width of the 'transect' was given by the width of a photograph, which can be calculated so long as the flying height and the focal length of the lens are known.

Infra red photography[23] along the entire length of transects was experimented with, the results of which were promising - though very expensive. Experiments using video-tape have been tried, but with limited results.

8.6 Cattle Counts

An elegant method was designed[63] for counting Masai cattle which used to present great difficulties because of their highly aggregated distribution. It was realised that Masai 'bomas' could be easily counted from the air, and that the total number of bomas in active use could be rapidly assessed. All that was then required was to fly over the bomas early in the morning just as the cattle were being taken off to graze, and photograph the herds. In fact a total count method was used here, but this could easily be adapted for sample counting..

SECTION 9 AERIAL TOTAL COUNTS

9.1 Introduction

The objective of a total count is to locate and count every single animal in a census zone. This is effectively the same as taking a 100% sample and there is therefore no sample error attached to the final estimate of numbers. Unfortunately this has led to the rather uncritical acceptance of total count figures, for people have tended to overlook the fact that other sources of error and bias become proportionally much more important. The main sources of bias in total counts are from failing to search the whole area, failing to locate all the animals and failing to count the animals accurately. Although it is perfectly possible to organise things in such a way that these sources of bias are minimised it is nonetheless extraordinary how many investigators have failed to do so, and it is even more ectraordinary that they are still failing to do so today.

An example of the kinds of problem encountered in total counts comes from work carried out on elephant in Uganda[7]. The census zone was being covered in long parallel transects which were run on strict compass courses, covering the ground at a rate of 670 km^2/hr, not using photography. This approach can be criticised on the following grounds. Firstly, the use of long transects makes it almost impossible to ensure that the whole area is searched, because by the time that the crew gets 'back' to an area they will have forgotten what was there, what the groups of animals looked like, how far they could see et. Secondly, the searching rate of 670 km^2/hr is far too high, especially for elephants. Even with highly conspicuous animals such as buffalo, where one is searching for large and obvious herds, a searching rate above 250 km^2/hr is impracticable. Finally, the failure to use photography can but only mean that the observers were grossly underestimating those animals that they managed to see. Four counts were carried out in which were found 5611, 6126, 7454 and 7815 elephants. This shows very clearly an increase in searching efficiency as they came to terms with a difficult method of censusing. It does not show an increase in elephant numbers, which is what the authors assumed. The last figure of 7815 elephant was within the range achieved by other observers[6] who were counting the same area some 6 years previously. They divided their census zone into blocks and searched each block in turn, for they realised that by doing this one stood a better chance of ensuring that the whole of a block was covered.

Much better work was done in the Kruger National Park[43], in that blocks were being counted and the observers were using photography on large herds. Even so, earlier than this, observers counting in Ngorongoro Crater and Manyara National Park, Tanzania, had already developed the basic technique for total counting[57,59]. They divided the census zone into blocks, then searched each block intensively plotting on a map the course of the aircraft and the location of all groups seen, using photography on large herds. By doing this they greatly minimised the most potent sources of bias.

An example of total counting carried out in a sensible fashion is provided by a series of total counts of elephant and buffalo in the Serengeti National Park, Tanzania. This work is written up in detail[49]. The method used was developed from earlier work[59]. As these total counts had been carried out each year since 1962, the problems encountered were to find out the sources and magnitude of any biases, to find out if the biases had been consistent from count to count, and to correct for these biases. Once this was done some meaningful statements could be made about changes in the number of buffalo.

9.2 The Method Used for Total Counting the Serengeti Buffalo[49]

(i) Blocks

The census zone of some 10,000 km^2 was divided into blocks, each block being searched by an aircraft. The boundaries of the blocks were easily observable roads, rivers or ridge tops, taking about 2 - 6 hours each to count. The advantage of using blocks is that navigation is less of a problem while it is easier to keep track of where you are and which areas have already been covered.

(ii) Searching (see Section 6.6)

Each block was searched systematically at a height of 500 - 800 feet. The flight lines, determined by the observer, were usually run across the shortest dimension of the block. This made it easier for the observer to keep track of his position.

(iii) Counting

Both observer and pilot had maps of the block. The path of the aircraft was marked in by the observer who also shaded in the portions searched. The location of each group of animals was marked in on this map, all large herds (above 20 animals) being photographed. In this way it was possible to detect gaps in the searching pattern whilst there was still time to do something about it. Double counting was minimised, and if it occurred then it could be detected from the photographs. Visual estimates were also made of the photographed herds to guard against photographic failure (see Section 6.6).

(iv) Overlap and searching rate

All searching extended two kilometres into neighbouring blocks so that there was a four kilometre overlap zone. This overlap zone was therefore counted twice, which later gave an indication of how many animals were being missed. In addition, the time taken over each block was recorded so that the searching rate (i.e. the rate of coverage of the ground) could be assessed.

9.3 The Magnitude and Consistency of Biases

The two major sources of bias in a total count are interrelated. The first is the proportion of the total area that is left unsearched, while the second is the proportion of the animals that is missed by the observer. In these censuses the observer had to decide how far away from the aircraft he could see the buffalo herds, and this determined the distance between the flight lines of the aircraft. There are therefore two main indices of searching 'efficiency'; the time taken over a block and the mean distance between flight lines. The consistency of searching efficiency between censuses can therefore be measured by investigating the consistency of these two factors. However, this does not give any idea of the absolute level of searching efficiency, which can only be found by careful experimentation.

(i) Absolute counting efficiency

An experimental census block of 195 km^2 was searched by four observers on separate flights in the course of a morning. The observers had all participated previously in these total counts, and they were told to census the block in the same way. Each observer's efficiency was measured by comparing the number of herds, and the number of individuals, that he located with the number known to be in the block. To start with, the pilot alone searched the block noting on a map the location of all herds that he saw. The first observer's efficiency was then tested against those herds that the pilot had seen, 'new' herds being marked on the map for the second observer. The second observer's efficiency was then tested against the known herds that the pilot originally saw plus the new ones that the first observer saw, and so on. The results showed that at a mean searching rate of 240 km^2/hr, 94% of the herds and 89% of the individual animals were being found.

In a separate experiment observers were required to spot a small herd of buffalo lying down in thick shade during the heat of the day, the most difficult conditions under which to observe buffalo. The maximum distance at which this herd was located was found to be 1.5 km away from the aircraft.

These two simple experiments therefore give absolute values against which observer efficiency on the total counts could be matched.

(ii) Searching rate

From the block times recorded in each census the searching rate was found to fall within the range of the searching rate in the experimental block. Searching rate was therefore constant between censuses, except with the first censuses between 1962 and 1966. The figures from these censuses could thus be corrected up to the average of 240 km^2/hour so that the biases between censuses became constant.

(iii) Distance between flight lines

The distance between flight lines on successive censuses was constant at 2 km (this could be measured off the maps filled in by the observers). The observers were therefore searching on average a strip of 1 kilometre width either side of the aircraft, well within the 1.5 km distance at which the most difficult type of buffalo observation was known to be possible. Variations in distance between flight lines was not found to correlate with the number of animals counted in a block.

(iv) Missed animals

Analysis of the overlap zones between blocks showed that less than 10% of the total number of animals known to be there were missed by either one of the crews. This again compares favourably with the results from the experimental block. The number missed in the overlap zones was constant between censuses.

(v) Visual estimates

The visual estimates, when compared against the counts off the photographs, were between 20% and 40% lower than the photographic counts. The average was 30% low. Apart from demonstrating yet again the fallacy of counting large groups of animals by eye, this enabled the earlier counts in which photography had not been used to be corrected.

(vi) Movements and double counting

Herds counted twice by mistake, or because they had moved between blocks, could be recognised from the photographs and from the located positions on the observer's map. This source of error was found to be negligible and constant between censuses.

(vii) Other factors

Possible sources of error from poor photography, mistakes in counting the photographs, time of day, missed bachelor males and herds in thick forest were all examined, and were found to be small and consistent from count to count.

9.4 The Design of a Total Count

These investigations of the sources and magnitude of biases were carried out in order to be able to test the null hypothesis that there had been no increase in the size of the Serengeti buffalo population. The investigations showed firstly that the absolute bias in the method was small, in the order of -10%; secondly, that the biases were constant between most of the censuses; and thirdly, knowing this, the earlier censuses could be corrected. The null hypothesis could thus be firmly rejected, and it can be safely said that the increase in the numbers of buffalo recorded on successive censuses had been due to an increase in population size and not due to a change in census technique or census efficiency.

The lessons from this for designing a total count are clear. So long as the following simple precautions are taken, reliable and consistent results will be obtained :-

* the census zone must be divided up into blocks, for this makes searching and navigation more efficient.
* the flight lines must be marked on a map, as well as the area searched and the location of each group seen.
* photography must be used on large herds of animals.
* an overlap zone between block boundaries must be counted.
* the time taken over each block must be recorded.
* some experimental work must be carried out to test the observer's efficiency when using the method, for this will show the absolute bias in the method.

