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AERIAL SURVEY OF ELEPHANTS IN ETOSHA NATIONAL PARK

(Including the results of the December 1984 census)

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February 1985

"Few observers, including myself, can believe that they miss animals on a transect while flying at 75m in good light. They can accept this intellectually because it has been tested, but it hardly seems possible."

Caughley (1977a,p35).

"This brings us to the question of whether emphasis should be placed on obtaining either an accurate or a precise population estimate.-- 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 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. On the other hand, accurate estimates are required,-- if a population is to be reduced by culling.--"

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

Norton-Griffiths (1978, p41)

CONTENTS

1. INTRODUCTION

The December 1984 census is the fourth in a series of four-month interval censuses started in December 1983. Two of these were conducted by fixed-wing aircraft as part of the elephant project, one was done with a fixed wing and helicopter in order to obtain culling quotas, and the remainder the biannual-multiple-observer-fixed wing-and-helicopter-census of Etosha.

The current objectives of counting elephants from the air is to accurately estimate the total number of individuals in the survey area, and the collection of additional environmental data. It is appropriate at this stage to investigate to what extent this objective has been achieved, and this report will, in addition to the presentation of results from the most recent census, present an investigation on precision and accuracy of data collected.

Any survey aiming to describe the density of objects is a major dilemma, with regard to protocol design, logistics, finances, staff and the physical application of methods. This type of work is sufficiently cost and effort-intensive to warrant optimization in all respects. Tragic consequences of inadequate planning and often just a lack of foresight, are non-valid comparisons between results obtained from censuses using different methods and resulting unfounded suggestions for management. Censusing personnel usually exhibit some degree of personal pride in a census, as this is seen as a glorified type of work instead of the routine duty which it should be, and resistance will be experienced when suggesting that results are unreliable.

Before any census or method can be criticized, it is essential to recognize that probably no single method can be identified as the most effective under variable conditions, or even a more specific set of circumstances as will be encountered in the census of an area the size of Etosha. Much controversy is apparent from the literature and the debate continues. It is however recognized that too much effort can be expended on devising, designing and refining methods, without a corresponding increase in effort expended on data analysis.

The suggestions of the leading authors in this field can therefore be summarized as follows (with regard to the study of population trends).

1. Choose, adapt, design, in that order of preference, a method compatible with local constraints on time, finances, personnel, terrain, species to be counted, aircraft to be used and objectives of counting.

2. Instead of striving to achieve maximum accuracy, strive to achieve maximum precision. Investigate the sources of bias and

variance, but instead of trying to eliminate those, rather try and define and describe them, and apply correction factors to estimates.

A most important aspect must be mentioned here, partially to explain why this type of analysis is conducted only now, and not from the start of this project, namely, experience. Counting personnel experience two types of learning during a census, experience-based increase in efficiency and motivation-based negative learning. Excited novices without experience may yield better results than unmotivated veteran counters. Furthermore, some degree of counting efficiency accrued during one census is retained during successive surveys, but negative learning can make a veteran inefficient.

Having personally counted for nearly 300 hours in the air does not necessarily make a good counter out of me, but the accummulated experience in census design, execution and analysis is considered now, for the first time, adequate to evaluate the whole approach in retrospect.

As stated in the 1984 progress report (Lindeque 1984 c) one of the current research objectives of this phase of the elephant project, is the establishment of a monitoring system to provide the basis for future policies. Aerial counting of elephants will probably be, as it is now, one of the most important research and monitoring exercises, and it will be with us for many years to come.

2. METHODS

2.1 Current census method

2.1.1 The method adopted for the first census in December 1983 was a best estimate of the optimum combinations of the major variables, such as strip width, altitude and airspeed. The sudden availability of the aircraft then, and limited period available precluded intensive planning and experimentation. A sample type of census could not be planned and the "total transect type of census" commonly used in Etosha was followed.

2.1.2 A variation from standard transect censusing was incorporated in the first census and followed in subsequent ones, namely that when herds were spotted, transects were interrupted, each group was counted while circling above as long as was required, and the transect then resumed from the point of interruption. This requires great navigational skills from the pilot, but when successful, enhances counting precision greatly.

2.1.3 In order to minimize errors in comparisons between successive censuses, the methods adopted in the first census were applied in subsequent surveys, except that more latitude was allowed in strip widths and altitude with variable vegetation cover. Transect width, altitude and airspeed varied between 2-4 km, 100-130 m and 60-150 km/h, respectively.

2.1.4 One census block, containing approximately 12% of the estimated total number of elephants, was recounted, following exactly the same methods, with the repeat count flown immediately after the first ended.

2.1.5 Herd sizes of elephants were recorded separately, as well as the number of adult cows and calves less than one year of age. All adults within a herd, unless identifiable as bulls, were regarded as female, and the number of 1 year old calves counted actually represented the 0-2 year age interval.

2.1.6 Etosha is relatively uniform with regard to topography and regular grid square patterns could not be used with confidence. Irregular burn blocks served as counting blocks. The approximate localities of all elephants and seasonal water catchments (containing water at the time) were recorded on a 1:500000 map. Census blocks used are illustrated in fig.1.

2.1.7 A photogrammetrical survey of all herds was done according to the method of Croze (1972) where vertical colour transparencies were taken of herds for analysis of population structure (a similar survey in may 1984 was discarded due to confusion of films by the processing agency. The acquisition of a camera data back which prints a code onto each frame has eliminated this type of disaster).

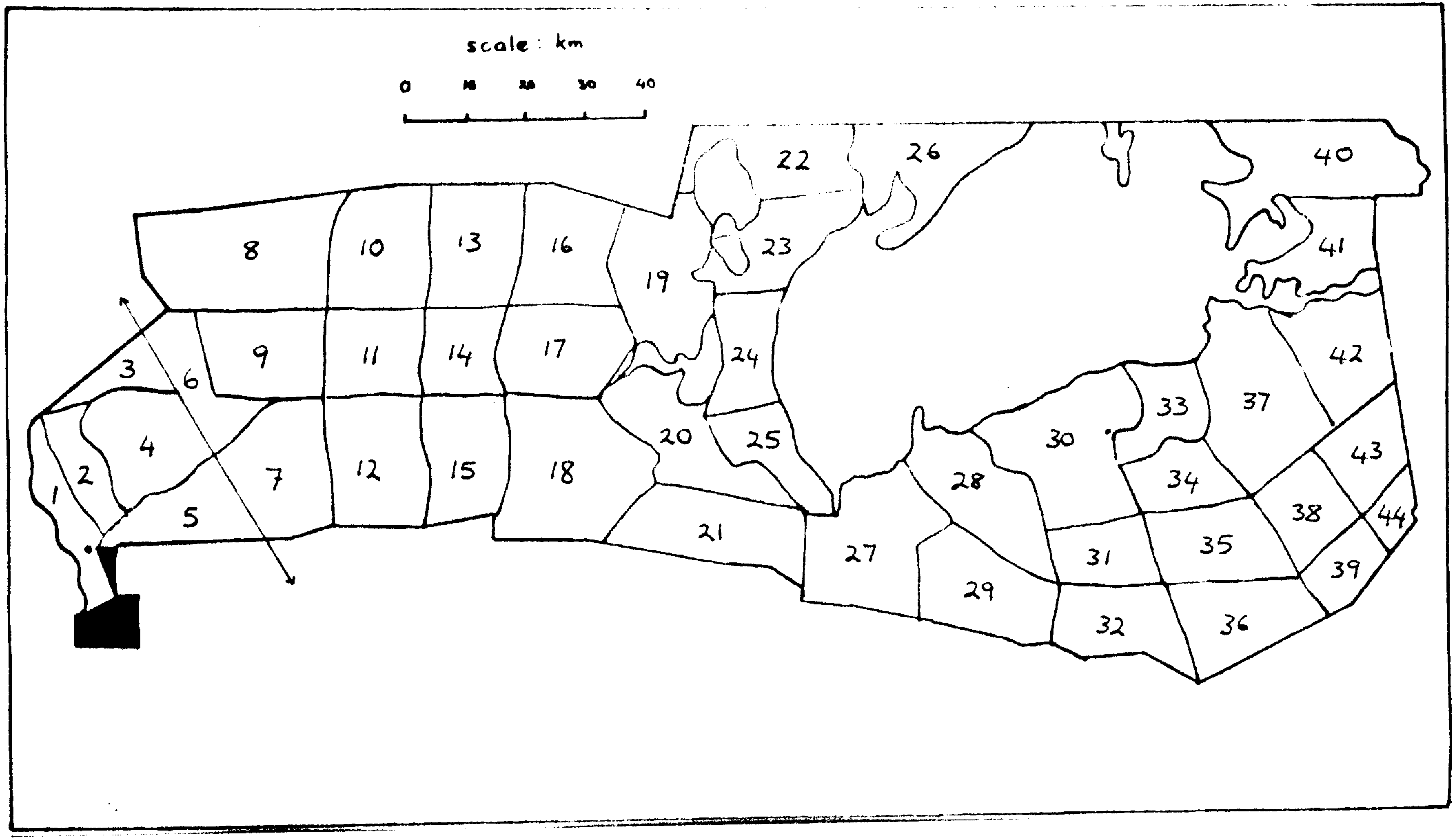


Figure 1. Census blocks used in December 1984.

2.1.8 Gross phenological status of the dominant plant species (identifiable from the air) was recorded from the air throughout Etosha (the results will be reported elsewhere).

2.1.9 Radiocollared elephants and lions were tracked during the census, but the results will be reported elsewhere.

2.2 Estimation of bias

2.2.1 Methods of calculating estimates of bias were as follows:

1. Repeat counts/double survey estimates: disparate observer binomial estimate of Magnusson, Caughley and Crigg (1978).

2. Partial regression analysis of major survey variables and apparent elephant density (Caughley 1974; Caughley, Sinclair and Scott-Kemmis 1976; Steel and Torrie 1980).

3. Total census undercount bias (Caughley 1977a).

2.3 Alternative census methods

2.3.1 The methodology of alternative census methods is best discussed in conjunction with some results, which can serve as examples. Detailed descriptions are provided by Jolly (1969b), Sinclair (1972), Norton Griffiths (1973,1978), Caughley (1977a,b), Pennyquick, Sale, Stanley Price and Jolly (1977) and Gauch (1982).

3. RESULTS AND DISCUSSION

3.1 December 1984 census

3.1.1 Figure 2 illustrates the total number of elephants counted in each block in Etosha. Comparisons between elephant numbers and herd compositions are presented in Tables 1 and 2.

Results of the photogrammetrical survey of herd structure have not been analysed yet, because the maximum growth asymptotes used in East Africa are considerably lower than that of elephants in Etosha. It is expected that adequate data will be collected during the 1985 cull to calculate growth curves, and apply this method.

3.1.2 Figure 3 illustrates the number and distribution of elephant bull herds in December 1984, while fig. 4 presents the

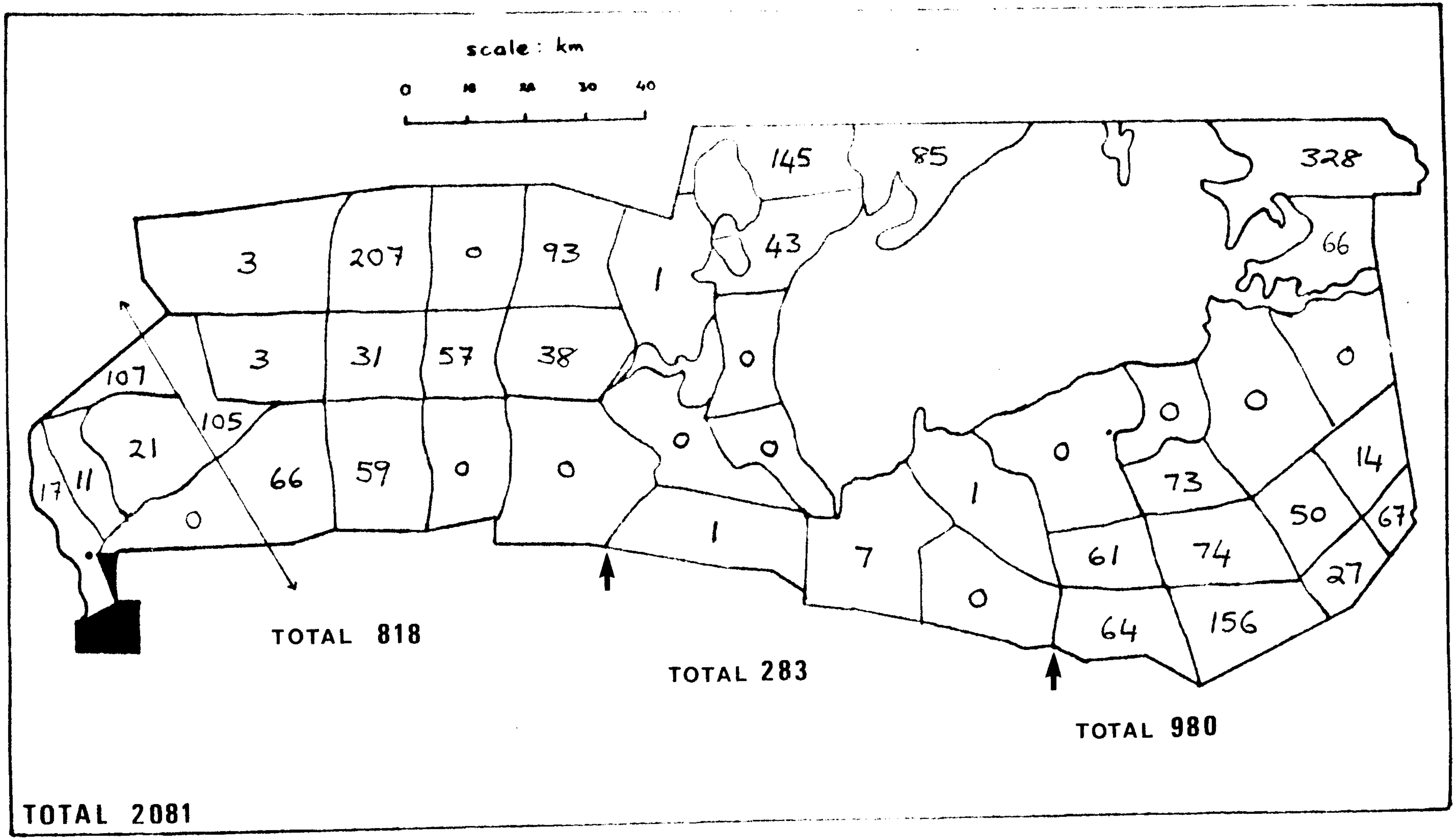


Figure 2. Total number of elephants counted in December 1984 in Etosha National Park.

Table 1: Comparisons between numbers and composition of breeding herds in the Western, Central and Eastern Districts of Etosha National Park.