9.5 Applications for Total Counts

Total counts are now normally used only when they can be shown to give better results than sample counting. With the Serengeti buffalo, for example, various sampling strategies have been attempted using the flight maps with the location of the herds. It was decided that 95% confidence limits of 10% of the estimate was the minimum precision required, with experiments showing that at least a 90% sample, if not more, would be required. The costs of this would be almost the same as those of a total count, so the total count is for the time being still used.

Total counts over large areas are only practicable with highly conspicuous animals such as buffalo or elephant, for then a strip of around 2 km can be used. If smaller strips have to be used then the method becomes too expensive. The other application for total counting is in small study areas, but even here the method becomes impossible if the densities of animals are high. For example, a biologist had a small study area of some 64 km^2 in the western corridor of the Serengeti National Park which he total counted at regular intervals. Total counts were used because he knew the area well and the animal densities were low. However, when the migratory wildlife populations flooded into this study area the densities became so high that he used sample counting, only reverting to total counts once the migrants had left. The time taken to total count this block at low animal densities was about the same as that taken to sample count it when the densities were high.

SECTION 10 GROUND COUNTING FROM VEHICLES

10.1 Introduction

Ground counts from a vehicle are only practicable when there is good access and visibility and when the animals are reasonably tame to vehicles. Given these conditions reliable and consistent results have been obtained. The great advantage of using a vehicle is that it travels slowly and therefore the counting rate is low. The vehicle can stop as necessary to make highly accurate counts, and there is also time to make incidental observations on behaviour, age and sex structure, condition, state of the vegetation etc. The disadvantage of a vehicle is that the slow rate of ground coverage makes it impracticable for use in really large areas. Vehicles have thus proved ideally suited for detailed studies in small study areas (c. 1,000 km^2) that are well known to the investigator.

Most of the problems concerning the design, implementation and analysis of sample and total counts from vehicles are exactly the same as those met using aerial methods; Sections 5 - 7 therefore apply equally well. From the practical point of view, there are four items of equipment that are essential. Firstly, an aircraft-type compass fitted in the vehicle; secondly, a really reliable range finder which must be carefully calibrated; thirdly, a good pair of binoculars; and fourthly, a roof hatch.

10.2 Block Counts and Total Counts from Vehicles

The objective here is the same as with aerial methods. The whole area must be searched, every animal must be located and accurately counted. The key to success is to map the location of every group that is seen, for this minimises bias from not covering the entire area. Gaps in the searching pattern will be revealed while there is still time to make corrections.

One biologist regularly counted impala and other species in two study areas of 12 km^2 and 6 km^2 in the Serengeti National Park. He knew the study areas (and the impala) extremely well, and was able to map all groups on a 100 x 100 metre grid squares, a level of accuracy unattainable with aerial methods.

In elk studies[35] all groups of animals were marked onto grid squares of 400 x 400 metres, while in other cases all groups were marked onto topographical maps[2,34,51]. In yet another instance all 'large and medium sized' mammals were counted in ten study areas in the Ruwenzori National Park, Uganda[19]. The study areas, which varied between 5 km^2 and 26 km^2, were covered with parallel strips some 800 metres apart and the location of each group was plotted on a map. In Nairobi National Park, Kenya, all animals were counted by dividing the Park into 15 blocks and searching each one[20]. Groups were not mapped, which may account for the fact that later workers in the same area consider that these counts were undercounts.

10.3 Vehicle Transect Counts

Vehicle transect counts are essentially the same as aircraft transect counts. The only difference is that vehicle transects do not usually cross the census zone from one side to the other because of difficulties of cross-country driving (e.g. major rivers, or even minor ones in the rainy season). Instead, investigators have tended to distribute many short transects at random locations within the census zone.

In the flat and open Amboseli Game Reserve, Kenya, the study area was some 600 km^2 and each month the observer[63] drove along a set of 25 randomly located transects, taking about three days. Twenty-five random points were located within the census zone and a five kilometre transect line passed through each of these points (the points were taken to represent the mid point of each transect). The transects were oriented to cut across the major vegetation boundaries. All animals were counted within a fixed strip that varied between 400 metres either side of the vehicle in open country to 200 metres either side of the vehicle in thicker country. The distance of any group of animals to the vehicle was checked with a range finder. The results were worked up using Jolly's Method 2 for unequal sized sampling units[27], and N, the total number of units in the population, was found by dividing the area of the census zone by the average area of all the 25 transects.

Essentially the same method has been employed in two study areas in Samburu District, Kenya; however, the same set of transects were used on each occasion. Other workers have used long transects that crossed from one side of the census zone to the other. Both of these studies used a sub-sampling technique in that instead of counting along the whole length of each transect, the observer stopped every kilometre and counted the number of animals in a circle of 400 m radius from the vehicle. This is a perfectly valid method of sample counting although the formulae for working up the results are slightly complicated[37].

10.4 Problems Concerning Strip Width in Vehicle Transect Counts

There seems, from the literature, to be some considerable confusion as to how to measure the strip width during a vehicle transect count. There are four main methods in use, of which, as far as I can see, only the first two are valid.

(i) Fixed width (Fig. 19.a)

In open country where there is no visibility problem a fixed width of transect strip has been used with success. The width is usually about 400 metres either side of the vehicle, the distance of a group of animals from the vehicle being checked with a range finder[54,65]. The width is chosen to be that at which the investigator is sure he will locate all animals. No bias will occur with this method.

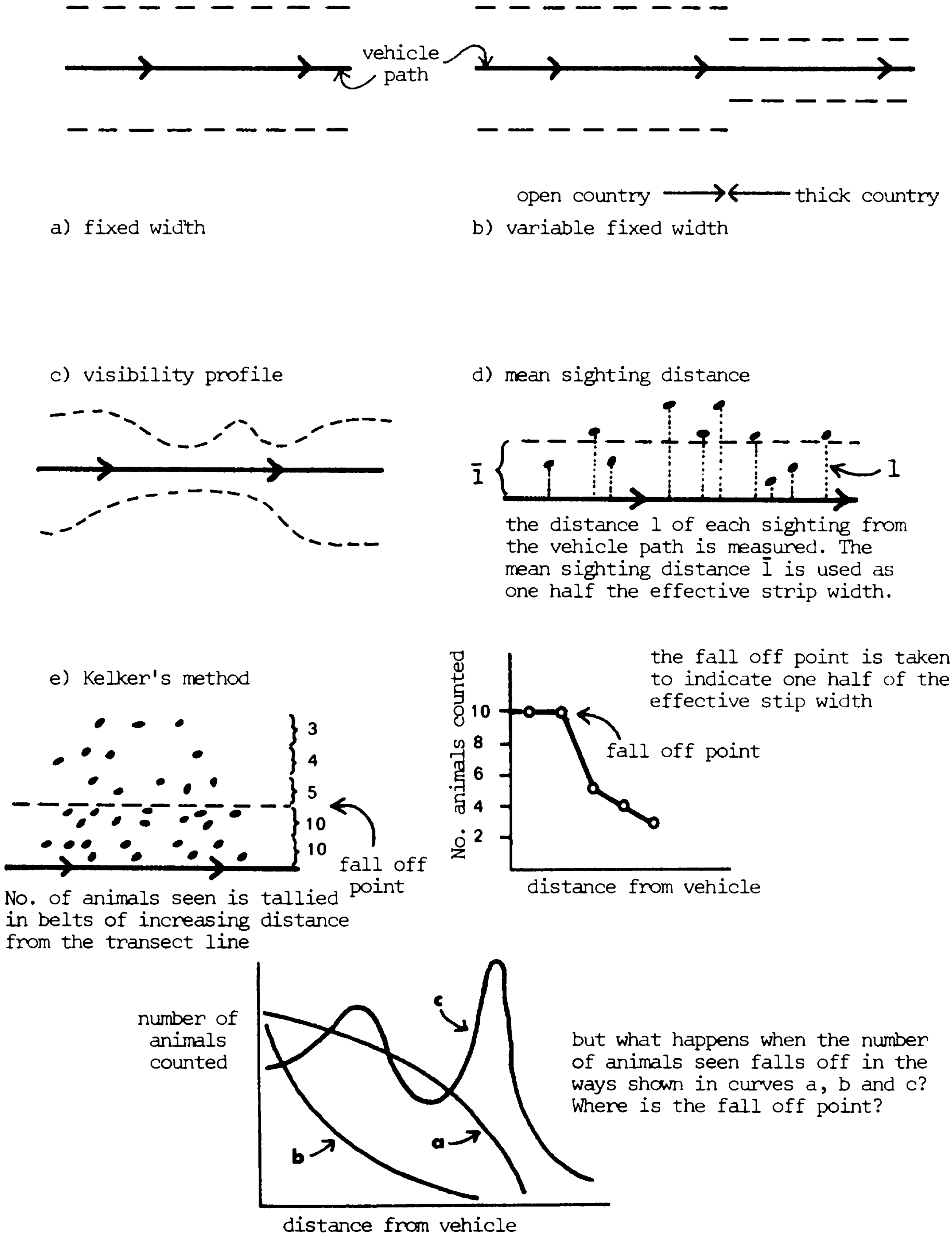
(ii) Variable fixed width (Fig. 19.b)

In open country it is possible to count all animals within 400 metres on either side of the vehicle, while in thicker country this is reduced to 200 metres either side of the vehicle[63]. In both cases there was assurance that all animals within the specified distance could be located, distances from the vehicle being checked with a range finder. No bias will occur with this method.