	West	Central	East	Total
Total number counted	691	254	808	1753
% of total	39.4	14.5	46.1	
Number of breeding herds	58	24	56	138
Mean size +- SE of breeding herds	12.4 +- 0.7 (2-24)	10.8 +- 0.9 (5-20)	14.1 +- 1.1 (4-43)	
Number of lyr old calves	70	42	88	200
% lyr old calves/ breeding herds	10.1	16.5	10.9	11.4
% lyr old calves/ total elephants	8.6	14.8	9.0	9.6
% breeding herds with no lyr old calves	24.3	2.4	21.4	21.7
Mean ratio +- SE of lyr old calves to adults in breeding herds	0.28 +-0.04 (0.0-1.0)	0.45 +-0.04 (0.0-0.83)	0.40 +-0.04 (0.0-1.0)	
Number adult cows	236	99	237	572
% adult cows/all elephants	28.9	35.0	24.2	27.5

Table 2: Comparisons between numbers and composition of bull herds in the Western, Central and Eastern Districts of Etosha National Park.

	West	Central	East	Total
Total number counted	127	29	172	328
% of total bulls	38.7	8.8	52.4	
% of total (all elephants)	15.5	10.3	17.6	
% of total counted (2081)	6.1	1.4	8.3	15.8
Number bull herds	42	17	55	114
Mean size +- SE of bull herds	1.7 +-0.2 (1-9)	1.3 +-0.1 (1-3)	2.3 +-0.3 (1-11)	1.9 +-0.2 (1-11)
% bulls in breeding herds/total bulls	44.1	20.7	23.3	31.1

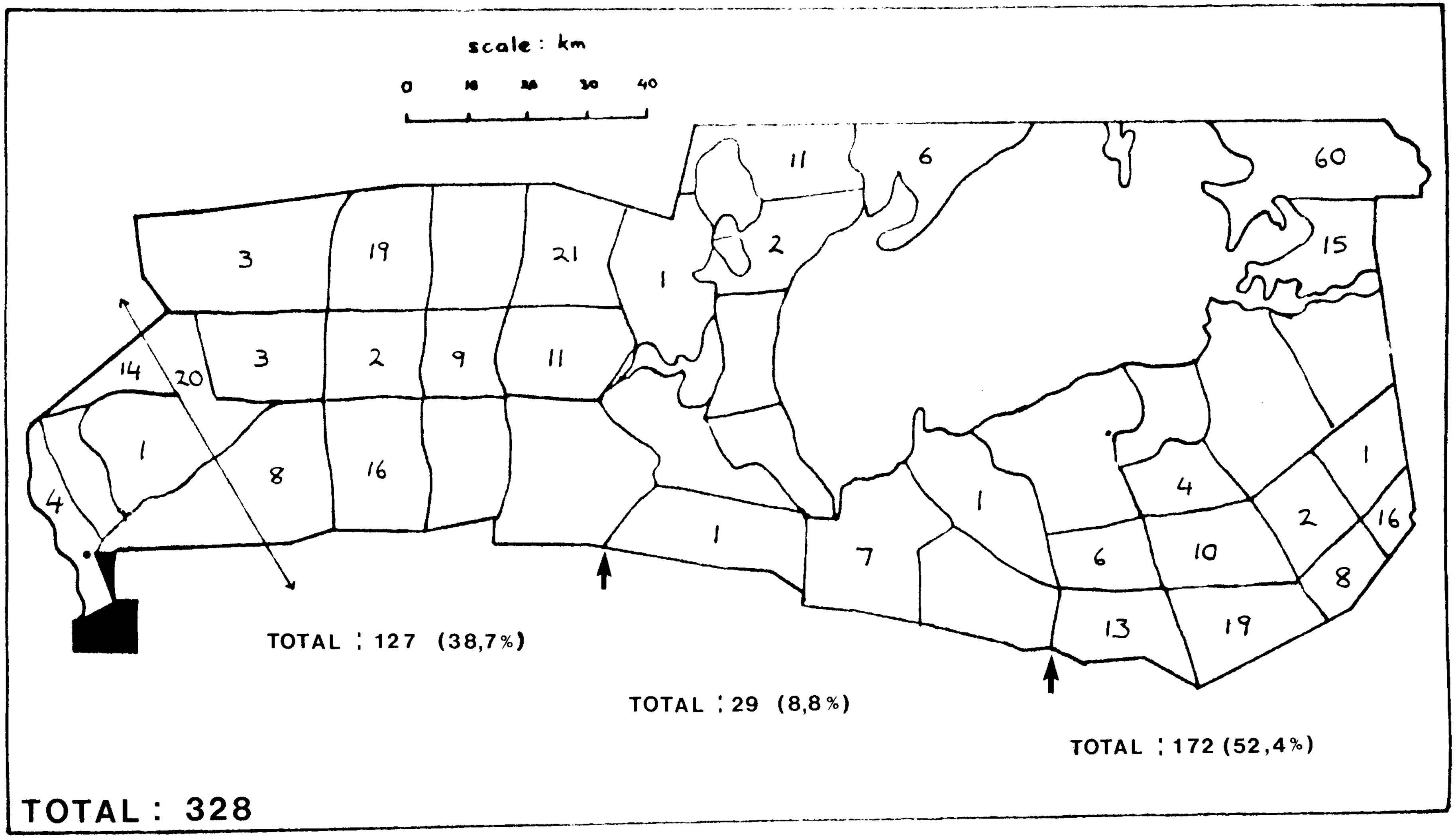


Figure 3. Number of elephant bulls in each block during December 1984.

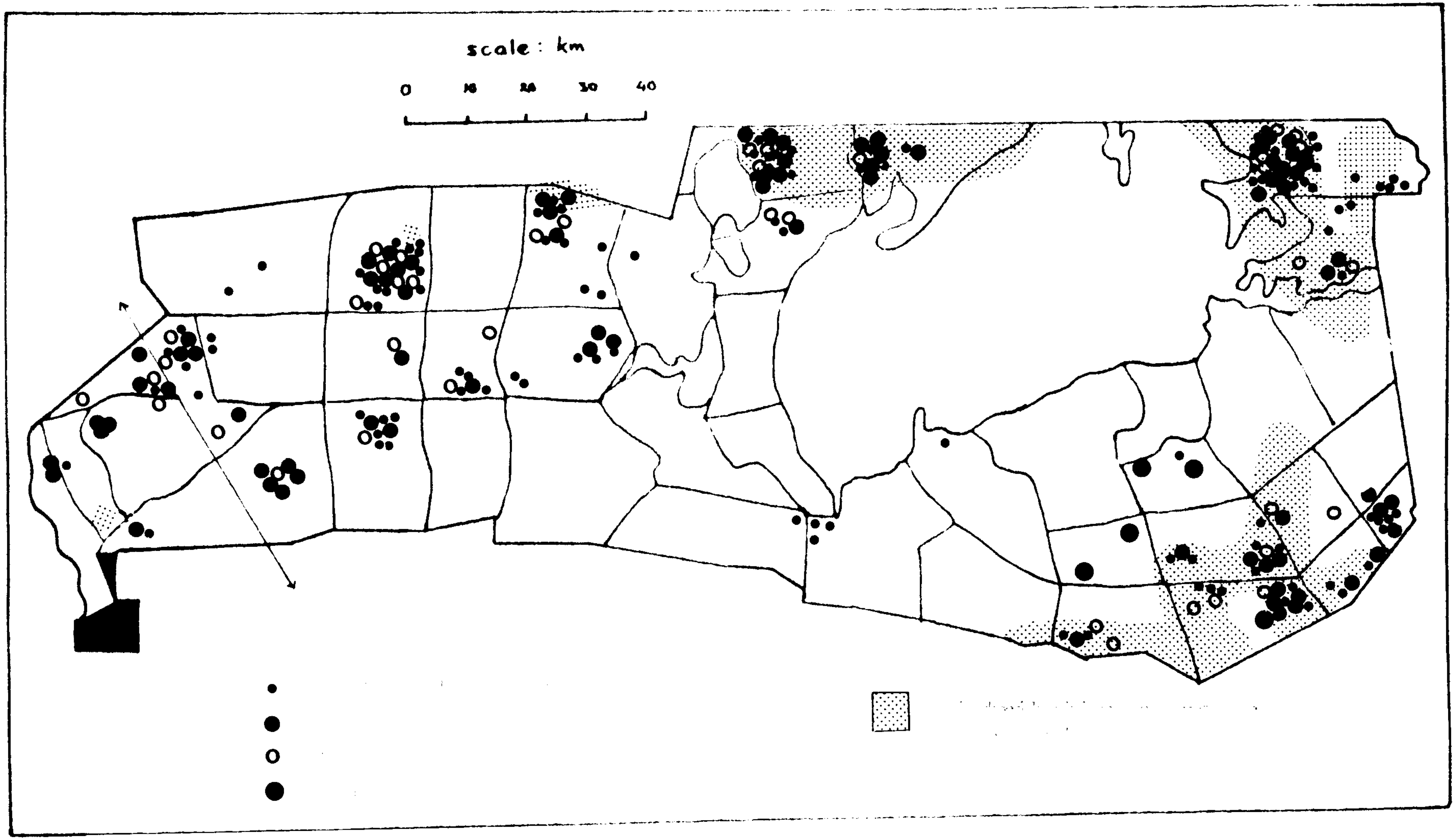


Figure 4. Distribution of rain water pools and approximate localities of all elephant herds.

approximate sizes and distribution of all elephant herds in relation to the distribution of seasonal water catchments.

3.1.3 A population estimate from the total count done in December 1984, remains an estimate only, with unknown variance if additional steps aren't taken to describe the variance. Such an additional step may be the repetitive counting of sampling units. Consecutive counts of the same counting unit can be used to estimate the variance pertaining to that block, but extrapolated to the total survey area.

3.1.4 Block 22 was flown twice in quick succession and the counts yielded were superficially very similar, namely 145 and 139 (4.3% difference), indicating repeatable precision well within acceptable limits.

If, however, the disparate-observers binomial estimate (Petersen's estimate) of the total number of elephants is applied (Magnusson et. al., 1978), the estimate ($\hat{N}$) is higher than both counts. This method relies on the repeatable identification of counted entities, where :

$$\hat{N} = \frac{(S_1 + B + 1)(S_2 + B + 1)}{B + 1} - 1$$

and

$$\text{Var}\ \hat{N} = \frac{S_1 \cdot S_2\ (S_1 + B + 1)(S_2 + B + 1)}{(B + 1)(B + 2)}$$

with

S_1 = Numbers seen in survey 1 but not in survey 2.
S_2 = Numbers seen in survey 2 but not in survey 1.
B = The number seen in both surveys.

The sum of S_1, S_2 and $(B \times 2)$ is larger than N, thereby indicating a totally unbiased estimate of N. The number of elephants missed (M) in both surveys is estimated as:

$$M = \frac{S_1 \cdot S_2}{B} = 47.9$$

The crux of this method hinges on the ability to distinguish between entities, and in this case, this was based on elephant group size. Circling above elephants caused some disturbance (eg.

splitting of herds), and could have caused the disparity between survey 1 and 2.

This method was repeated with groups matched (B) based on the number of cows and young calves rather than absolute size, and the result was N (+- SE) = 177 +- 3.1 (approximately 24% higher than the highest count).It is expected that not all the changes in group sizes could be counteracted by rematching,(as there were 21 and 13 groups in surveys 1 and 2 respectively) and some movemement in or out of the unit could have occurred.

It is clear that even a reasonably precise double count of a block does not necessarily reveal too much about accuracy in one block, and even less in the total survey area. It would not be valid to raise the total number counted by 24%. This avenue of investigation seems to be futile, as further refinements such as simultaneous counting one block by two aircraft would be too dangerous.

If any correction factor is required under these circumstances, the 4.3% difference between surveys 1 and 2 would be more appropriate as an estimate of the variance attributed to changing precision. The accuracy of the census remains obscure.

3.2 Investigation into bias

A model describing the sources of variance in an aerial census has been described by Caughley (1974) and tested by Caughley et.al.(1976). This model, with modifications has been applied to the December 1984 census, with the following steps:

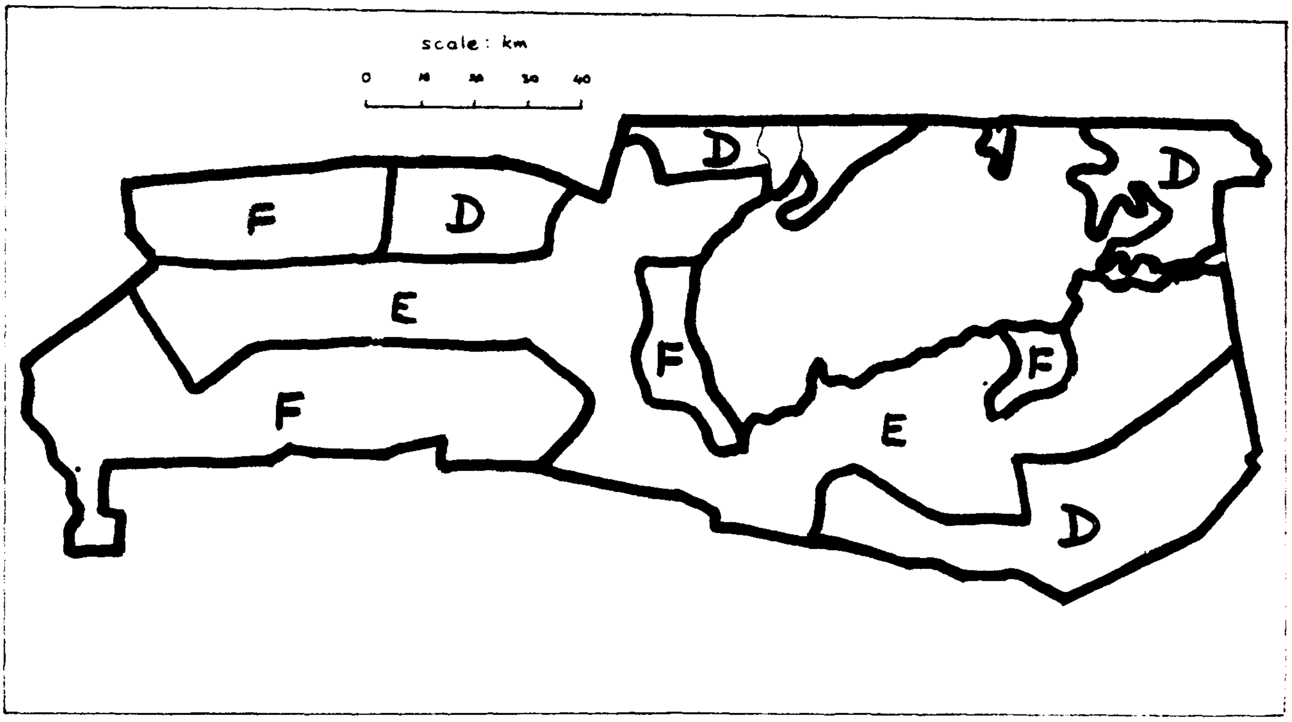
3.2.1 The survey area was stratified into three strata of high, medium and low vegetative cover, based on assessment from the air. These strata are illustrated in fig. 5.

3.2.2 Of the dozens of variables encountered during a census, transect width, altitude and airspeed are regarded as major sources of error. Two of these, namely transect width and altitude were investigated in this report, while airspeed, if not always constant, was not measured.

Four treatment combinations of strip width and altitude were applied to blocks in the census, namely:

Low altitude + Narrow transects (100m + 2km)
Low altitude + Wider transects (100m + 4km)
Higher altitude + Narrow transects (130m + 2km)
Higher altitude + Wider transects (130m + 4km)

Any treatment combination was assigned to a specific block as an estimate of an optimum combination for counting conditions in that block. This was often thwarted due to unexpected changes in



D	High vegetation cover
E	Medium vegetation cover
F	Low vegetation cover

Figure 5. Stratified map of survey area according to vegetative cover.

elephant density, wind at altitude, visibility at altitude, sightability at time of day and other atmospheric conditions (dust,rain,fog). This has entered some element of randomness into the allocation of treatment combinations to blocks, but the conditions of random allocation suggested by Caughley (1974) were not fully met. The whole exercise therefore, was regarded as a way to investigate the effects of the major variables and their interaction on sightability, and not necessarily to produce correction factors.

3.2.3 Two complications have to be dealt with at this stage. Transect width in itself was found to be variable as opposed to being statutory (either 2 km or 4 km wide). In practice, as determined from the number of transects actually flown relative to the size of each block, 2 and 4 km transect widths varied between 1,8-3,4 km and 3.8-5.8 km. Table 3 presents the deviations from the designated transect widths in the four treatment combinations.

From Table 3, it is clear that greater variation occurred with the demarcation of 4 km strips than 2 km strips, and the greatest variation occurred at the greatest altitude. The present method of demarcating strip width by a fixed marker on the wing strut is therefore inadequate, and streamers attached to wing struts will be used in future (as described by Pennyquick and Western, 1972). Variation in altitude, due to the lack of a proper altimeter and aircraft instability in flight are nevertheless also regarded as contributing factors.

In order to estimate the effect of variation in designated strip widths, all analyses were done in duplicate, one using "real" transect width and the other the statutory width.

The second complication arises from the stratification of Etosha into cover types. A brief look at figures 2 and 4 will suggest that elephant distribution is perhaps correlated with the high cover stratum, and this aspect may confuse the results. In order to eliminate this effect, as well as stratification errors, the strata with the highest cover (D) and medium cover (E) were lumped and analysed separately, and similarly the strata with medium (E) and low cover (F) were lumped.

3.2.4 The numbers of elephants counted in each unit was expressed as a density ($Y=N/km^2$). Area of counting units was determined by using a planimeter on existing 1:500000 maps.(These maps are known to be inaccurate but will suffice for our purpose).

3.2.5 Partial regressions of apparent density (Y) on strip width (real=X_1 and designated=X_2)and altitude (X_3) were calculated, using a polynomial multivariate regression method following Caughley (1974) and Steel and Torrie (1980). This analysis was calculated separately for each stratum, strata combined, and the total unstratified area.

The expression used takes the form of :

Table 3. Deviations from statutory transect widths.

Altitude (m)	Statutory transect width(km)	Mean +- SE of deviations	Range	Number of samples
100	2	0.63+-0.18	(1.9-3.1)	8
130	2	0.60+-0.19	(1.8-3.4)	9
100	4	0.33+-0.24	(3.8-5.6)	7
130	4	0.86+-0.25	(3.6-5.8)	7

$$\hat{Y} = b_0 + b_1X_1 + \ldots\ldots\ldots b_kX_k$$

where

$\hat{Y}$ = Apparent density of elephants.

X_1 = Real strip width.

X_2 = Statutory strip width.

X_3 = Altitude.

b_0-b_3 = Regression slope constants, and the Y-intercept constant b_0 is an estimate of true elephant density.

Either X_1 or X_2 were used, as well as X_1 and X_2 together, but the latter form was omitted from discussion due to interpretative difficulties. Exponential terms of X_k to describe hyperbolic functions were not used in the analysis.

To estimate b_0 (there written as β_0), the regression equation is written as a matrix

$$X'X\hat{\beta} = X'Y$$

where

$$= \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (X'X)^{-1}X'Y \qquad \text{and}$$

$$b_0 = \bar{Y} - b_1\bar{X}_1 - b_2\bar{X}_2$$

The regression lines are illustrated in fig. 6 a-f, with the statistically significant relationships marked * ($F > p0.05$) and ** ($F > 0.01$). The calculation of F was done as part of the analysis of variance in 3.2.6.

3.2.6 A full analysis of variance was done with each combination and are presented in an abridged form in Tables 4 a-f for each analysis in each stratum or combination of strata. Although bulky, this is useful to indicate the significance of the influence of each variable on the density of elephants, and how this differs between strata.

Some general conclusions are suggested from this analysis, namely

1. Elephant density (by implication the sightability of elephants) increases with increasing altitude.

2. Sightability decreases with increasing transect width.

3. Greater bias resulted from the use of either 2 or 4 km as statutory transect widths than from the deviations in designated transect width.

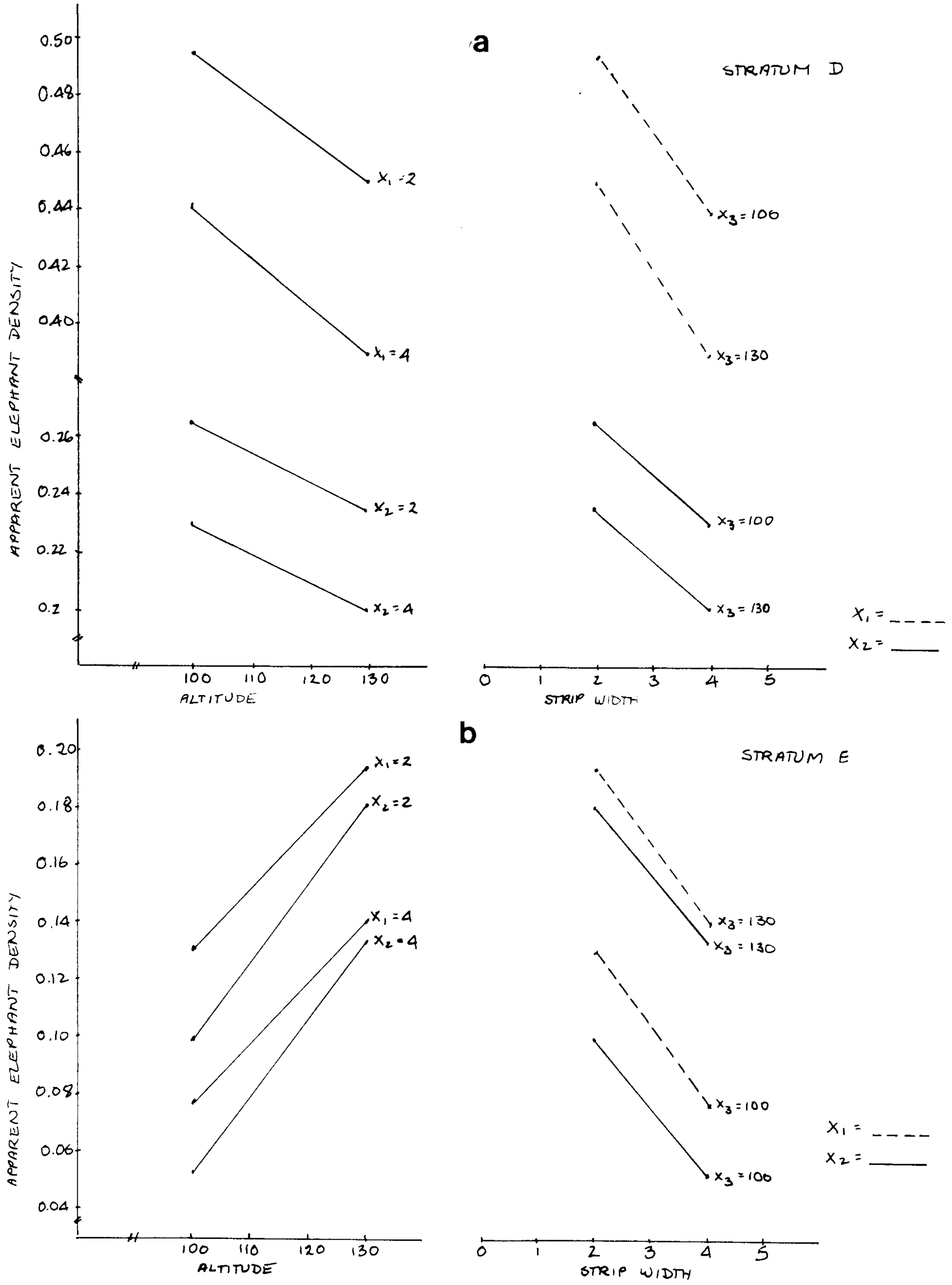


Figure 6. Trend of apparent elephant density on altitude, strip width (real and statutory) in each stratum (a-f).

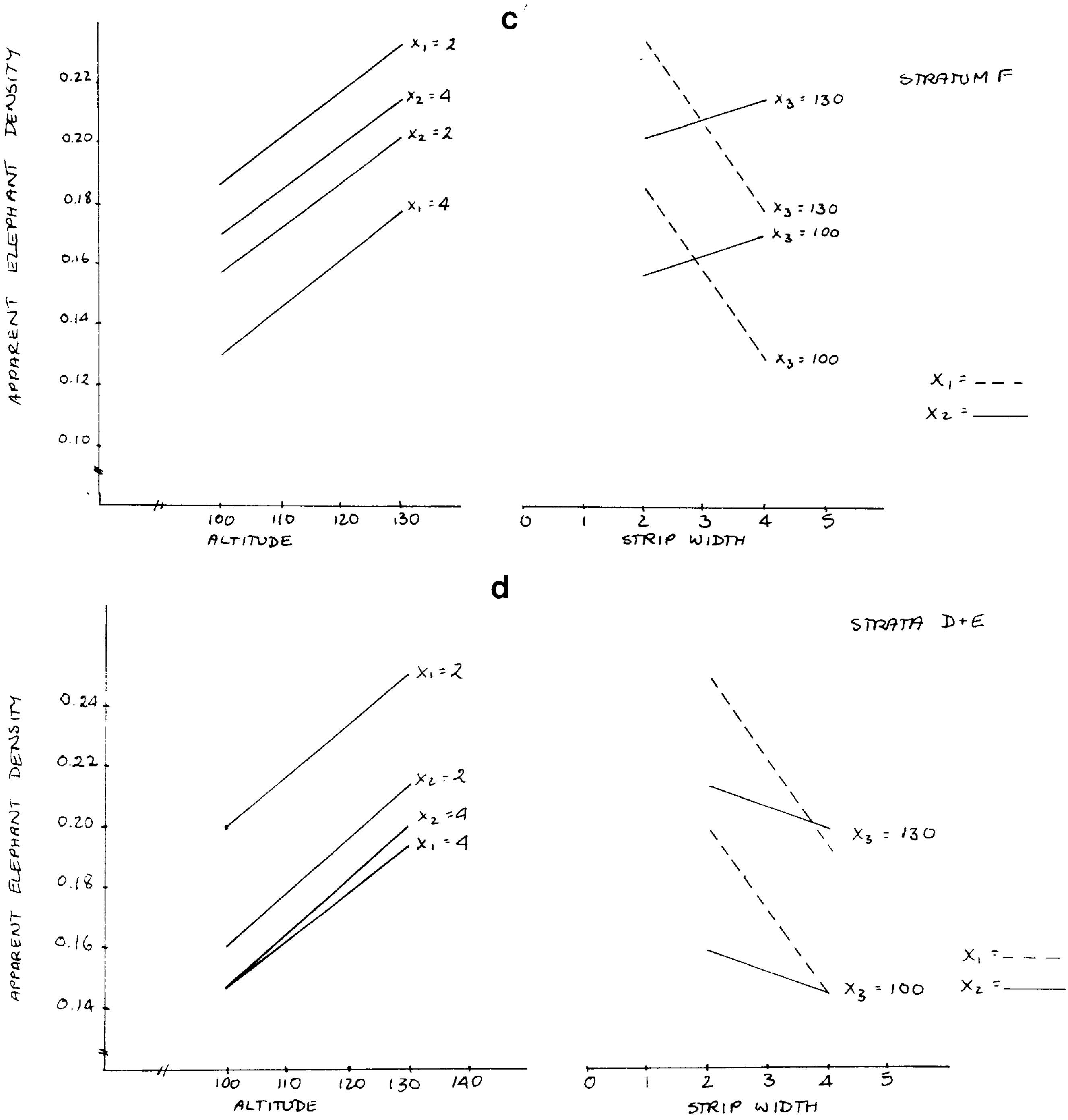


Figure 6. Continued (c and d).

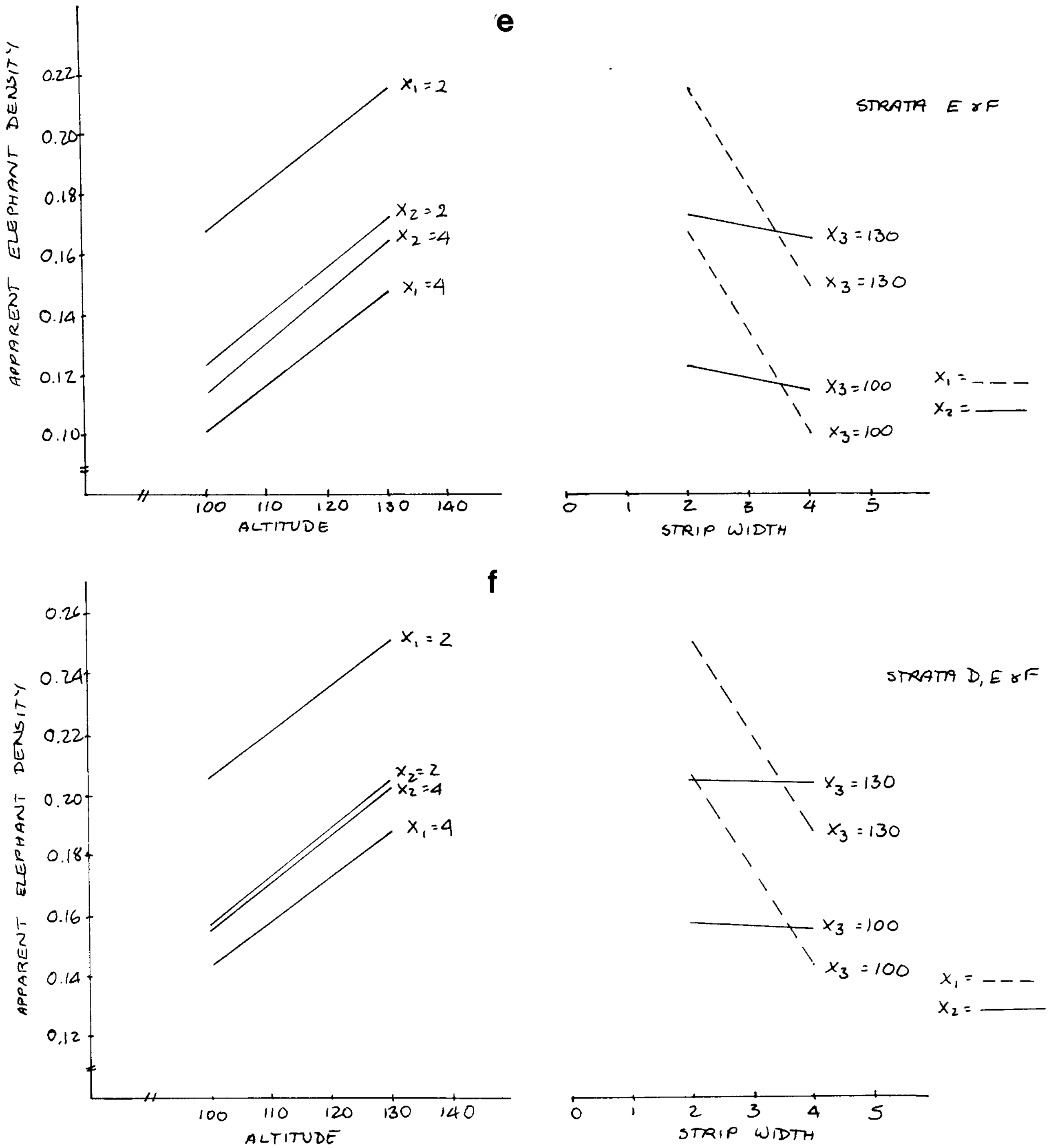


Figure 6. Continued (e and f).