(iii) Fixed visibility profile (Fig. 19.c)

The concept of a visibility profile assumes that the distance at which an animal can be 'seen' will vary along the length of a transect, and by mapping this visibility profile the area covered by each transect can be measured. All that then has to be

Fig. 19 Methods of determining the strip width when transect counting from vehicles.



done is to count all animals seen along the transect, then divide this by the 'area' of the transect which gives an estimate of density. This method has been applied most in situations where the same transect(s) are run on a number of occasions[31].

The profile can be measured in one of two ways. One method is to get an assistant 'dressed in khaki and carrying a white hankerchief' to walk away from the transect line recording the distance at which he 'disappears'. This is carried out at intervals along the length of a transect, the distances being subsequently plotted on a map. The vanishing points are then joined up and the area covered by the transect is measured from the map. The other method is to record the distance at which all animals are seen, and to use the maximum distances as representing the edge of the transect strip. These distances are again plotted on a map and the area of the transect measured.

At first sight this seems to be a valid approach, but there are, in fact, some grave drawbacks. These are :-

(a) if a khaki clad game scout is used then this tells you the visibility profile for a game scout rather than the visibility profile for large mammals. So far as I know, no one has carried out any experiments to see whether the two can be taken as being the same.

(b) if the maximum distance at which animals are seen is used, then it stands to reason that the larger and more conspicuous animals will be the ones that set the outer limit. The visibility profile may thus refer only to these species rather than to the smaller and less conspicuous ones. None of the investigators who have used this method seem to have considered this. The effect of this is that the estimates of density will be biased by different amounts for different species, which is a very unsatisfactory state of affairs. The bias will tend to be downwards, i.e. the recorded densities will be less than the actual ones.

(c) the visibility profile must change in the course of a year, between dry and wet seasons, between burnt and unburnt. The transect 'area' will thus vary, which will again cause variable biases on the estimates of different species. This again does not seem to be considered by investigators. The effect of this can be very great. For example, if the real density of animals does not change then it will appear to increase as the visibility becomes greater. This is simply because the area of the transect increases as visibility increases; hence more animals are likely to be counted; yet the calculations do not allow for this, in that they assume a fixed, smaller transect area. On the other hand, animals could move into an area leading to an increase in real density, but if the visibility were reduced this would not show up in the estimates.

To my mind there has not been nearly enough experimentation on visibility profiles to allow them to be used.

(iv) Variable visibility profile

There are two methods in use whereby the visibility profile is measured each time that a transect is run. Both rely on the measured distance of animals seen from the vehicle.

(a) mean sighting distance (Fig. 19.d)

The idea is that the distance of all animals to the vehicle is measured, at right angles to the transect line[62]. The mean sighting distance then gives you one half of the effective strip width. Thus, if the mean sighting distance along a transect was 253 metres, the effective strip width would be 253 metres either side of the vehicle, e.g. 506 m total strip width, and only those animals seen within 253 m either side of the vehicle would be used in the calculations of density[55]. This method produces highly biased results[45]. I have tried a number of simulations of this method and it consistently produces gross overestimates of density when compared with fixed width transects.

(b) Kelker's Method (Fig. 19.e)

An adaptation of this method was developed[29] that has been used by a number of observers[15,24,25,44,45]. All animals seen are counted and the distance of each group from the transect line is measured. The number of animals seen is then tallied for belts of increasing distance away from the transect line, e.g. in belts of 0 - 50 metres, 51 - 100 m, 101 - 150 m etc. The number of each species in each belt is then inspected, and the point at which the numbers 'fall off' is taken to represent one half of the effective strip width. Animals seen further away than this are discarded from the calculations. For instance, if on a particular transect the impala observations 'fell off' after 100 metres, then 100 m either side of the vehicle would be taken as the strip width. On this same transect the giraffe figures might not 'fall off' until 250 metres, in which case 250 metres either side of the vehicle would be used for the giraffe calculations. Although this method overcomes some of the shortcomings of the mean visibility method it still leads to overestimates of density. It has been pointed out[17] that the method only works if the observations fall off in a fairly abrupt manner. It becomes difficult if they fall off gradually, or if they fall off and then increase again (Fig. 19.e).

There has unfortunately been little rigorous experimentation to test any of these variable strip methods. Some experiments were tried[15,24], but in each case the controls were not at all satisfactory. This may explain why different observers came to completely opposite conclusions as to which method was best.

To my mind the only approach which is certain to avoid any bias is to use a fixed transect strip width for all transects, irrespective of local differences in visibility. The visibility profile method is open to many sources of bias that are difficult and laborious to correct, while both of the variable visibility profile methods lead to overestimates of density. (The reason for this is that these methods are based on the assumption that the <u>only</u> reason that you do not see an animal is because you cannot see it. The fact that the animal may not be there is overlooked.)

The approach previously mentioned[25,63] seems to be the best. Both the investigators in question took considerable trouble to measure the distance at which they could see animals in the different vegetation types and during the different times of the year that they were working. Based on this they chose a strip width in which they were sure that they could see all animals, everywhere in the census zone. One[63], as pointed out, decided to use variable fixed strips, for open country and for the thicker parts. The other[25], chose a single width of 100 metres either side of the car for use in all vegetation types, even though in some areas he could see very much further than this.

10.5 Road Counts

Road counts are an adaptation of vehicle transect counts which have been used in those areas where access off the road system is difficult or impossible. The principle is that the vehicle drives along the road system and the observer counts all animals seen within a certain distance of the vehicle. This method has been used by several investigators[15,24,25,54]. There are certain problems with road counts that must be overcome if the method is to be of any use at all.

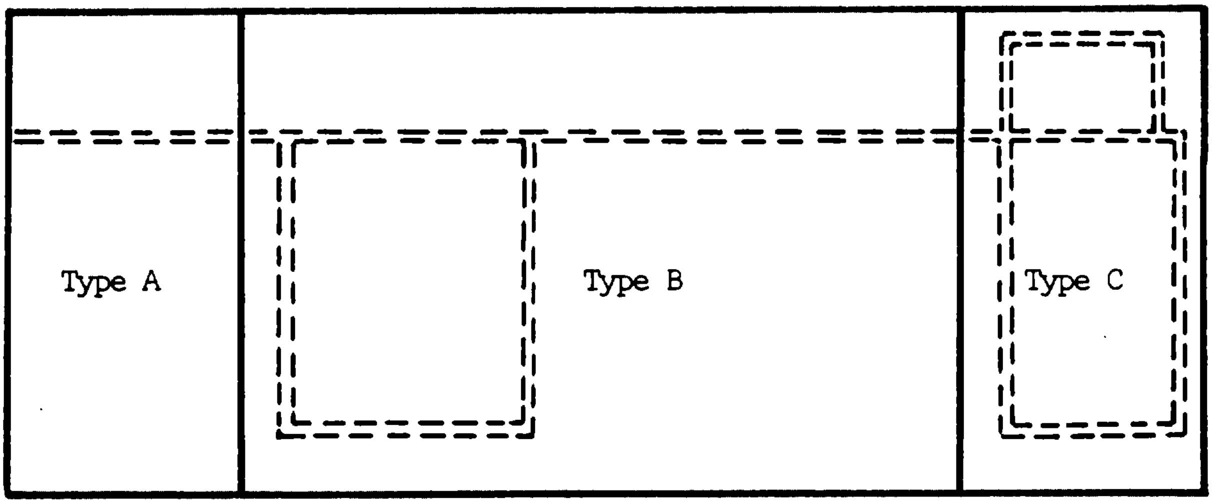
(i) Bias

Road counts are open to considerable bias because the road system is unlikely to be representative of an area. Roads tend to be built in good 'game viewing' or scenic areas, often running alongside rivers. For engineering reasons they are usually built along rather than across contours. As it is well known that animals tend to distribute themselves along rivers, and along contours, the road count is likely to produce highly biased results. More importantly, the bias is likely to change in the course of the year as the distribution of the animals change. Another awkward point is that road edges tend to be 'habitat' for some species (e.g. gazelle who like the annual grasses that grow on the disturbed soil on road edges).

This danger is demonstrated in Fig. 20 and Table 7. An area is shown with its road system, in which we are assuming that there are three main vegetation types, and that animals are counted within a fixed distance of the road. The percentage of each vegetation type sampled by the road system is shown in Fig. 20 from

Fig. 20 The Potential for Bias in a Road Count

An area (solid line) consists of three vegetation types A, B, and C. The dotted lines represent the road system within this area.



	A	B	C
area of each vegetation type	20%	60%	20%
percentage of road system in each vegetation type	10%	51%	39%
percentage of each vegetation type sampled by the road system	10%	18%	41%
Under sampled	x	x	
Over sampled			x

TABLE 7

The effect of bias in road counts

Assume there are 1,000 animals within the area, and that their distribution changes during the year in the way shown. The road count will indicate a gradual increase in numbers as the dry season progresses.

X = number of animals in each vegetation type

x = number of animals counted on the road count

		vegetation type					
		A	B	C	Σ	density estimate	
WET	X	600	200	200	1000	2.5	$Y = 1000$
SEASON	x	60	36	83	179	2.1	$\hat{Y} = 840$
EARLY DRY	X	100	700	200	1000	2.5	$Y = 1000$
SEASON	x	10	125	83	218	2.6	$\hat{Y} = 1040$
LATE DRY	X	50	100	850	1000	2.5	$Y = 1000$
SEASON	x	5	18	351	374	4.5	$\hat{Y} = 1800$

which the bias in the sample is obvious, for Types A and B are undersampled, whilst Type C is oversampled. An unbiased estimate would only be achieved if the proportion of the total road system within each Type was roughly the same as the overall proportion of each Type in the whole area.

The result of this is demonstrated in Table 7 which also shows how the bias can lead to different results at different times of the year. We assume that there are 1,000 animals within the area, and that their distribution at three times of the year is as shown in Table 7. In the wet season most of the animals are in Type A, there being a gradual shift until the late dry season when most of the animals are in Type C. The results from the road count do not show the same number of animals throughout the year. They show, instead, a steady build-up in numbers from 840 in the wet season to 1,800 in the dry season. This is a totally spurious result, and is one that could lead to some very wrong management decisions.

It is very simple to overcome this source of bias. All that needs to be done is to calculate, from the road count, the density of animals in each vegetation type, and then multiply these densities by the area of each vegetation type in the whole area. This gives an estimate of total numbers for each Type. Adding these together gives the total number of animals in the whole area[25].

(ii) Sample error

There is no straightforward method of calculating the sample error from a road count, for a road system cannot be regarded as a sample of units in the same way as a set of transects. The only valid alternative is to make a number of road counts within a short period of time, using the variance of the estimates as an approximation of the sample error[24]. The procedure, therefore, is to make, say, four road counts all the same week and to calculate an estimate of total numbers from each count. The mean of these is then taken as the final estimate of numbers, the 95% confidence limits being calculated from the variance of the four estimates. The formulae shown in Table 5 would be used.

Generally speaking, road counts should be avoided unless absolutely necessary, at least as a method for estimating total numbers. If they have to be used, e.g. when cross country driving is impossible and if aircraft are not available, then very great care must be taken to compensate for the sources of bias inherent in the method.

10.6 Discussion

Ground counts, like aerial counts, only give reliable and consistent results when carried out in a sensible manner. From the literature it is apparent that ground counting has been used mainly for detailed studies of habitat utilisation and social organisation, rather than for estimating population size *per se*. This reflects both the advantages and disadvantages of ground counting : namely the slow rate at which an area is covered and the time available for making detailed observations, and consequently the difficulty of covering really large areas.

In small study areas of up to one hundred square kilometres or so, most investigators have favoured total counting methods in which all animals seen are plotted onto a map. This gives an estimate of the total numbers in the study area, while the patterns of distribution and resource utilisation can be analysed using the method outlined in Appendix 1.3 and Appendix 1.4.

Total counting from the ground is not suitable for larger areas or for situations in which large numbers of animals are to be enumerated. However, Western[63] and Rainey (personal communication) were able to cover areas of up to 1000 km^2 by randomly locating transects within them. Population estimates were obtained in the same way as outlined in Figure 18. The area of each transect ('z') was found by multiplying the transect length by the transect width, while the 'y' was found by summing the numbers of each species seen along the individual transects. Patterns of habitat utilisation were analysed by the methods set out in Appendix 1.4 (iii). Both Western and Rainey were thus able to monitor for a number of years the seasonal patterns in distribution, movement, change in social organisation and habitat utilisation of large populations of wildlife and domestic stock which were utilising extensive areas of rangeland.

Ground counts become more difficult when larger areas than this are attempted. However, one recent successful example comes from the Serengeti National Park (report in preparation) where the numbers of large predators and their prey on the open grasslands of the Serengeti Plains were censused from vehicles. The census zone, covering some 3000 km^2, was divided first into three blocks which ranged in size from 1700 km^2 to 500 km^2. Parallel transects crossing the census zone from one side to the other were located systematically 2.5 km apart along a common base-line. Some of the transects were thus up to 60 km in length.

All animals seen within 100 metres either side of the vehicles were counted. Transect area 'z' of Figure 18, was found by multiplying transect length (in this example measured from the vehicles' odometers) by transect width (200 metres). The 'y' for each transect was the total number of each species counted along the length of each individual transect. 'Z' was found by measuring the area of the census zone from a map and 'N' by dividing the length of the base-line by the transect width. An estimate and a variance for each species were then obtained from each of the three blocks by using the procedures laid out in Figure 18.

This census was effectively a stratified sample count for the census zone had been divided into three strata (blocks) and samples had been taken in each (page 36). The estimate of numbers for the entire Serengeti Plain was therefore found by summing the estimates and variances from each block, as is shown in Table 6.

This is one of the largest single areas to be censused using vehicles, and it was really only practicable because the Serengeti Plains are flat, open, treeless grasslands with few hindrances to cross country driving. More heavily wooded areas or more hilly areas would present considerable problems. Nevertheless, the same principle could be applied only using shorter transects - an extension of the basic method used by Western and Rainey.

Three methods suggest themselves for really large areas. First, the census zone could be divided into small blocks of up to one hundred square kilometres each (the sample units) and a number of these selected at random for total counting*. Second, extensive road counts could be attempted, given that the precautions outlined above are followed. Third, Western's method could be extended (yet again) by dividing the census zone into large blocks of a thousand or so square kilometres each and then sample counting within a sample of these blocks. This involves two-stage or sub-sampling, and the statistical manipulation of the data become a little more complicated[37].

*See Spinage, C.A., Guinness, F., Eltringham, S.K. & Woodford, M.H. (1972). Estimation of large mammal numbers in the Akagera National Park and Mutara Hunting Reserve, Rwanda. La Terre et la Vie No. 4 : 561-570.

SECTION 11 INDIRECT METHODS OF COUNTING ANIMALS

11.1 Introduction

There are certain situations in which none of the direct methods discussed so far can be applied. For example, when the animals are totally, or almost, invisible, or when only a proportion of the total animals in an area can be seen at any one time. In these cases indirect methods of counting have to be used, the most relevant of which are discussed below.

11.2 Mark-Release-Recapture (or Capture-Recapture) Methods

The basic theory of mark-release-recapture methods is that a known number of animals from an area is caught and marked in some obvious way. The animals are then released. A suitable period of time is allowed for the marked animals to mix in the population, before further catches are carried out. The total number of animals can then be estimated from the proportion of marked to unmarked animals in the catches. This method theoretically only works if there is random mixing of the marked animals, if there are no births or deaths between release and recapture, and if there is no immigration or emigration - conditions rarely met with under natural circumstances. The theory and practice of this method is fully described in a number of papers[8,16,26,32,33]. These authors give full details of how to estimate population totals, birth rates, survivorship etc.

This method was developed for use by entomologists and small mammalologists, but it has been successfully applied to wildlife research. The 'marking' has usually taken the form of 'knowing' individual animals by sight, although marking with collars or ear tags has been used, while the 'recapture' part of the method has depended upon resightings of these known or marked animals[14,30,47,53,56]. These investigators worked with such widely differing animals as roe deer, alligators, elephants, hyaenas and lions.

11.3 Change in Ratio Methods

Change in ratio methods were developed from capture-recapture theory. The relative abundance of two types of animal in a population must be known at time T_1, e.g. the relative abundance of males and females. This ratio is then changed by removing a known number of one type at time T_2; it is then re-estimated. The total number of animals can be calculated from this change in ratio. The method is considered in detail by various authors[40,46] who show how to calculate numbers, birth rates, death rates, survivorships etc.

The method was developed for the management of cropped populations of wildlife (e.g. deer populations, when the number of stags shot in a given period of time is known, or pheasant populations, when the number of cock birds shot is known) and for fisheries, e.g. when a number of a certain type of fish is put into a stream or lake. It could therefore be applied to large African mammal populations in situations where carefully controlled cropping was being carried out.

11.4 Pellet Counts

Pellet counts were developed for deer research in the United States. The theory is that if you know the rate of defecation then you can work out from pellet counts the number of animals in an area[36,58]. The main practical problems concern knowing the rate of defecation, locating all the piles of pellets, and accurately identifying and ageing the pellets. The method could conceivably be applied to counting animals such as dik-dik, and perhaps forest elephant.

11.5 Broadcasting Tape Recorded Calls

The idea here is to use a tape recording of a social call to elicit a vocal or visual response from an otherwise silent or invisible animal. This method is used quite widely in the USA for wildfowl counts[5,52], and has been employed in East Africa on hyaenas[30]. In this case lion feeding noises were broadcast to attract hyaenas, and *vice versa*.