Table 4: Summary of analysis of variance on apparent elephant density in strata D, E, F, DE, EF and DEF

Table 4a

STRATUM D

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.001	1		0.030
Altitude	0.003	1		0.146
Interaction:				
Y/X1,X3	0.003	1		0.111
Y/X3,X1	0.005	1		0.223
Residual	0.182	9	0.023	
Total	0.216	11		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.005	1		0.207
Altitude	0.003	1		0.147
Interaction:				
Y/X2,X3	0.004	1		0.155
Y/X3,X2	0.002	1		0.091
Residual	0.209	9	0.0232	
Total	0.216	11		

TABLE 4b

STRATUM E

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.019	1		0.477
Altitude	0.721	1		18.495**
Interaction:				
Y/X1,X3	0.037	1		0.936
Y/X3,X1	0.739	1		18.954**
Residual	0.312	8	0.039	
Total	1.070	10		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.514	1		12.715**
Altitude	0.721	1		17.854**
Interaction:				
Y/X2,X3	0.026	1		0.634
Y/X3,X2	0.233	1		5.775*
Residual	0.323	8	0.0404	
Total	1.070	10		

[illegible]

STRATUM F

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.025	1		0.140
Altitude	2.757	1		15.351*
Interaction:				
Y/X1,X3	0.025	1		0.136
Y/X3,X1	2.707	1		15.072*
Residual	0.898	5	0.180	
Total	3.630	7		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	2.659	1		16.303**
Altitude	2.757	1		16.904**
Interaction:				
Y/X2,X3	0.058	1		0.355
Y/X3,X2	0.156	1		0.955
Residual	0.815	5	0.1631	
Total	3.630	7		

TABLE 4.[illegible]

STRATA D and E

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.047	1		0.730
Altitude	4.128	1		64.906**
Interaction:				
Y/X1,X3	0.034	1		0.528
Y/X3,X1	4.115	1		0.528
Residual	1.272	20	0.064	
Total	5.434	22		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	3.860	1		60.409**
Altitude	4.128	1		64.599**
Interaction:				
Y/X2,X3	0.028	1		0.429
Y/X3,X2	0.295	1		4.620*
Residual	1.278	20	0.064	
Total	5.434	22		

TABLE 4[illegible]

STRATA E and F

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.101	1		0.936
Altitude	9.107	1		84.402**
Interaction:				
Y/X1,X3	0.201	1		1.863
Y/X3,X1	9.207	1		85.329**
Residual	1.727	16	0.1079	
Total	11.035	18		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	8.763	1		75.284**
Altitude	9.107	1		78.239**
Interaction:				
Y/X2,X3	0.065	1		0.558
Y/X3,X2	0.409	1		3.514
Residual	1.863	16	0.1164	
Total	11.035	18		

TABLE 4C

STRATA D,E and F

X1,X3

Source	SS	df	MS	F
Main effect:				
Transect width	0.127	1		1.142
Altitude	14.129	1		127.059**
Interaction:				
Y/X1,X3	0.257	1		2.311
Y/X3,X1	0.127	1		1.142
Residual	3.115	28	0.111	
Total	16.987	30		

X2,X3

Source	SS	df	MS	F
Main effect:				
Transect width	13.693	1		149.487**
Altitude	14.129	1		154.247**
Interaction:				
Y/X2,X3	0.292	1		3.188
Y/X3,X2	0.728	1		7.948*
Residual	2.565	28	0.092	
Total	16.987	30		

3.2.7 Some exceptions and comments are:

Stratum D

1. The conclusions in 3.2.6 are not valid (from F tests in 3.2.6) in Stratum D (highest cover), therefore altitude and transect width did not significantly affect the recorded densities. This implies that 57.6% of the elephants counted in the survey (those in stratum D) were counted with negligible bias attributed to strip width and altitude. The analysis therefore indicates that elephants in Stratum D may be counted with confidence, using transect widths of 2-4 km (preferably 2) in combination with altitudes of 100-130 m (preferably 100m).

Strata D and E

2. When strata D and E were lumped (as discussed in 3.2.5) the trend of decreasing sightability with increasing altitude in stratum D, which was not significant, was reversed in the combined analysis to conform with stratum E. The significance of this phenomenon with regard to practical predictions for stratum D is obscure and discarded until further experimentation provides confirmation.

Stratum E

3. Deviation from designated strip widths in stratum E was insignificant, although apparent elephant density significantly decreased with increasing strip width and decreasing altitude. This implies that the recommended census method for stratum E is an altitude of 130m combined with a transect width of 2km.

Stratum F

4. Apparent elephant density increased significantly with both increasing altitude and transect width. The recommended counting method is therefore an altitude of 130m and a strip width of 4km. This makes much practical sense, as the typical conditions in the area designated as stratum F are open plains or low mopani shrubland.

Strata E and F

5. Indications are that stratum E has greater affinities to stratum D than F, with regard to counting elephants and there appears to be no justification in lumping strata E and F.

6. Stratification based on vegetative cover, the strata D, E and F in this report is generally supported by the regression equations. Each stratum has one or more unique features with

regard to sightability and until stratification can actually be based on aerial mapping of woodlands, shrubland and open plains, the present classification will suffice. One confusing aspect is that the more densely covered stratum D is suggested to be counted at 100m altitude and 2km transect width, while the less densely covered stratum is to be counted at the same transect width but an altitude of 130m. It is possible that a further interaction between elephant density and one or both variables might have caused this situation. Further investigation is required.

Strata D,E and F combined

7. If one combination of methods is ever to be used over the whole of Etosha, then it appears that an altitude of 130m and a transect width of 2km are preferred. There is no doubt however, that stratification results in better counting methods for a more specific set of circumstances.

3.2.8 Apart from indicating perhaps which combination of variables should yield a population estimate closest to the absolute population estimate derived from the y intercept, partial regression analysis can also be used to estimate correction factors to be applied to the total counted in each block, as well as an estimation of the variance of the estimate of population size.

3.3 Y-intercept estimation of true population size and the variance of estimates

As discussed in 3.2.5, the y-intercept b_0 is an estimate of true elephant density, which when multiplied by the area of the stratum yields the number of elephants. These estimates are presented in Table 5, as well as the standard error calculated as:

$$SE_{b_0} = \sqrt{\frac{\text{Residual Mean Square}}{n}}$$

where the residual MS is obtained from the analysis of variance (Table 4 a-f).

An F-test of the null hypothesis $\beta_0 = 0$ is included in Table 5, where the f value is calculated as:

$$F_{[n_x, n-n_x-1]} = \frac{\text{Mean Square } \beta_0}{\text{Residual Mean Square}}$$

This test, in fact, tests the possibility that b_0 is not independent from b_1 and b_2, which if accepted will cause the rejection of b_0 as a valid estimator of elephant density (see Steel and Torrie 1980).

Non-significant R values in Table 5 are multiple correllation coefficients (Table 7) of regression lines not adequately representing the original data points.

From Table 5a, it appears that all b_0 estimates of stata D,E and F are not valid, due to either a non-significant b_0 estimate, non-significant R value or non-significant X_{1-3} estimates (from Table 4a-f). The X_2X_3 regressions (designated strip width : altitude) of the combined strata are however acceptable.

All estimates of population size ($\hat{Y}$) are nonsensical and are discarded. This is explained as the consequences of not randomly assigning treatment combinations to blocks.

The standard errors of $\hat{Y}$, as in Table 5b, may however still be used, as SE is calculated from the residual mean square and not the regression (or b_0) mean square. It is very risky to choose SE values from Table 5b in order to correct totals counted, especially since the nonsensical b_0 estimates and SE values were calculated from the same distribution if not from the same sum of squares. If one is to be selected, the stratum $DEF_{x_2x_3}$ value is perhaps the soundest. Any X_1X_2 value should not be considered, as it was clear from Table 4a-f that X_1 was not a significant influence on the estimate of $\hat{Y}$.

The absence of any significant main effects and variable interactions (Table 4a-f) in stratum D is reflected in the low SE of this stratum. Strata with decreasing cover show increasing SE's, expected to be a function of clumped distribution of elephants and overall lower densities, rather than sightability.

The question might still be, that how can one use the SE values but reject the y-intercept values? It must be remembered that the residual sum of squares is an indication of an overall failure of the model to fit the data. The calculation of SE is derived from a refinement of the residual SS to a mean square, incorporating an element of sample variance, namely the degrees of freedom of the residual SS.

Norton Griffiths (1978), as well as Caughley (1977), have speculated on the behaviour of the regression curve close to the y-axis. It may well be that a para/hyperbolic function would suit that part of the expected curve better, while the linear regression used in this report will adequately describe the data between the extremes measured, but not extrapolations.

Both the reasonably low SE values (as far as total counts go) and the multiple correlation coefficients R (Table 7) indicate that the regression equations represent the data adequately

Table 5a. Y-intercept (b_0) estimates of true elephant numbers in all strata

Strata	b_0	Area km^2	$\hat{Y}$ (b_0 area)	Total counted	%Δ $\hat{Y}$/y	NS
D						
X1X3	0.0059	4402	26.0	1169	2.2	b , R, X1, X3
X2X3	0.0069	4402	30.4	1169	2.6	b , R, X1, X3
E						
X1X3	0.7578	4394	3329.8	421	790.9	b , X1
X2X3	0.7469	4394	3281.9	421	779.6	b
F						
X1X3	2.7326	3562	9733.5	491	1982.4	b ,R , X1
X2X3	2.8150	3562	10027.0	491	2042.2	b ,R
DE						
X1X3	0.1000	8796	879.6	1590	55.3	X1
X2X3	0.0040	8796	35.2	1590	22.1	
EF						
X1X3	0.0750	7956	596.7	912	65.4	X1
X2X3	0.0390	7956	310.3	912	34.0	
DEF						
X1X3	0.1210	12358	1495.3	2081	71.9	X1
X2X3	0.00013	12358	1.6	2081	0.1	

b F<(p0.01)
R R<(p0.01)
X1 }
X2 } F<(p0.05)
X3 }

Table 5b. Standard errors of Y-intercept (b_0) estimates of true elephant numbers in all strata.

Strata	$SE_{b_0} = \frac{\text{Res MS}}{n}$	$SE_y = \frac{\text{Res MS}}{n}$ x area	$\frac{SE_y}{\text{actual cnt}}$ %	% of actual elephants counted in each stratum
D				
X1X3	0.0441	194.0	16.6	52.2%
X2X3	0.0440	193.6	16.6	
E				
X1X3	0.0595	261.6	62.1	20.2%
X2X3	0.0606	266.2	63.2	
F				
X1X3	0.1498	533.7	108.7	23.6%
X2X3	0.1631	508.6	103.6	
DE				
X1X3	0.0526	462.5	29.1	76.4%
X2X3	0.0527	463.6	29.2	
EF				
X1x3	0.0754	599.6	65.8	43.8%
X2X3	0.0783	622.7	68.3	
DEF				
X1X3	0.0599	740.2	35.6	100.0%
X2X3	0.0544	671.8	32.3	

indeed, and there should be few objections to the use of the SE values in a restricted way.

3.4 Calculation of correction factors from partial regression analysis

Caughley et.al (1976) suggested that the percentage actually counted (y/Y%) at any specific combination of variables can be estimated as :

$$Y = b_0 + b_1x_1 + b_2x_2 \text{ multiplied by } 100/b_0$$

Correction factors, corrected totals and the percentage deviations from apparent elephant density are presented in Table 6. The last column in Table 6 was included to list the reasons why correction factors should be rejected, due to one or more components and attributes of the partial regression equation which were found statistically not significant earlier in the analysis. Table 7 presents the multiple correlation coefficients of the regression equation in all strata. Significant R values (as denoted in Table 7) indicate acceptable " goodness of fit " between points and regression lines.

Three values, however, could not be rejected on any grounds. The effect of nonconformation to random norms is nevertheless clearly seen, since neither of the correction factors make any sense at all. The factors regarded as responsible are the same as discussed in 3.3.

3.5 Estimation of total census undercount bias

A method has been suggested by Caughley (1977a), to estimate the elusive "total count undercount bias". If censuses have been done at different levels of sightability (eg. prior to deciduous leaf drop versus counting after leaf drop), then an estimate of true population size can be obtained from :

$$x = s^2 \frac{1}{k} + \bar{x}^2 \frac{1}{N}$$

where
N = true population size.
$\bar{x}$ = mean number counted at one level of sightability.
s^2= variance of counts.
k = constant, describing extent to which mean sightability varied between surveys at one level of survey efficiency.

Both k and N are unknown, and one therefore needs two estimates of $\bar{x}$ and s^2 to solve the equation.

Table 6. Correction factors (C), corrected totals and percentage deviation from apparent elephant densities in all strata.