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APPENDIX 1 THE STUDY OF MOVEMENTS AND DISTRIBUTION

1.1 Introduction

Animals form a dynamic relationship with their environment that can be studied at two quite different levels of time and space. On the one hand the basic environmental factors of an ecosystem set the overall pattern of the distribution of a species, while on the other hand the individuals of a species are able to respond to fluctuations in local environmental conditions by moving about within their local habitat. The first type of relationship tends to be permanent in historical terms, changing only in response to long-term trends in climate, soils, vegetation and human population levels. The second type of relationship, the local ones, are fluid and changeable, and largely reflect the species' responses towards fluctuating resource levels.

The second Handbook in this series[28], and other recent publications[8,9], deal extensively with methodologies for studying the movement and distribution of large mammals. This Appendix, therefore, will only present an outline of these types of study.

1.2 The Study of Movements and Distribution over Large Areas

Many fundamental aspects of management require information on the movement and distribution of animals within very large areas such as whole National Parks or Game Reserves including the land surrounding them, whole administrative regions and even whole countries, areas that range in size from 5,000 km^2 to 500,000 km^2. By and large, there are four main categories of information of interest :-

(a) the total range of migratory and resident species, especially the wet season dispersal areas and the dry season concentration areas, and the density distribution of each species within its total range. This information is important when planning the boundaries of new Parks or Reserves, or when planning extensions to existing conservation areas. It is also important for planning the development of human activities such as ranching, cultivation, sport hunting and cropping in the country lying around existing Parks.

And it is of particular use in planning rangeland development projects.

(b) identifying unit populations. This is of obvious relevance to Park management, especially when there is the possibility of large scale immigration. It is also important for the study of population dynamics which must be aimed at a unit population rather than at a segment of a population. Cropping schemes must also be based on unit populations rather than on segments of populations that happen to lie in some convenient place.

(c) identifying areas of high species diversity and density for planning tourist development. Nothing is more frustrating than to see a tourist circuit built in the 'wrong place'. For example, the Serengeti National Park, Tanzania, is renowned for the annual migrations of wildebeest, yet the main tourist circuit only passes through a part of the wet season concentration areas.

(d) identifying the main environmental factors underlying the observed patterns of distribution and movement.

Perhaps the most widely used method for collecting this kind of information is the Systematic Reconnaissance Flight or SRF[3,7,8,9,17,18,19,29]. The basic approach is to create a framework of grid squares by gridding a map of the area of interest and then sampling within each grid square. The flight lines are spaced systematically across the census zone so that they run down the middle of each row of squares, and data are collected systematically within each square along each flight line.

Although the grid squares can be theoretically of any size, some compromise has to be reached between the size of the total area and the scale of the expected movements. Small areas of up to 5,000 km^2 could be gridded as fine as 2 x 2 km, but larger areas require larger squares otherwise the method becomes too time consuming and expensive. 5 x 5 km squares have been used for areas up to 10,000 km^2, and 10 x 10 km squares for areas up to 500,000 km^2. The Kenya Rangeland Ecological Monitoring Unit, for example, has now covered all of Kenya's 500,000 km^2 of rangeland on a 10 x 10 km square basis.

When designing an SRF or a series of SRFs, the following points should be borne in mind :-

(a) an area larger than that thought to be utilised by the animals concerned must be covered initially. It can be later reduced in size.

(b) it is as important to visit the areas where the animals are not as it is to visit the areas where they are. Negative observations are as important as positive observations.

(c) data should be collected about all the species encountered.

(d) the surveys must be repeated a number of times throughout the year, and ideally for a number of years, so that the overall patterns of movement can be described. One SRF at the height of the wet season and one at the end of the dry season is the minimum requirement.

(e) bear in mind that movements of a scale smaller than that of the framework of sampling units will not be shown. Similarly, movements of a phase shorter than the sampling interval will not be shown. In most East African applications, where seasonal movements have been the main item of consideration, SRFs have been spaced monthly or bimonthly, and in some instances have been continued for over six years.

A fairly standardised methodology has now emerged in East Africa for these SRFs. Flight lines are most usually oriented north-south or east-west along UTM grid lines. On north-south lines, the convention is that the line passes along the western boundary of a grid square; east-west flight lines pass along the southern edge of a grid square. The use of the UTM grid system is an important standardisation because all data are comparable.

Flying heights and speeds on these SRFs are the same as for any other kind of transect counting; most operators have standardised to 300 feet above the ground, 100 mph ground speed, and strips no wider than 150 metres either side of the aircraft.

The pilot is responsible for height control and navigation. He also calls out the beginning of each flight line, and the beginning of each sample unit along the flight lines, every five kilometres for example. This requires skill and concentration on his part, and accurate map reading to locate the beginning of every sub-unit. One common variation now quite frequently used is for the pilot to call out every minute along the flight lines. This considerably lessens his operational load, and after the flight it is possible to cast the minute-long sections into grid squares by working out the actual ground speed of the aircraft.

The front-seat recorder, sitting alongside of the pilot, collects operational and environmental information. As well as recording take off and landing times, start and stop times of each transect etc., he also records the readings from the radar altimeter at least once in each sub-unit. The environmental information can be of many different kinds and will depend upon the interests of the investigators. The publications already referred to give examples of the range of variables that may be meaningfully recorded. Commonly recorded are the extent of burns; the greenness of the vegetation; the ground cover of grass, bushes and trees; soil colour; vegetation type; erosion; drainage density; landscape characteristics; water availability in ephemeral pools, dams, streams and rivers; density of settlements; types of crops being grown; stages of growth. Most usually the front seat recorder writes these observations down onto coding sheets, starting a new line for each sub-unit along the transects. This is one of the few occasions where writing down is preferred to tape recording.

The two rear seat observers have the same jobs as already described, namely locating, identifying and counting all animals seen in their transect strip, photographing the large groups, and recording all the information onto their tape recorders. Of particular importance is that they record the start of each sub-unit when the pilot calls them out.

Data transcription is critical to the success of these SRFs, and it is important that the two rear seat observers and the front seat recorder match their tape records to ensure no sub-units have been missed, or transcribed incorrectly. Considerable effort must be taken to ensure accurate transcription of records.

The raw data from an SRF consist of the numbers of each species seen by the observers within each sub-unit, grid square or sample unit (these terms are used interchangeably by different investigators), while the front seat recorder has a number of environmental observations within each sub-unit as well. The first step, therefore, is to convert these numbers into densities by dividing them by the area sampled in each sub-unit (naturally only after the photo-corrections have been made). Thus the density of a species in a sub-unit is found by dividing the total number seen by both observers by the length of the sub-unit multiplied by their summed strip widths. This is quite a laborious process when the area sampled is large, and computer based, data processing systems have come to play an important role. One such system is available in IBM or ICL Fortran compatible forms[29].

Eventually, however, the data from an SRF are reduced to estimates of animal density in each sub-unit in the census zone, along with environmental information about each sub-unit. Additional environmental data can always be added later, for example rainfall data, geological data, disease vector data etc., by simply superimposing the same system of grid squares onto the appropriate map.

There are numerous methods for analysing these data :-

(a) overall distribution maps[19,27]

An overall distribution map for a species is obtained by averaging the densities in each sub-unit from a series of SRFs. Density contour lines can then be drawn by eye or by some more objective method such as trend surface analysis[6,17]. Comparisons between species' distributions may be made, and they can be related to other environmental factors.

(b) wet and dry season ranges[19,27]

Wet and dry season ranges are found by averaging the observed densities for 'wet season' and 'dry season' SRFs.

(c) movements[19,27]

The extent and rate of movements are found by simple inspection of a series of SRF distribution maps.

(d) species associations[17,27]

Association analyses will reveal the characteristics of different communities of animals and their distribution.

(e) species diversity[17,20,27]

Species diversity and species number, both useful for planning tourist development, are simply obtained from SRF data.

(f) total density and biomass[17,27]

Total density is found by summing the densities for each species in each sub-unit. Total biomass, or even metabiomass (metabolic weight), is found by multiplying the observed densities by the mean body mass for the species.

(g) factors underlying distribution and movements[17,19,27,28]

The factors underlying the observed distribution and movements can be studied by identifying ecological variables that correlate highly with them. High correlations do not of course prove any causal relationship, but they at least indicate areas worth further investigation. Overall distribution maps tend to show high correlations with gradients of rainfall, plant productivity and vegetation structure, and strong negative correlations with factors such as the percentage of land under active cultivation. Patterns of movement often show strong correlations with other seasonal phenomena such as rainfall patterns, burning patterns, green 'flushes' and water distribution.

(h) numbers[17,18,28,29]

One great advantage of the SRF method is that estimates of population number can be obtained in addition to the information on distribution and movements. The analytical approach is somewhat different though, for the total number of animals counted along each flight-line (transect) is used rather than the number in each sub-unit. Numbers are therefore calculated in exactly the same way as already described. Numbers for sub-divisions of the census zone are found simply from the segments of the transects passing through them.

SRFs are now very widely used. The KREMU team have now censused all of Kenya's rangelands and the data will be used for large scale rangeland and wildlife development planning. A similar programme is starting in Botswana and in six west African countries. In East Africa, smaller scale applications of the method have been used for environmental monitoring[28], for land-use planning[7], and for calculating the amount of compensation owing to Masai pastoralists for tolerating wildlife grazing on their rangeland.

1.3 The Study of the Seasonal Patterns of Habitat Utilisation

Much research has concentrated on how communities of large mammals utilise the available resources with the objective of identifying those resources that might be limiting the size and distribution of each species. The most common approach has been to describe the seasonal patterns of utilisation of vegetation types, whether defined on the basis of the structure or the composition of plant species. These vegetation types (or habitats) represent homogeneous areas and therefore tend to be homogeneous for important resources such as food, water, shade, protection from predation etc. The seasonal preferences for different vegetation types have thus given clear insights into the most important resources.

These studies call for highly detailed work in small study areas (< 1000 km^2) that are carefully chosen to be representative of the habitats used by a particular species or of a particular community of species. Intensive sampling is carried out usually at no more than monthly intervals, along with other detailed work on rainfall patterns, fire, and the growth and productivity of the vegetation. The objective of the various methods discussed below is to obtain distribution data in such a way that vegetation type selection (and avoidance) may be demonstrated. These studies are not possible unless a vegetation map of the study area has been prepared.

(i) aerial total counts

Sinclair[21,22,23] had two study areas of approximately 50 km^2 that were representative of the major habitats of the buffalo in the Serengeti National Park, Tanzania. Since his main interest was in buffalo and wildebeest, he total counted each study area once a month, plotting each observation onto a vegetation map that was divided into grid squares of 250 x 250 metres. He carried out ground work on the structure and productivity of the vegetation types, and from the air mapped such variables as fire and 'green flush'.

(ii) ground total counts

Jarman (in prep.) counted impala and all other species in two study areas of 6 km^2 and 12 km^2 at frequent intervals. All observations were plotted on a vegetation map ruled into grid squares of 100 x 100 metres, and observations on social grouping, behaviour, condition, etc. were recorded as well. Detailed vegetation work was also carried out. Martinka[15] located all observations on a grid of 400 x 400 metres, while others have mapped observations directly onto vegetation maps[2,16,26]. Field and Laws[5] mapped their observations onto vegetation maps gridded into 400 x 400 metre squares.

(iii) aerial transect counts (Fig. A1)

The principle here is to record when the aircraft crosses from one vegetation type into another. The flight lines are marked in on a vegetation map of the study area. If the pilot has this map then he calls out to the observer every time a vegetation boundary is crossed, and the observer records this on his tape or data sheet. Alternatively, the observer can carry the map himself. This is in fact extremely simple to do once the pilot and observer become well acquainted with the study area. By making these records it is possible to calculate later the density, or numbers, of each species in each vegetation type[4,27,28].

(iv) ground transect counts (Fig. A1)

The same principle applies to ground transect counts. Western[27,28] made monthly counts along 25 transects in a 600 km^2 study area. He counted all species seen as well as making observations on social groupings, behaviour, condition, state of the vegetation etc., and he recorded when he crossed from one vegetation type into another.

This same method can be used with road counts[11] and foot transect counts[13]

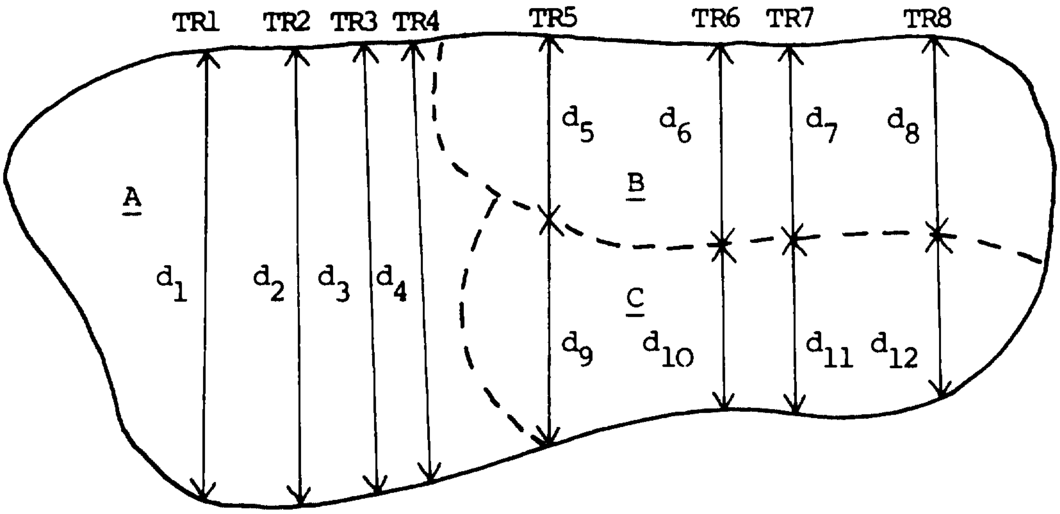
1.4 Type of Analysis

The objective of the three methods of analysis described below is to demonstrate the selection or avoidance of vegetation types. The null hypothesis in each case is that the animals are distributed randomly with respect to the different vegetation types, i.e. they are showing neither selection nor avoidance.

(i) presence/absence methods

Presence/absence methods can be used to show vegetation type selection or avoidance if the data have been recorded on a grid square basis. Cole's Coefficient of Association[25] is the simplest index to

Fig. A1 Aerial and Ground Transects crossing census zones that have been divided into vegetation types.

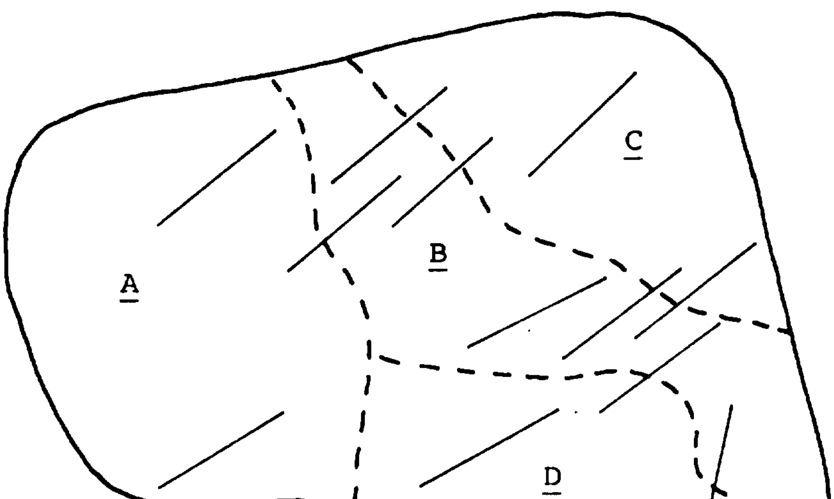


a) Aerial transects crossing a zone divided into three vegetation types A, B and C; observations are kept separately for each segment of a transect that falls within a different vegetation type (transects 5 - 8); density of animals in

Type A would be calculated from d_1, d_2, d_3, d_4

Type B would be calculated from d_5, d_6, d_7, d_8

Type C would be calculated from d_9, d_{10}, d_{11}, d_{12}



b) The same principle applied to ground transects chosen at random points within a census zone; in this example there are four vegetation types.

use. The association between a vegetation type and a species is found by constructing a 2 x 2 table in which the four cells are :

1) the number of grid squares in which the vegetation type occurred and the species occurred,
2) the vegetation type occurred and the species did not occur,
3) the vegetation type did not occur and the species did occur,
4) the vegetation type did not occur and the species did not occur.

Cole's coefficient, and a standard error, is calculated from this table, the value of the coefficient indicating whether the species was selecting, avoiding or showing no preference for the vegetation type. Associations between species can be measured as well. Several workers have made extensive use of this method[5,22].

(ii) methods using the number of animals observed

This method should only be used if it is not possible to calculate the density and the variance of species in the different vegetation types. Data from road counts are often in this form, for there are no 'sampling units' from which a variance can be calculated (see Section 10.5). The method uses the total number of animals observed in each vegetation type, and it compares this Observed number against the number Expected if the animals had been distributed randomly with respect to vegetation types. On this null hypothesis the number Expected in each vegetation type should be proportional to the area of the vegetation type in the sample. Thus, if vegetation Type A comprised 15% of the total sample, then it should contain 15% of the total animals seen. The Observed and Expected values are then tested against each other using a X^2 test[1].

The steps in the calculations are shown in Table A1. First, calculate the area of each vegetation type that has been sampled (by multiplying the length of road passing through each vegetation type by the width of the strip counted), and then express each of these areas as a % of the total area sampled. Next, count the number of animals seen in each vegetation type (Observed numbers, in Table A1), and add these figures. Finally, calculate the Expected numbers for each vegetation type by taking a % of the total number counted equal to that % of the vegetation type in the whole sample (thus in Table A1,

TABLE A1 Calculations for avoidance or selection of vegetation types using the numbers of animals counted. The data for this table come from Fig. 20 and Table 7 (Section 10).

	Vegetation Type			
	A	B	C	Total
length of road (km) in each vegetation type	10	68	44	122
width of counting strip (km)	0.8	0.6	0.7	
area sampled in each vegetation type (km^2)	8	41	31	80
% of total area sampled	10	51	39	100
number of animals counted in each vegetation type (Observed number)	60	36	83	179
number of animals Expected in each vegetation type (Expected number)	18	91	70	179
$X^2 = \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}$	98	33	2.4	
significance level	p = <0.001 selected	p = <0.001 avoided	n.s. no preference	

18 animals are Expected in Type A because Type A comprised 10% of the whole sample).