X1X3

Stratum	C	x	Total counted	=	Corrected total	% of tot. counted	Significance rejected
D	0.488		1169		570.9	48.8%	bo,R,X1,X3
E	-0.210		421		88.4	21.0%	bo,X1
F	0.433		491		212.6	43.3%	bo,R,X1
DE	0.557		1590		885.6	55.7%	X1
EF	0.507		912		462.4	50.7%	X1
DEF	0.660		2081		1373.5	66.0%	X1

X2X3

Stratum	C	x	Total counted	=	Corrected total	% of tot. counted	Significance rejected
D	1.655		1169		1934.7	165.5%	bo,R,X2,X3
E	1,032		421		434.5	103.2%	bo
F	0.024		491		11.8	2.4%	bo,R
DE	-0.022		1590		35.0	2.2%	No grounds for rejection
EF	-0.262		912		238.9	26.2%	
DEF	0.001		2081		2.1	0.1%	

bo=NS	F<(p 0.01)
R =NS	R<(p 0.01)
X1=NS	F<(p 0.05)
X2=NS	F<(p 0.05)
X3=NS	F<(p 0.05)

Table 7. Multiple correlation coefficients (R) of X1X3 and X2X3 regression equations in all strata

	X1X3		X2X3	
D	0.1658[1] (9)	NS	0.1691 (9)	NS
E	0.8417 (8)	**	0.8356 (8)	**
F	0.8676 (5)	*	0.8800 (5)	*
DE	0.8751 (20)	**	0.8745 (20)	**
EF	0.9184 (16)	**	0.9117 (16)	**
DEF	0.9037 (28)	**	0.9214 (28)	**

$$^{1}R_{y\cdot 1\cdot\cdot\cdot\cdot k} = \sqrt{\frac{\text{Regression SS}}{\text{Total adjusted SS}}} \quad ;\ df\ (n-k-1)$$

* F > (p 0.05)
** F > (p 0.01)

Table 8 presents all the population estimates of elephants from aerial counts since 1973, separated into dry season counts and wet season counts, as the two levels of sightability. Following Caughley (1977a), the total is calculated as 2964,3.

When only the four most recent censuses were assessed separately, the total is calculated as 1741,7.

The tantalizing consequences of the latter estimate unfortunately do not apply. Not only the sightability varied between wet and dry seasons, but the actual number of elephants present, as we believe, due to the migratory nature of the elephant population.

It could be a statistical quirk or a real phenomenon, that when the 32,3% SE is applied to the corrected total for the four most recent censuses:

$$1741.7 \pm 32.3\%$$

$$\therefore \quad 1741.7 \pm 562.6$$

the total actually counted (2081) is well within range.

3.6 Summary of results of investigation into bias

1. The main parameters evaluated deviated somewhat from what could be ascertained for censusing large mammals in other regions. We are flying higher and in particular, counting wider transects than elsewhere and it could be worth it to include a treatment combination of 70m altitude and 1km strip width in further censuses. Norton Griffiths (1978) describes the common method in East Africa as 100m altitude, 180 km/h air speed and a maximum of 150 metres strip width.

2. Caughley's (1974) model of census variables influencing apparent densities of animals must be regarded as a serious indication of the level of confidence which should be placed on census results. This type of model is particularly suitable to a single species census, and practical implementation has yielded general confirmation of the model. There is, however, an error term associated with the y-intercept estimate of true population density. Nobody at this stage appears to know how to deal with this error term and it can't be ignored (Norton Griffiths,1978).

3. It seems encouraging that the stratum potentially posing the greatest counting problems, D (high cover), was counted so well, in terms of the analysis. It seems that when one expects problems, increased alertness compensates. It is significant that stratum D is the closest we've got to the East African woodlands, which are ususally counted using much more narrow transects.

Table 8. Population estimates of elephants from aerial counts since 1973.

	Time of year	Aerial count of elephants	
Dry season counts	Sept 1973	1293	
	July 1974	835	
	July 1976	1170	
	Sept 1978	1298	
	June 1982	2204	
	May 1984	1158	$\bar{x}$ =1811.0
	Sept 1984	2464	s^2 =852818.0
		$\bar{x}$ = 1488.9	
		s^2 = 362630.8	
Wet season counts	Mar 1977	836	
	Mar 1978	824	
	Dec 1983	1437	$\bar{x}$ =1759.0
	Dec 1984	2081	s^2 =207368.0
		$\bar{x}$ = 1294.5	
		s^2 = 356827.0	

4. Strata E and F, with medium and low vegetative cover, also had greater variability in elephant density and distribution and this might have caused the greater amount of significant main effects of census variables on elephant density, and interactions between variables. It is also possible that the difference in cover between strata D and E is far greater than between E and F, and stratification might have to be adjusted.

5. The soundest estimate of variance of the population total, is regarded as +- 32.3% (or 2081 +- 672). It appears that areas densely populated with elephants and woody vegetation (stratum D) can be counted with good precision (SE: +- 16.6%) while the chances of missing entire herds in the less densely populated areas are better (Table 5b). The reasonably low SE of the elephant census is not typical in all "total count type" censuses. It is suspected that the modified counting technique discussed in 2.1.2, as suggested by Norton Griffiths (1978), has eliminated a significant source of error and bias. It is furthermore not impossible that the regular census team has certain vested interests in the quality of census results, which leads to greater efficiency.

6. It is an obvious consequence of unreliable estimation of population size using the y-intercept b_0 values, that correction factors relying on the same b_0 values will be equally unreliable (3.4).

7. The estimation of total undercount bias in 3.5 could become very valuable if done over a reasonably long period of time. With the data available, and independent knowledge of recent population increase, the census totals prior to 1983 cannot be used. Censuses in that period were too variable and superficially analysed for solid comparisons with current results, which hopefully are on a sounder statistical foundation.

3.7 Conclusions and comments on bias

This exercise, with all its shortcomings was extremely valuable, since a working protocol for bias investigation was developed, to be applied to subsequent censuses, where experimental design will conform to all statistical requirements.

Some general truths became evident, regardless of the fact that some impossible "truths" also cropped up. By doing the whole exercise using the available if not exactly spotless data base, all steps except the calculation of sensible correction factors (3.4) and y-intercept estimates of population size (3.3) could be assessed.

It seems imperative that this analysis be repeated after the next census, with both changes in census design, data format and analysis. With regard to the latter aspect, the introduction of exponential terms in the regression equation to give a hyperbolic relationship instead of a linear one, will be attempted.

Prior to the next census, a computer programme incorporating all aspects of this analysis, instead of the several smaller programs used for this report, will hopefully be completed and functional. The ideal situation of day-by-day analysis of collected census data will then be one step nearer.

3.8 Sample count methods

3.8.1 The "total count method", where the whole survey area is physically searched using aerial transects, has declined in popularity, and in fact, the only two large areas currently censused in this way are Etosha and the Kruger National Park. In order to investigate the very attractive advantages offered by a sample count, simulated sampling was applied to the four most recent censuses of elephants in Etosha.

3.8.2 Three basic sample count techniques are available, two of which were used in this analysis, namely the transect sample count and the block sample count. The remaining method, quadrat sampling, could not be used owing to the navigational difficulties in locating a quadrat in relatively featureless topography.

3.8.3 The simulations used were based on the distribution maps of elephants in each census, (as in fig. 4), but actual herd sizes were used. In the case of transect samples, standard transect widths of 4km were used throughout (fig. 7). All elephants plotted on a distribution map and occurring within the limits of a transect were counted as the total sum per transect.

3.9 Transect sampling

This approach entails the selection of a sample of transects from a finite number of transects which can be fitted within the boundaries of the survey area. The sample is drawn either randomly (random transect sample count) or regularly (systematic transect sample count).

Both random and systematic samples were drawn and assessed. The validity of any sample estimate of population density or variance of the estimate, should however be assessed prior to further analysis. This is achieved by determining the appropriate sampling intensity.

3.10 Sampling intensity

The optimum sampling intensity is that which would yield the minimum variance of the estimate in terms of effort (flying

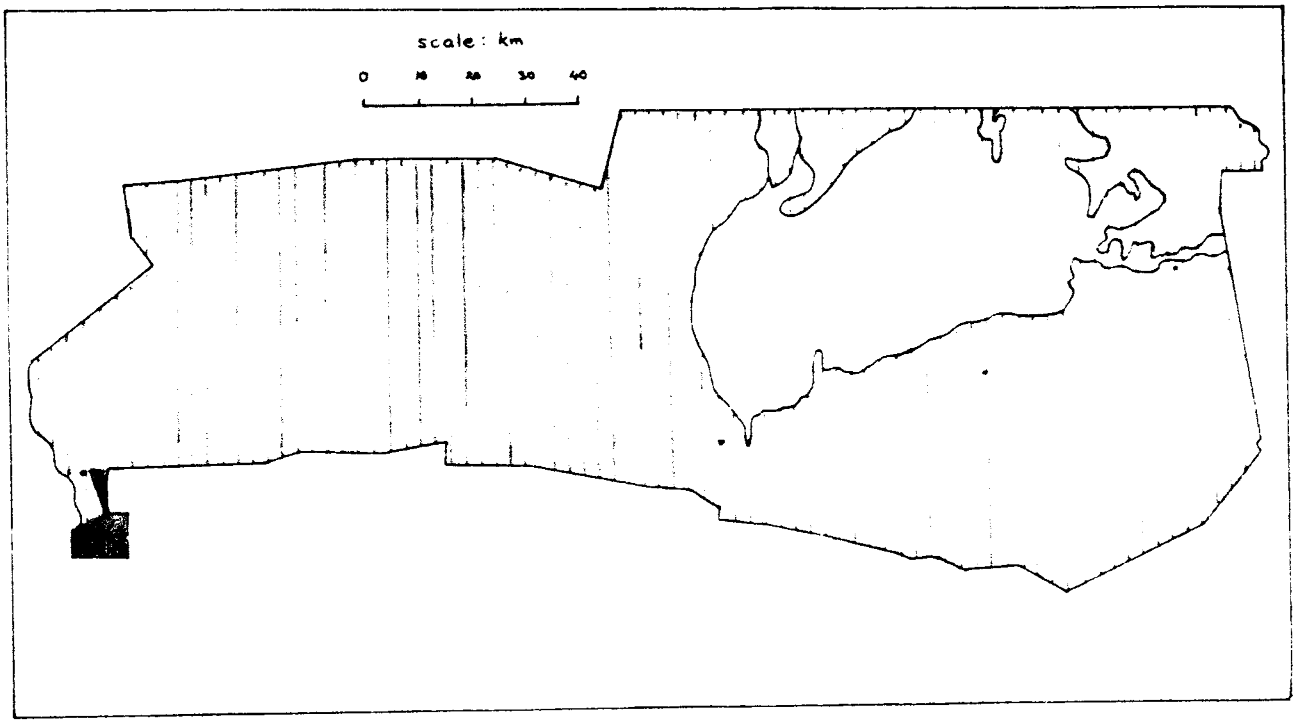


Figure 7. North-South 4 km wide transects used in census simulations.

time). This is estimated by step-by-step increasing the sample size until the resulting curve indicates that additional samples will not increase the precision of the estimate.

Norton Griffiths (1978) suggests the use of Jolly's (1969) method 2 for unequal sized sampling units to calculate the population estimate (Y) and 95% confidence limits of Y (this means there is a 95% certainty that the true number of animals lies in the stated range).

where

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

and

$$\hat{Y} = Z\,\hat{R}$$

and

$$\mathrm{Var}(\hat{Y}) = \frac{N(N-n)}{n}\left(s_y^2 - 2\,\hat{R}\,s_{zy}^2 + \hat{R}^2\,s_z^2\right)$$

where

s_y^2 = the variance between elephants counted in all the units

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

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

$$= \frac{1}{n-1}\left[\Sigma z^2 - \frac{(\Sigma z)^2}{n}\right]$$

s_{zy} = the covariance between the elephants counted and the area of each unit

$$= \frac{1}{n-1}\left[\Sigma zy - \frac{(\Sigma z)\,(\Sigma y)}{n}\right]$$

and population standard error

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

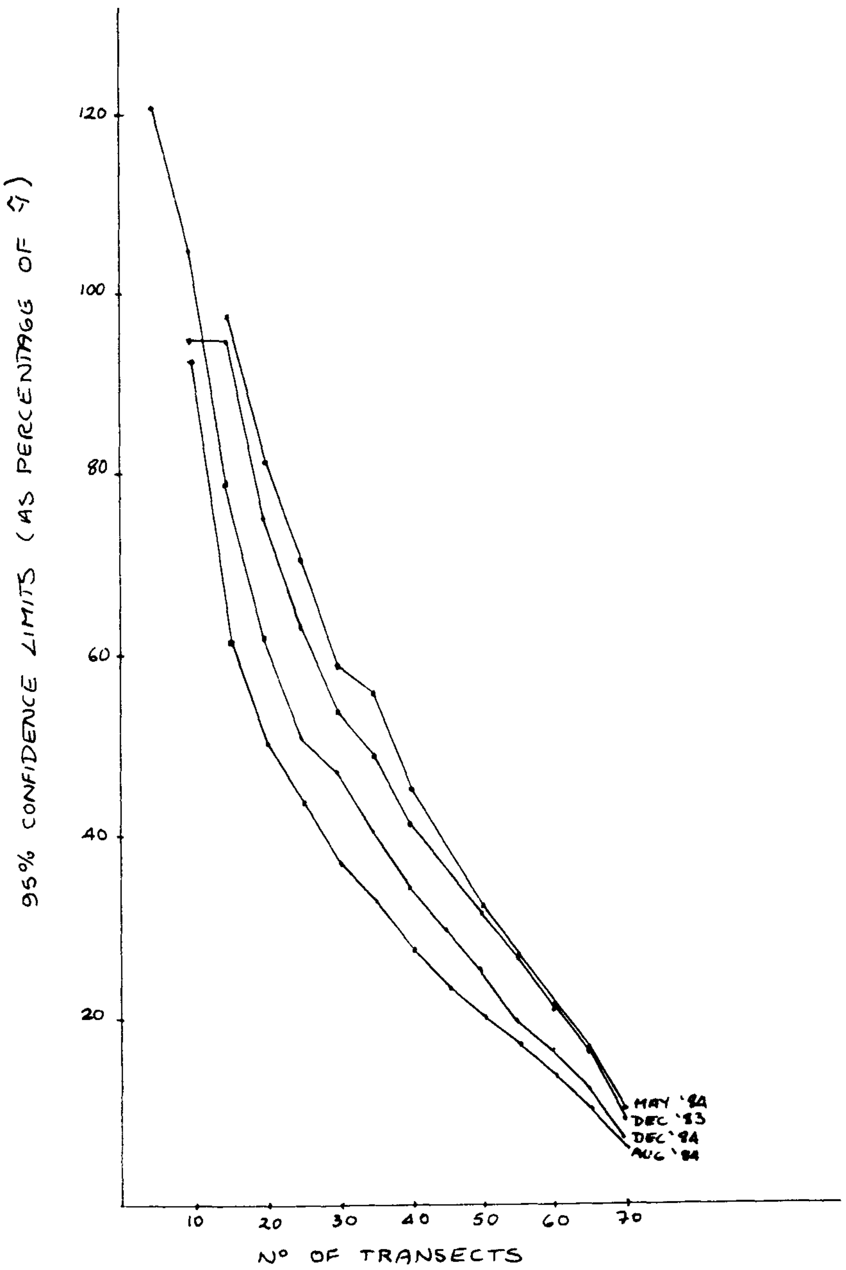


Figure 8. 95% confidence limits as a percentage of the estimated number of elephants (7), relative to the number of transects used, in the four most recent censuses of elephants.