The X^2 value for each vegetation type is given by

$$\frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}$$

any X^2 of more than 3.841 being significant at the 5% level (for there is only 1 degree of freedom). The results in Table 8 show that the animals are selecting vegetation Type A (for the Observed values are significantly higher than the Expected values); they are avoiding Type B (for the Observed values are significantly less than the Expected values), and they are showing no particular avoidance or preference for Type C.

This type of analysis has been used in a study of the seasonal patterns of vegetation type use by large mammals in the middle Zambezi valley[11]. The only drawback to the method is that it is rather easy to obtain significant results, especially when the observed numbers are large. Perhaps, therefore, the 1% level of significance should be used, rather than the 5%.

(iii) methods using the density of animals

The best methods to use from the statistical viewpoint are those that rely on the Observed densities of animals in each vegetation type. The null hypothesis here is that if the animals are distributed randomly with respect to the vegetation types, then their density in each vegetation type would be the same. This null hypothesis is tested by comparing the observed densities against the mean density in the whole area surveyed.

The first step is to calculate the density in each sample unit, or portion thereof, in each of the vegetation types. If grid squares have been used as sample units, then the density refers to each square. If transects have been used, then the density is calculated from the portions of the transects in each vegetation type. Thus, in Fig. A1 a), the densities of animals would be found for each portion of the transects in each vegetation type, d_1, d_2, d_3 etc.

The most straightforward analysis is to use a simple one-way analysis of variance such as that given in Bailey[1] and as used by

Norton-Griffiths[17]. The advantage of this analysis is that it is very simple to carry out, and in addition one single set of calculations enables you to compare the density in each vegetation type against the overall mean density as well as the densities in each vegetation type against each other. Once you have become used to handling a one-way analysis of variance, you can graduate to two-way analysis[1,10,24], which tests a number of species and a number of vegetation types, or a three-way analysis (which tests species, vegetation types and seasons of the year).

Alternatively the analysis can be done in a slightly more laborious way by calculating the density and variance in each vegetation type and the mean overall density, and then testing these against each other using a t test or d test[1]. This is exactly equivalent to using an analysis of variance method, but it takes longer and it is easier to make mistakes.

1.5 Following Known Animals

The literature is crammed with studies of movements and distribution in which known animals have been followed. The animals are known either by distinguishing features (e.g. ear tears in elephants); by marking with collars, ear clipping or ear tags; or by affixing a radio transmitter and using radio location[12,14]. The basic methodology is to make systematic observations of the animal's position (e.g. daily, weekly, monthly) and to plot these positions on a map. These data give measurements of daily rates of movement, wet and dry season ranges, movements to and from water, home ranges, territories and vegetation type utilisation.

The data tell a great deal about the movements of an individual but not necessarily about the movements of a population or of a segment of a population. Of course, if you follow a marked animal in a herd, then the whole herd is effectively marked. Usually, however, the information on individuals' movements is used to augment information on a population's movement.

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APPENDIX 2 TRAINING OBSERVERS

It is really quite extraordinary that among the numerous articles and publications about the techniques for counting animals there appears to be not a single one devoted to training observers, either for ground observation or for aerial observation. Quite obviously, most observers have simply 'grown into' their jobs, first by being passengers in vehicles or aircraft, then perhaps by standing-in when a more experienced observer was unavailable, and finally by deciding that they know what it is all about.

This dearth of information as to how to go about training observers was sharply highlighted recently when the Kenya Rangeland Ecological Monitoring Unit (based in Nairobi, Kenya) was faced with the task of training a cadre of eight Kenyan aerial observers from scratch. None of the recruits had been in an aircraft, most had never seen one close to, and few had ever encountered the large mammals common to Kenya's rangeland areas. Nevertheless, within three months these trainee observers had reached a level of performance equal to that of the most experienced aerial observers that could be found to test them against.

A full account of this training programme is in the process of preparation, so only the most salient points will be given here as a guideline.

The census method adopted by KREMU was essentially the same as that described in Appendix 1, and the task facing their observers was exacting. They had to spot, identify and count all animals within their transect strip, photograph large groups and record all these data unambiguously onto their tape recorders, along with flight-line and sample-unit information. After each flight the observers had to transcribe their tape records onto data sheets and later match the photographs to these tape records. Finally, they had to analyse the photographs and count the animals on them and then amend the tape records.

The training programme was built around a series of exercises of increasing complexity, each one introducing a new task to those already learned. On the first exercise the observers were taught simply to locate and identify animals; then to write down their sightings; then to count the animals and write down the numbers; then to use tape recorders; and finally to use cameras. The duration of the flights was steadily increased as the course progressed until a standard census flight of three hours was achieved.

Pre-flight, laboratory sessions gave opportunity to explain the exercises, to practise with tape recorders and cameras, and to teach operational procedures. Extensive, post-flight debriefings were used for working up the data, for transcribing and checking the tape records and for analysing and counting the photographs.

Colour slides were used extensively throughout the course. They were particularly useful for teaching species identification, typical habitat and group sizes, and techniques for scanning, locating and counting groups of different sizes.

Perhaps the most useful teaching aid during the course was the intercom system fitted in the aircraft. The instructor, who was sitting alongside the pilot, was able to examine the same strip as the observer immediately behind him and could thus check on his identification and on his counting. Furthermore, the instructor could listen-in while the observer was making his tape record and could thus check on his accuracy. Every half hour or so the two observers were made to switch positions so that the instructor could interact with both.

Table A2 shows the sequence of the exercises in this course and the approximate number of hours spent by the observers on the various activities.

A summary of the observer training programme is given below :

Exercise 1 :	Pre-flight	simple operational procedures; introduction to the aircraft, seating, seat belts, intercoms, location of survival gear
	Flight	writing down date, name, side of aircraft, take off time, landing time; spotting and identifying animals; pilot flies from group to group, circles group if necessary
	Post-flight	discussion of exercise; checking of flight data

TABLE A2 Hours spent by the trainee observers in the various activities on the KREMU aerial observer training course

Exercise	pre-flight	flight	mean duration per flight	post-flight
1 Spot/identify	2	2	1	2
2 + write down	2	3	1½	4
3 + count	2	6	1½	10
4 + tape recorders	6	8	2	16
5 + cameras	8	12	3½	20
TOTAL	20	31		52

Exercise 2 :	Pre-flight	practice with data sheets
	Flight	spotting and identifying animals; writing down observations; pilot still flies from group to group
	Post-flight	checking flight data; simple distribution maps
Exercise 3 :	Pre-flight	practice with writing down flight-line and sub-unit information, and numbers
	Flight	counting groups and writing down numbers; writing down flight-lines and sample units; pilot flies systematic flight path, calling out beginning and end of flight-lines and sample units
	Post-flight	checking flight-line, sample unit and other operational data; summarising numbers seen; simple distribution maps and population estimates
Exercise 4 :	Pre-flight	extensive practice in use of tape recorders; practice at transcribing pre-recorded tapes onto computerised data sheets; operational procedures and checks of the tape recorders
	Flight	counting animals within transect strip; recording data onto tape, along with all operational data
	Post-flight	transcribing tape records onto data sheets; checking tape records.
Exercise 5 :	Pre-flight	extensive instruction in use of motor drive cameras, reloading, operational checks, use of automatic exposure control etc.
	Flight	photographing all large groups and recording data; recording all other data as well
	Post-flight	films developed; tapes transcribed; matching photographs to tape records; working out areas of overlap; counting photographs; amending data sheets; discussion of photo technique

Use of Colour Slides

A large number of 35 mm colour slides of animals were taken from the normal operating height and sighting angle. Transect rods often appear in the slides. The main uses were :-

* identification of species in typical habitats and group sizes
* techniques of scanning and locating animals

* techniques for counting large groups
* appearance of same sized groups at different distances
* appearance of different sized groups at same distances
* estimating proportion of a group inside the counting strip
* multi-species groups

In a standard session with colour slides, thirty six were projected for ten seconds each, and the observers had to write down the species and the numbers. The slides were then repeated, slowly, and the instructor discussed each slide with the observers.

APPENDIX 3 MORE ABOUT COUNTING BIAS

An extensive literature is now growing up about the main sources of counting bias in aerial surveys and on the ways to estimate and counteract their influence. The most recent and important work is that of Caughley[2] who, in a series of carefully designed experiments in Australia, explored the effects of a number of factors on the densities of animals recorded by observers.

Caughley found that in general the most significant factors were those of aircraft speed, aircraft height above ground and strip width; others such as time of day, fatigue and length of survey appearing to be less important. Furthermore, there was relatively little interaction between these main sources of bias. Over the ranges measured by him, speed and width were each effectively having a linear and additative influence on sightability, while height was having a parabolic and additative influence.

One objective of Caughley's experiments was to test his previously stated hypothesis[1] that a regression of observed density on speed, height and strip width could be extrapolated backwards to the y-intercept to give an estimate of 'true density', at the zero values of these variables. The experimental results generally favoured his hypothesis, and assuredly the estimates based on the y-intercept were nearer to the 'true density' than were the unaided visual ones.

In a subsequent census of kangaroos[3], Caughley used the experimentally derived y-intercepts as correction factors for the observed densities. Indeed, each observer had two correction factors, to take into account the density of the vegetation.

Undoubtedly, these studies of Caughley must now be taken very seriously when designing census work. They demonstrate the inadvisability of using fast census speeds and wide strip widths, until recently quite the fashion. Furthermore, they demonstrate methods for adjusting the results from censuses carried out in his way. And they indicate that the now commonplace compromise among census operators in East Africa of 100 mph air speed, 300 feet height and a maximum of 150 metres strip width is along the right lines.

But a word of caution before speeds are reduced and heights lowered. A recent tragic accident in Kenya, in which the whole crew of a census aircraft was killed, has made those of us interested in enjoying our dotage think seriously of four hundred feet as a minimum, safe operating height.

Caughley's work still leaves a number of questions unresolved. For example, occasionally other factors such as time of day would have a highly significant effect on observed density. It was also clear that the nature of the relationships between the main factors and the observed densities changed with animal density, with species, with vegetation and occasionally with individual observers.

Caughley recognises that his approach is best suited to censuses of single species in relatively uniform habitats. The situation becomes most complicated where there is marked heterogeneity in density, species, habitat and distribution, as is common in most East African, multi-species censuses. Correction factors may well have to be found for each combination, an awsome task only practicable under circumstances where long-term work is being carried out.

In most East African census work, observers have been trained to take photographs of all large groups (larger than ten animals) rather than to try and guesstimate them[4]. This considerably reduces counting bias, although certain individual observers of long standing experience consistently guesstimate with very little bias the number of animals counted later from their photographs. Furthermore, in the East African situation often as many as 95% of the total number of a species counted will be on the photographs. The remaining proportion may scarcely warrant the expense of obtaining correction factors. This may explain why, in at least one East African study[5], factors appearing unimportant in Caughley's experiments appeared to be significantly associated with counting bias.

There are two further technical points that must be considered. First, the behaviour of the regression lines close to the y-intercept is almost impossible to investigate experimentally because of safety aspects - although a helicopter could be employed for this. It is likely that the regression lines curve sharply in towards the y-intercept in the region of, say, 5 - 25 feet height and 5 - 25 metres strip width and 5 - 25 mph speed. Changes of these magnitudes in the main factors may have little effect on sightability. In which case the y-intercepts as calculated will overestimate the 'true density'.

Second, there is an error term, often as high as 35%, attached to the y-intercept estimate. I am not sure at this stage what should be done with it, but it cannot be ignored. It must contribute, perhaps substantially, to the overall error of the estimate.

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APPENDIX 4 OPERATIONAL PROCEDURES AND CHECK SHEETS FOR CENSUSES

4.1 Introduction

Although aimed primarily at aerial survey crews, the following operational procedures and check sheets should prove of value to anyone setting out on census work. These lists are by no means exhaustive, and individual census operators will undoubtedly amend them to fit their particular requirements.

4.2 Pre-flight

(a) pilot

aircraft and equipment operational
survival gear on board
air/ground rescue co-ordination
check maps and flight lines
check order in which to fly flight lines
stop watch and spare
pens, pencils

(b) front-seat recorder

check maps and flight lines
check adequate data sheets, clip board
check stop watch and spare
pens, pencils, ear plugs (cotton wool)

(c) rear-seat observers

check tape recorder working, record/play back
check batteries and spares
check tapes unrecorded, and spares
pack recorder, tapes, batteries into flight bag
ear plugs
check camera operation, wind on, shutter operation
check battery levels if appropriate
check lens taped to infinity
check ASA set correctly
check shutter setting
check exposure setting, operation
check all films labelled on trailer, cassette and detachable sticky label
load film, check wind on
stick label onto outside of camera
load camera, spare films, batteries into flight bag

Note : It is advisable to carry at least one spare camera and one spare tape recorder on every flight.

: Each camera and each tape recorder should have a unique number so that malfunctioning equipment can be identified.

: When loading film, especially in the aircraft, the following procedures are recommended :

check leader fully taken up into wind-on spool and both sets of sprocket holes engaged
check normal wind on (twice) with camera back open
close back, check locked
wind on three times, checking counter and spool

(d) pre-flight briefing of all crew

objective of census
flight plan
recording methods
pilot calling-out methods
procedures if tape/cameras fail
procedure if tape/camera runs out during flight line
emergency procedures, location of survival gear
ground/air rescue co-ordination

(e) pre-flight

front-seat recorder write down onto data sheet :

date, name, flight code
pilot's name
observer LEFT and observer RIGHT
aircraft identification

rear-seat observers record onto tape :

date, name, position (L/R), flight code, camera number,
tape recorder number
tape number
film number in camera (it's on the sticky label)

rear-seat observers play back tape recorder

rear-seat observers check camera operation, ASA, shutter, lens

4.3 In-flight

(a) pilot

record take off time
give warning of run-in to start of flight line
call out "flight line NUMBER"
check with all crew members that flight line number is correctly recorded
call "start of flight line NOW"
call "sample unit NUMBER"
call "end of flight line NOW"
call "BREAK" if flight line is to be stopped temporarily

Note : break either at end of sample unit, or at convenient land mark; record landing time.

(b) front-seat recorder

record take off time
write down flight line number, check with pilot
write down start time of flight line
write down number of sample unit
record observations
record radar altimeter when pilot NOT looking
write down next sample unit number
write down end of transect time
record landing time

(c) rear-seat observers

record flight line number, play back, check with pilot
record sample unit number
record observations
record photographic information
record "end of flight line number"

between transects

check tape recorder still working, batteries, tape to run
check camera still working, film counter, ASA, exposure, lens, shutter

changing tapes

record tape number, play back
record date, name, position, flight code, film in camera, play back

changing films

rewind fully into cassette, unload
remove detachable label from camera, destroy
remove detachable label from new cassette, stick onto camera
load film, check wind on
check all camera operations
record new film number onto tape
play back and check

changing tape recorder or camera

record new tape recorder and/or camera number onto tape
record reasons for change, new tape number, new film number etc.

Note : If possible, change films and tapes between flight lines. If caught short, ask pilot to break flight line as soon as possible.

: Say into recorder "elephant, elephant, seven"; this gives the recorder time to get to full speed after switching on.

: Say into recorder "correction, correction .." if an observation is to be changed.

: Remember ALWAYS to take photographs with the camera near vertical and NOT horizontal. If Horizontal, effective eye position is lowered, and more animals are included into the viewing strip.

4.4 Post-Flight

(a) pilot

tend to aircraft
record flight times, census zone, flight line numbers into aircraft journey log book and into personal log book

(b) rear-seat observers

transcribe tape records onto data sheets
check through again carefully
match film and tape numbers to transcription
match camera and tape recorder numbers to transcription
put used tapes and films away safely
throw away used batteries, spoilt cassettes etc.

(c) front-seat observer

tidy up data sheets

(d) crew debriefing

recorder and observers match flight line numbers and sample unit numbers
clear up any mistakes while memory is still fresh
label and pack together all data sheets, films, tapes
discuss census operation
plan next flight

Note : It is most advisable to keep tapes until the census data are fully processed. Often you will find difficulties with matching the tape transcripts with the photographic record. Access to the original tape record is then very useful.

4.5 Setting Up and Calibrating Transect Streamers

(a) setting up

follow procedures outlined on Page 53; requirements wax pencils, tape measure.
write down for future reference

observer's name and height
aircraft identification
side of aircraft
height of observer's eye above the ground when sitting inside

height on upper and lower window marks
distance of inner and outer streamer from fuselage

(b) markers

lay out brightly whitened markers in a straight line along runway - small markers every 20 metres; large marker every 100 metres

(c) calibration

pilot flies across line of markers

at right angles to them
at census height and at census speed (or slower)
with aircraft level and no bank

front-seat recorder fixates on radar altimeter
rear-seat observer counts markers between streamers
rear-seat observer shouts "NOW" as the markers pass by
front-seat recorder writes down reading of radar altimeter
rear-seat observer calls out number of markers
front-seat recorder writes down number, and checks

Repeat at least five times for each observer.

Repeat at two other heights, 100 feet above and 100 feet below census height.

(d) calculations

calculate strip width for nominal census height
repeat procedures if strip width too far from planned width
calculate correction factor for height above ground
record this along with data itemised under (a) above

Notes : It is advisable not to use cameras for counting the markers between the streamers. Difficulties in taking the photos from exactly the correct posision tend to invalidate the results.

: most census operators now use fishing rods (glass fibre) set into strong wooden clamps to demarcate the strip. The clamps are shaped to fit over the wing struts and are removable. Spare bolts, wing nuts and spring washers for the clamps should be carried in the aircraft. The rods should be painted with white rings so that they show up better in the photographs. After calibrating the strip width, mark position of clamps with paint. This indicates if they slip during the flight.

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