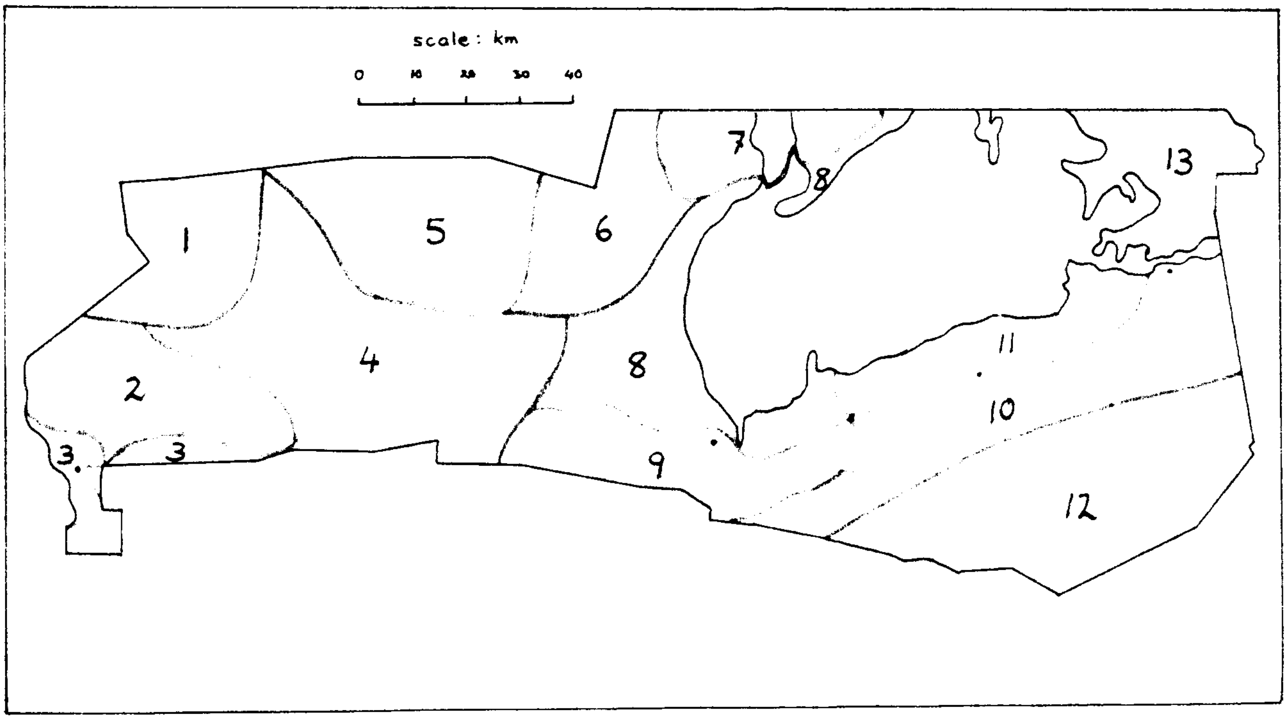


Figure 9. Map of the survey area stratified into 13 strata based on broad topographical outlines and seasonal concentration areas of elephants.

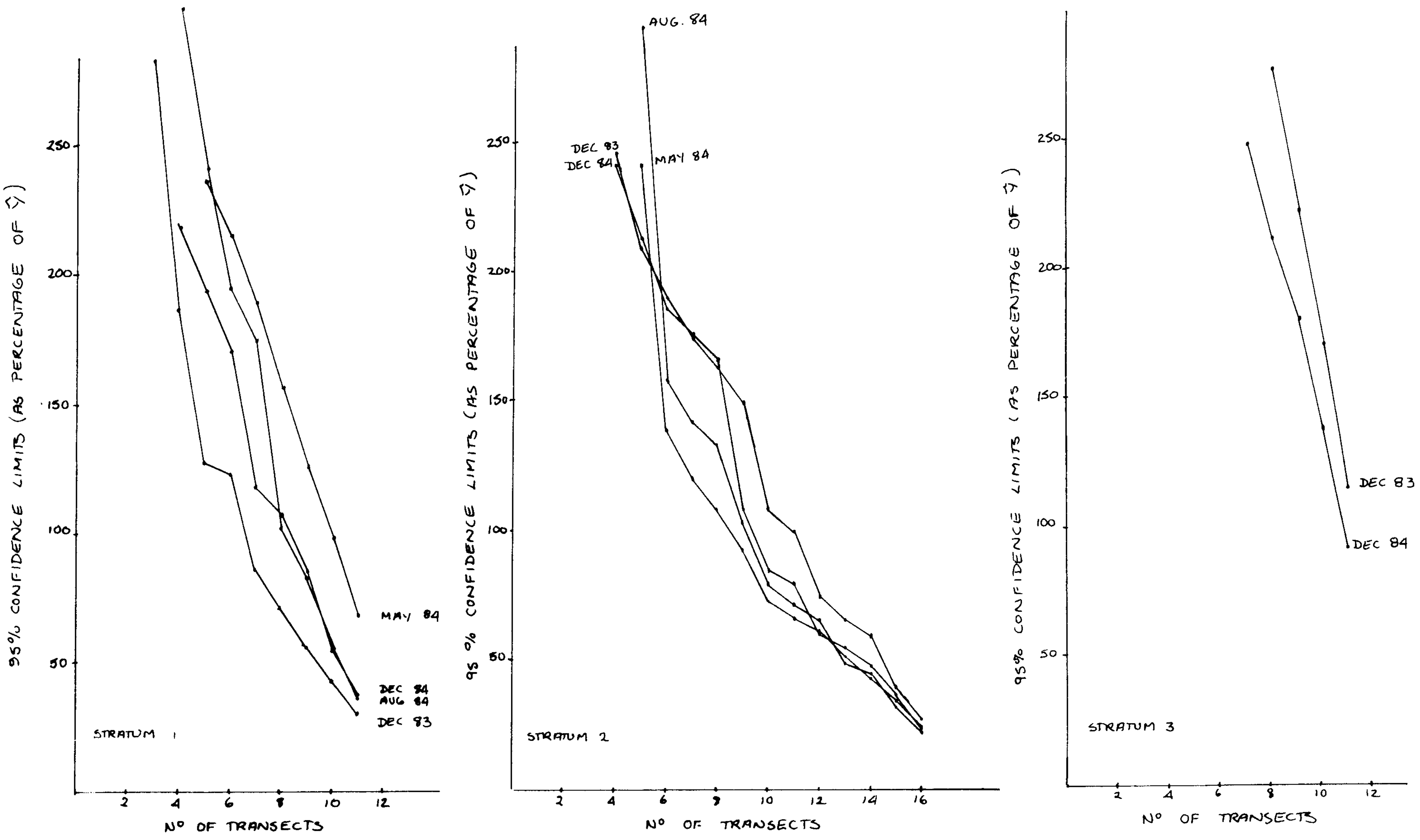


Figure 10. 95% confidence limits as a percentage of estimated elephant numbers (7) in 13 strata (a-m).

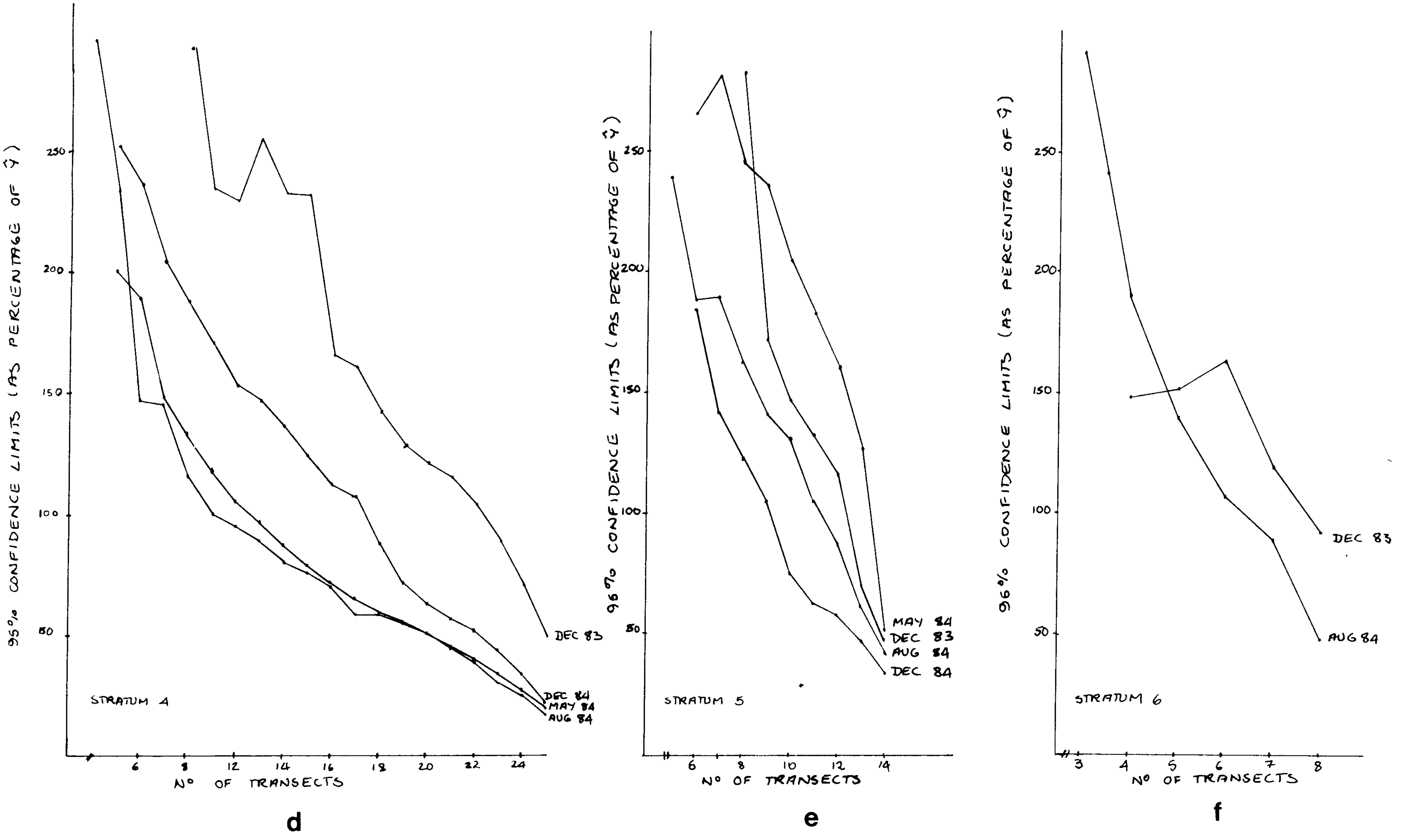


Figure 10. Continued (d-f).

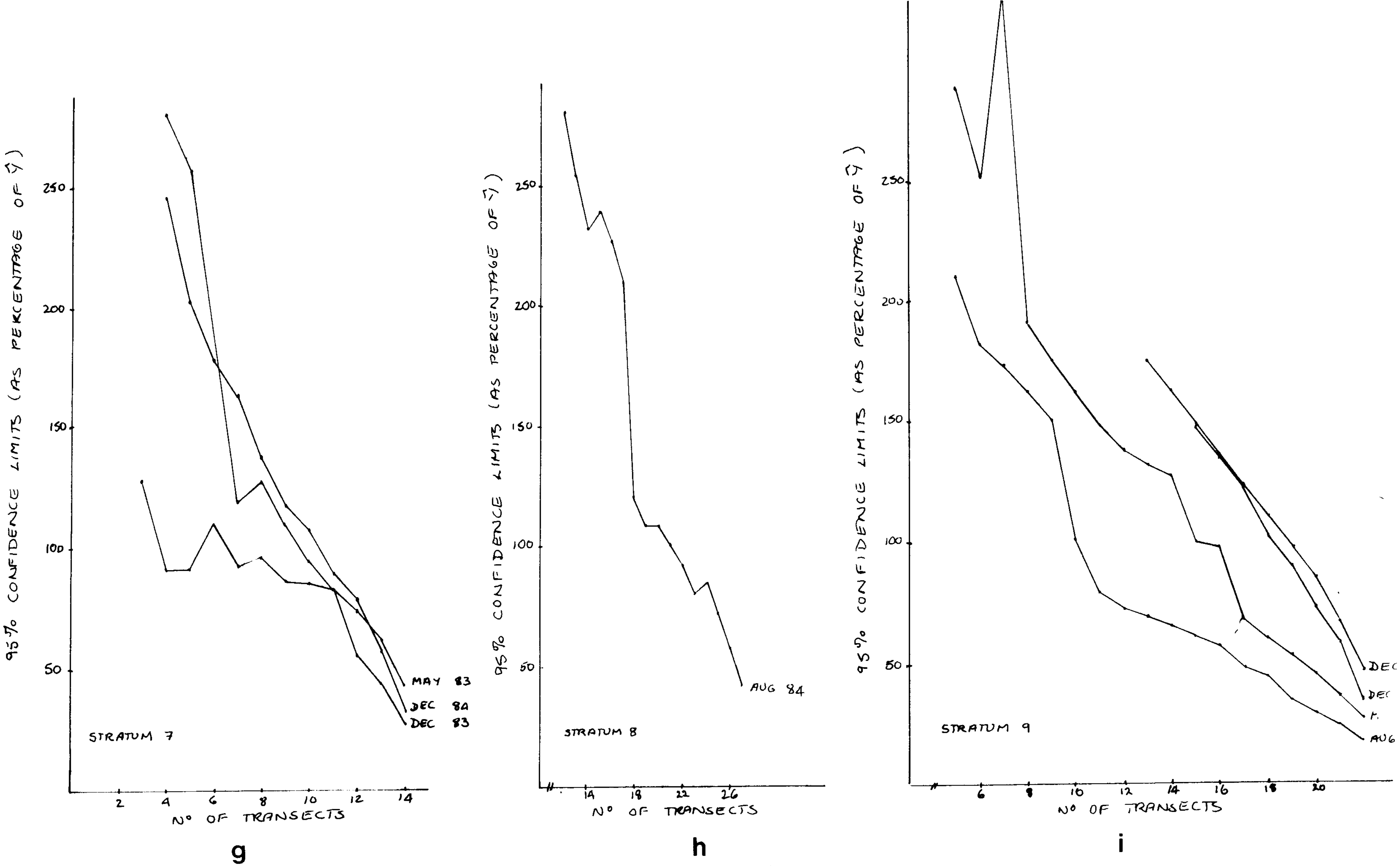


Figure 10. Continued (g-i).

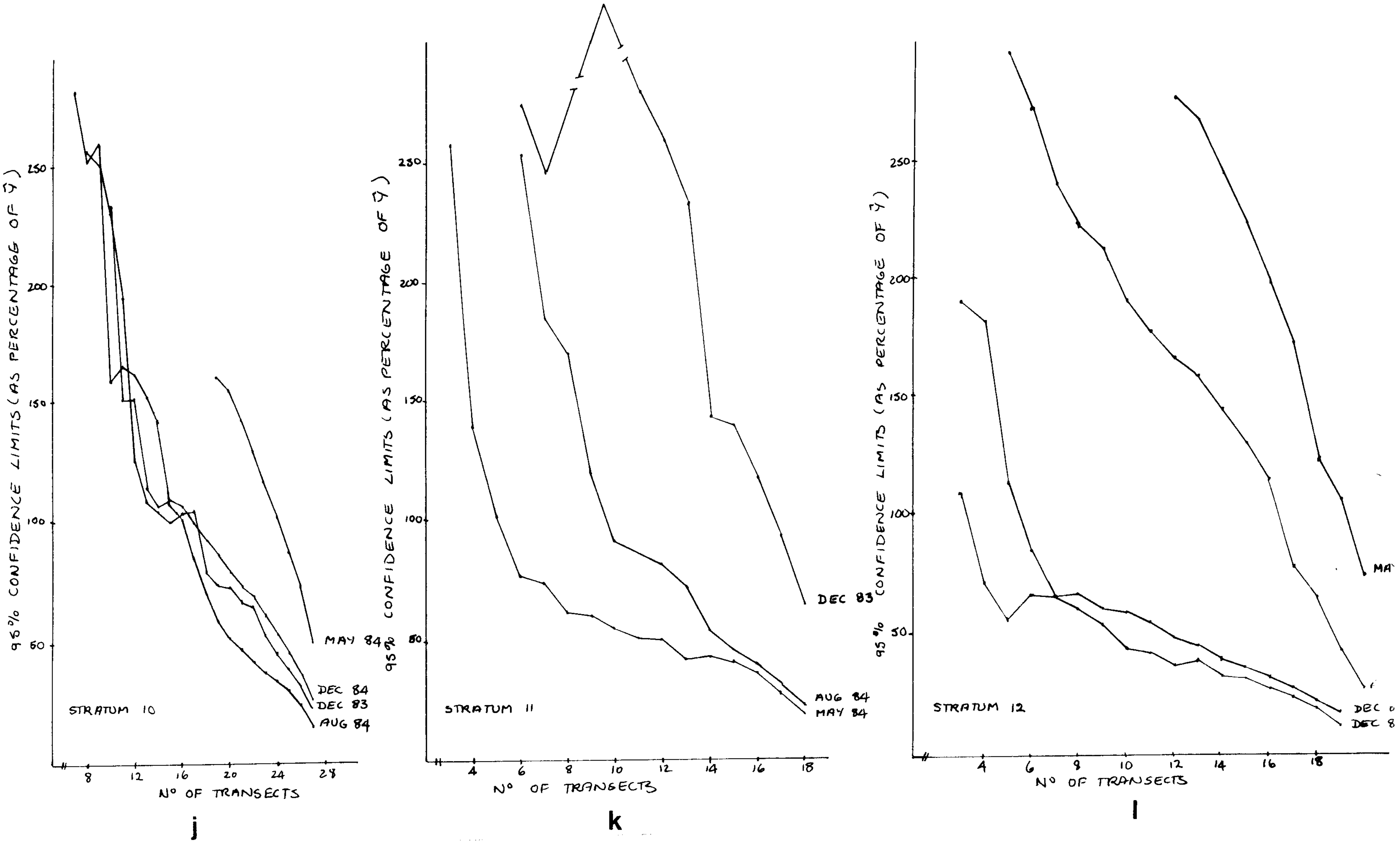
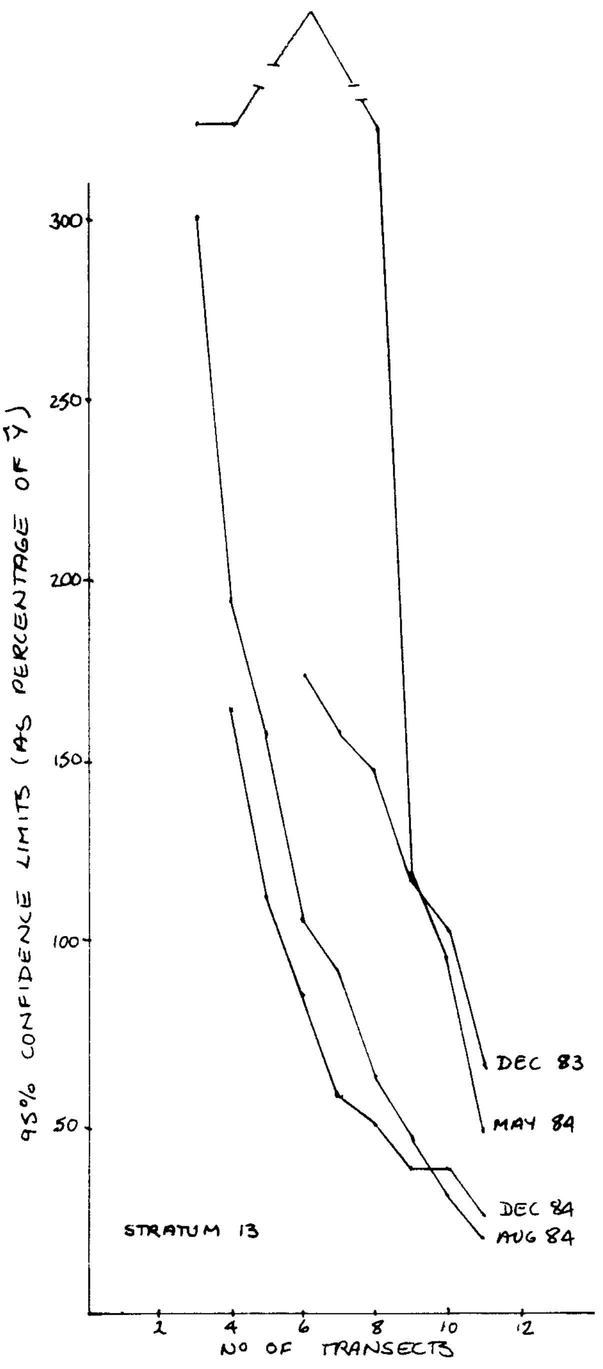


Figure 16. Continued (j-l).



m

Figure 10. Continued (m).

The relationships between precision of the estimate (expressed as the 95% confidence limits of $\hat{Y}$ as a percentage of $\hat{Y}$) and increasing sample size for the four most recent censuses of elephants in Etosha are illustrated in fig. 8. It is evident that no clear indication of optimum sampling intensity can be obtained from fig. 8, nor a specific indication that the four censuses (at different times of the year) differed greatly with regard to seasonal distribution pattern.

3.11 Stratification

In order to improve the accuracy of the sample estimates, stratification of strata based on a combination of environmental features was done. Known seasonal concentration areas of elephant based on distribution records from previous censuses following broad topographical vegetational outlines were identified as strata, and each stratum analysed separately. Thirteen strata were identified (fig. 9) and the 95% confidence limits and population estimate in relation to sample size are illustrated in fig. 10a-m.

3.12 Percentage similarity

An alternative indication of optimum (or reliable) sampling intensity is obtained by expressing the affinities between samples of transects drawn in the sample as the percentage similarity (Gauch 1982) where:

$$PS = \frac{200 \quad \min A_j A_k}{A_j + A_k}$$

where

200 = denominator if samples are relativized to 100 (expressed as a percentage)

A_j ,A_k = abundance of elephants in samples j and k

min = minimum abundance of elephants in either samples j or k (by implication, the number of elephants in common in samples j and k).

The use of percentage similarity is perhaps more elegant than the 95% confidence limits as a percentage of $\hat{Y}$ of Norton Griffiths (1978), which is a more complicated concept.

A group of five randomly selected transects (without replacement) was compared to another group of five, similarly drawn. This process was repeated 20 times and the mean percentage similarity and standard error calculated (for 20 groups).

Additional groups of 20 times 10,15,20 --- 70 transects were assessed and illustrated in fig. 11 a-d (four most recent censuses)

The resulting curves still showed some irregularities, and the group size was increased to 40 (for the Dec.1984 census only), that is 40 times 5,10,15,....70 transects were drawn and assessed. This is illustrated in fig. 12, which is not a great improvement on fig. 11d.

In order to apply this assessment of sampling intensity to the various strata some modifications to the original strata (fig. 9) had to be made, in order to have enough potential transects in each stratum for a reasonable comparison. The new strata are illustrated in fig.13 and the percentage similarity curves for all strata using the December 1984 census are illustrated in fig. 14 a-g.

The mean percentage similarity (+- SE) achieved after sampling 50% of the stratum and the percentage similarity (mean +- SE) at 100% sampling intensity are recorded in Table 9 for all strata in the December 1984 census.

In all except two strata, the PS at 50% sampling intensity were within 10% of PS at 100%. The two exceptions are strata 8,9 and 11 combined where elephant density is extremely low, and stratum 13, where very few transects could be fitted into the area.

It must then follow, that Etosha can be sampled confidently at a range of sampling intensity suitable to each stratum. In this analysis, transect widths of 4km were used throughout, although previous analysis into bias indicated that a range of transect widths will have better effect in the different strata. Additional experimentation is once again required.

Additional input to streamline census design is however well worth the effort, since every one transect not to be counted in the census will reduce the overall cost, effort and time by approximately 1.4%. This is most attractive at potential sampling levels of 50%.

3.13 Population estimates and variances from random transect sample counts

Figure 15 illustrates the mean population estimate ($\hat{Y}$ +- SE) of 20 groups at the different sampling intensities of the 1984 December census simulation. The actual number of elephant counted from the simulated census was 2075 (as opposed to the total of 2081 counted from the air). Different ways of calculating the total and variation in the area of the survey area make it difficult to compare the 2081, 2075 and transect estimates directly (for example, the area covered by a transect survey will never be identical to the area covered by a block survey). It is also useful to remember that the total actually counted

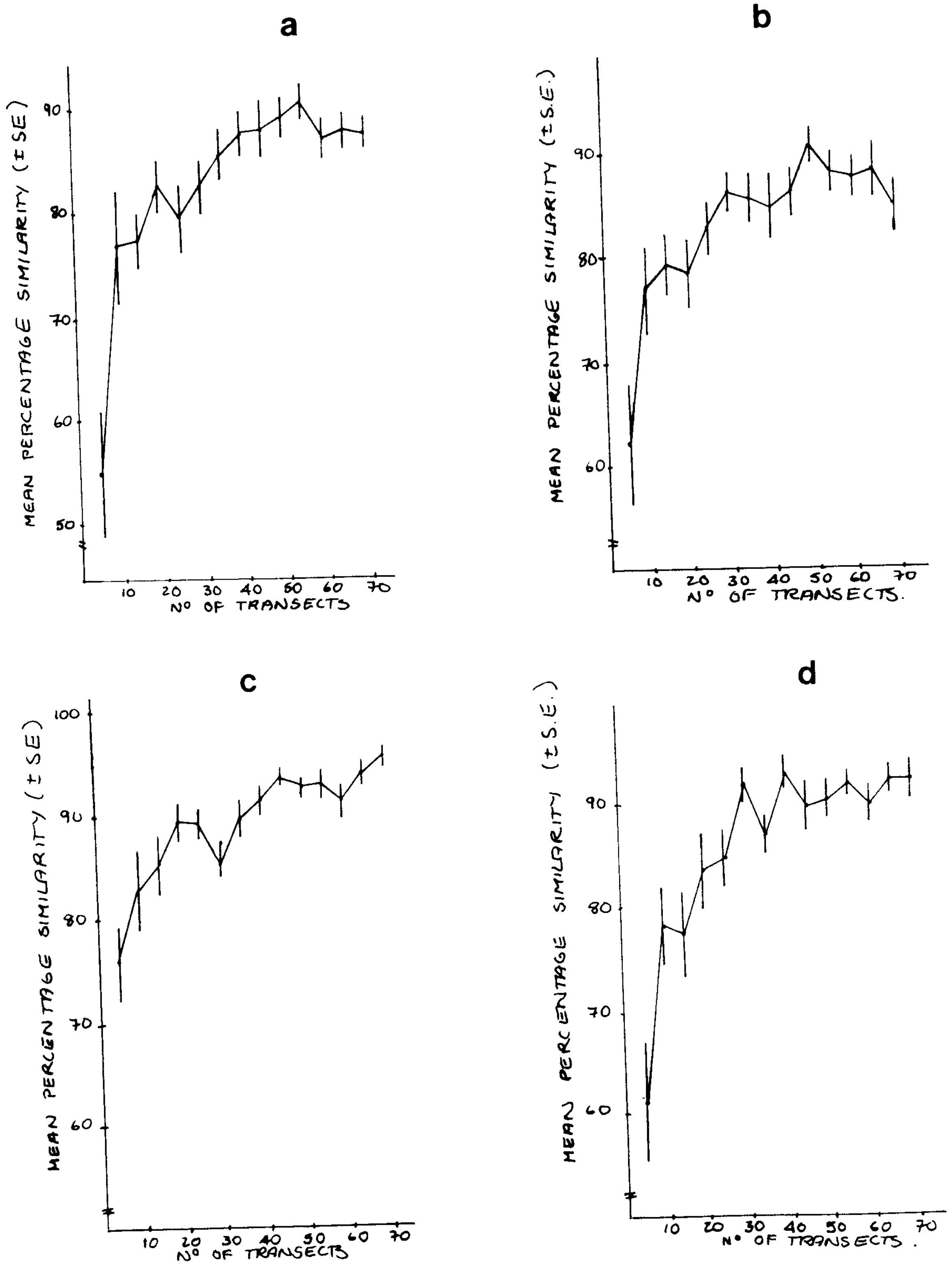


Figure 11. Mean percentage similarity (+- SE) of 20 groups of 5,10,15....70 transects for censuses in December 1983 (a), May 1984 (b), September 1984 (c), and December 1984 (d).

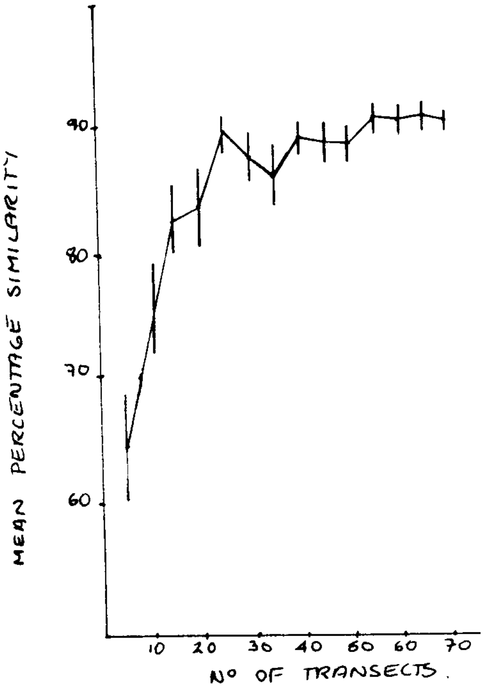


Figure 12. Mean percentage similarity (+- SE) of 40 groups of 5,10,15......70 transects for the census in December 1984.

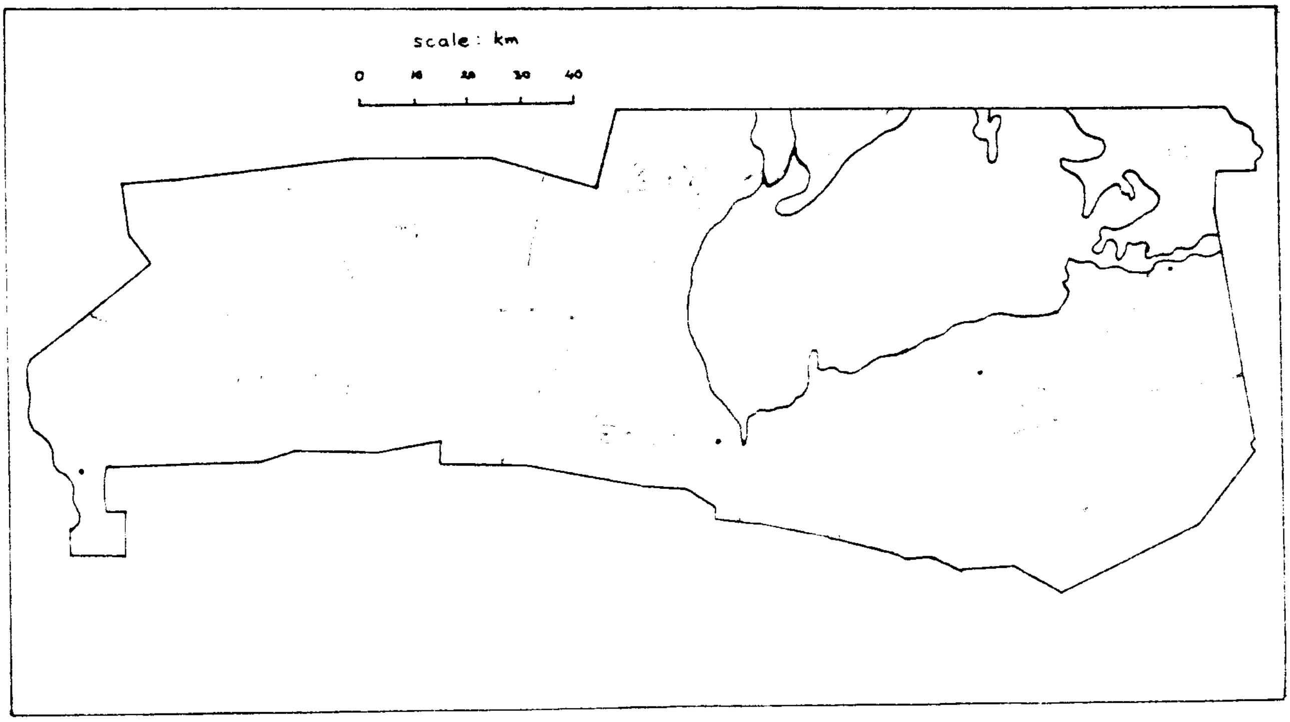


Figure 13. Modified stratification of survey area for transect sample simulations.

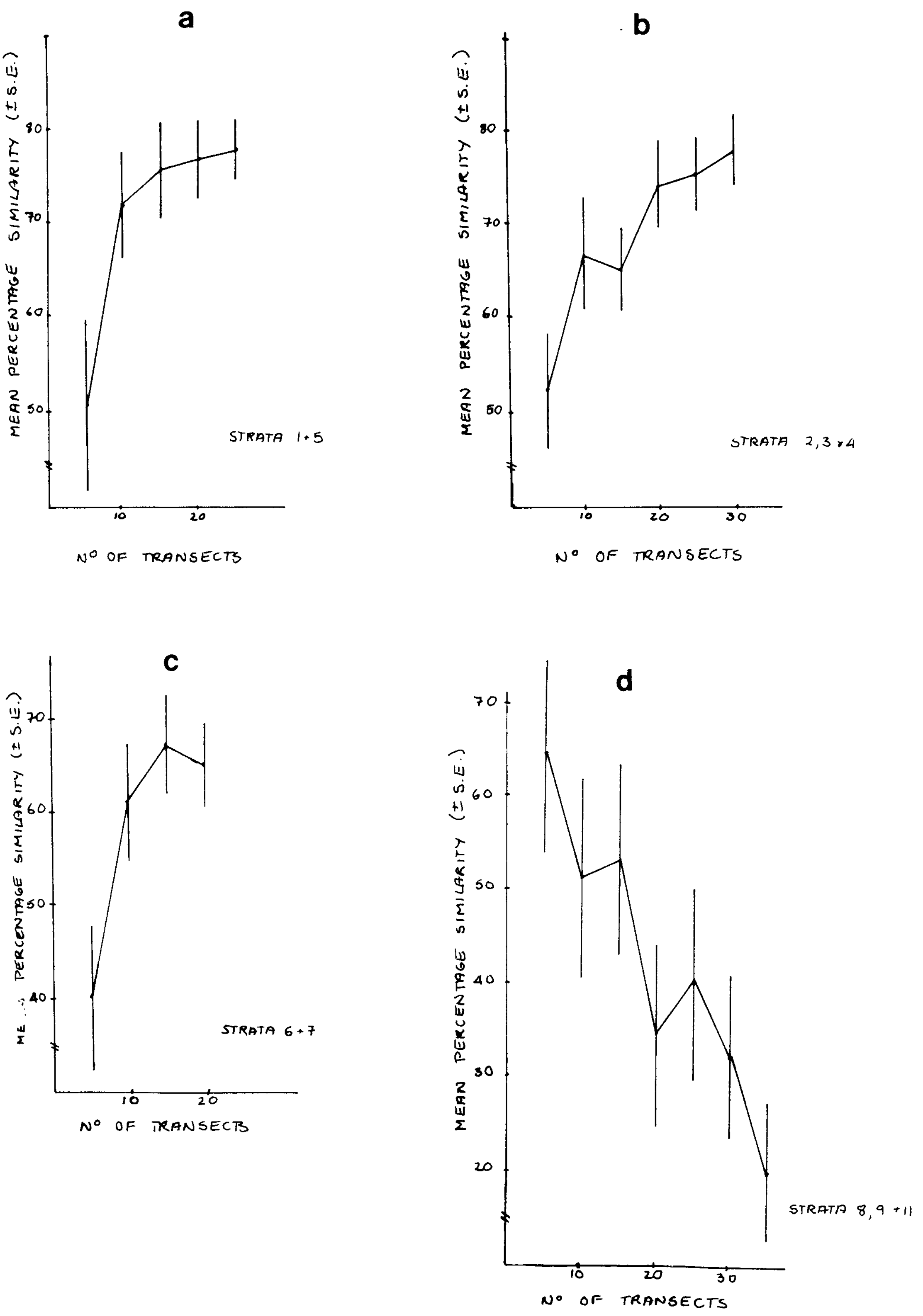


Figure 14. Mean percentage similarity between 20 groups of 5,10,15.....n transects in seven strata for December 1984.

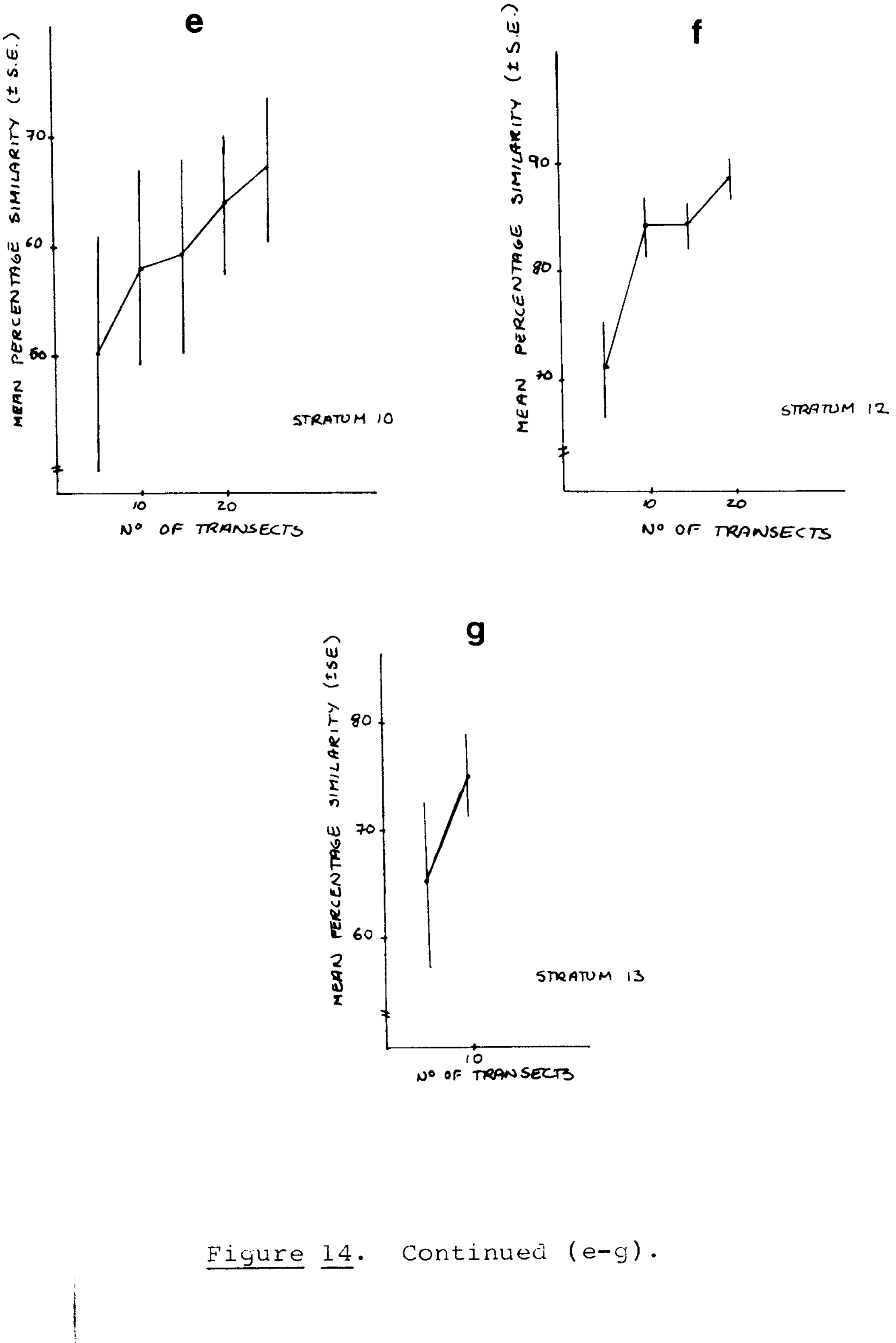


Figure 14. Continued (e-g).

Table 9. Mean percentage similarity at 50% and approximately 100% sampling intensity of random transect samples in all strata.

Strata	Mean PS(+- SE) at approx.50% sampling intens.	n trans.	Mean PS(+- SE) at approx.100% sampling intens.	n trans.
(1+5)	75.8 +- 5.2	15	78.0 +- 3.3	25
(2+3+4)	65.0 +- 4.5	15	77.9 +- 3.8	30
(6+7)	60.9 +- 6.3	10	65.0 +- 4.6	20
(8+9+11)	53.5 +- 10.1	15	19.7 +- 7.5	35
10	59.2 +- 9.3	15	67.0 +- 6.8	25
12	84.1 +- 2.3	10	88.6 +- 2.0	20
13	65.2 +- 7.6	5	75.1 +- 3.6	10
Total area unstratified: (20 samples)	86.8 +- 1.6	35	92.1 +- 1.7	70
Total area unstratified: (40 samples)	86.1 +- 1.5	35	90.4 +- 0.8	70

(2081) is nothing but a raw uncorrected sum of block totals.

The relationship illustrated in fig. 15 is very important, if transect sampling is ever to be considered, as it gives an indication of the accuracy of the sample estimate and possible variation to be expected at the designated sampling level, as indicated by a percentage similarity: sampling intensity curve.

It was therefore decided to rerun the program an additional three times, selecting 40 groups of 5,10,15,... 70 random transects. These are illustrated in fig. 16 a-c, and it appears that the similarity found, inspires some confidence in these results. A close look at figures 15 and 16 a-c will reveal that although random transects are selected, chance may still play an important role. This effect however, will hopefully become less severe when the survey area is stratified. The clumped type of distribution of elephants is probably the main contributory factor in variation of the population estimates, since a handful of transects actually accounted for the bulk of the population. Elephant distribution, evident from fig. 4 and Lindeque (1984 a,b) is indeed the most important contra-indication for the use of random transect sampling, and it will be useful to consider other approaches.

3.14 Systematic transect sampling

3.14.1 This type of sampling is essentially identical to random sampling, with the obvious exception of randomness. Assessment proceeds along the exact same way.

As mentioned, clumped distribution of animals, practical difficulties in locating random transects and a fair proportion of "dead" flying time, may render random transect sampling less attractive. Systematic spacing of transects however, introduces a host of new problems, including a less precise population estimate and severe statistical doubts.

Caughley (1977), however, maintains that systematic sampling may very well yield a more biologically acceptable result than random sampling, as long as the limits of the data and the robustness of assessments are appreciated.

By virtue of the type of simulation used in this report, where 73 North-South transects spaced 4 km apart were drawn on a map, a resemblance to systematic sampling has been incorporated in random sampling (a discrete distribution of transects instead of a continuous distribution was used for practical reasons).

As with random sampling, the issue of sampling intensity with regard to systematic sampling will have to be investigated first. This time however, sampling intensity is equal to the spacing between consecutive systematic transects.

3.14.2 Two very important disadvantages of systematic sampling

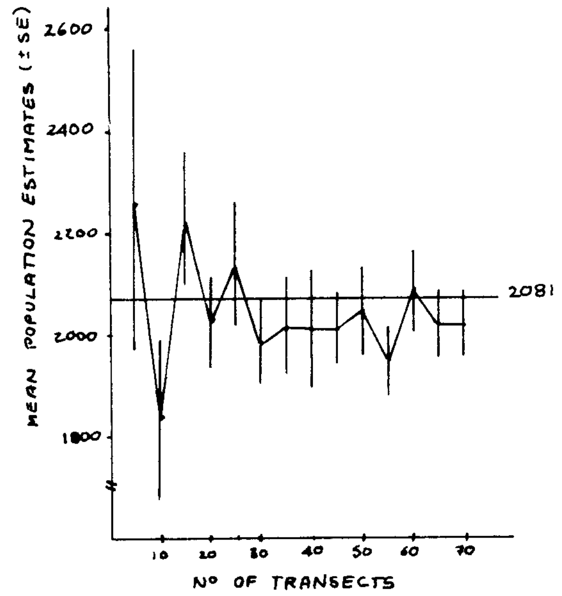


Figure 15. Population estimate of elephants (Y+-SE) calculated from 20 groups of 5,10,15.....70 random transects for the total survey area in December 1984.

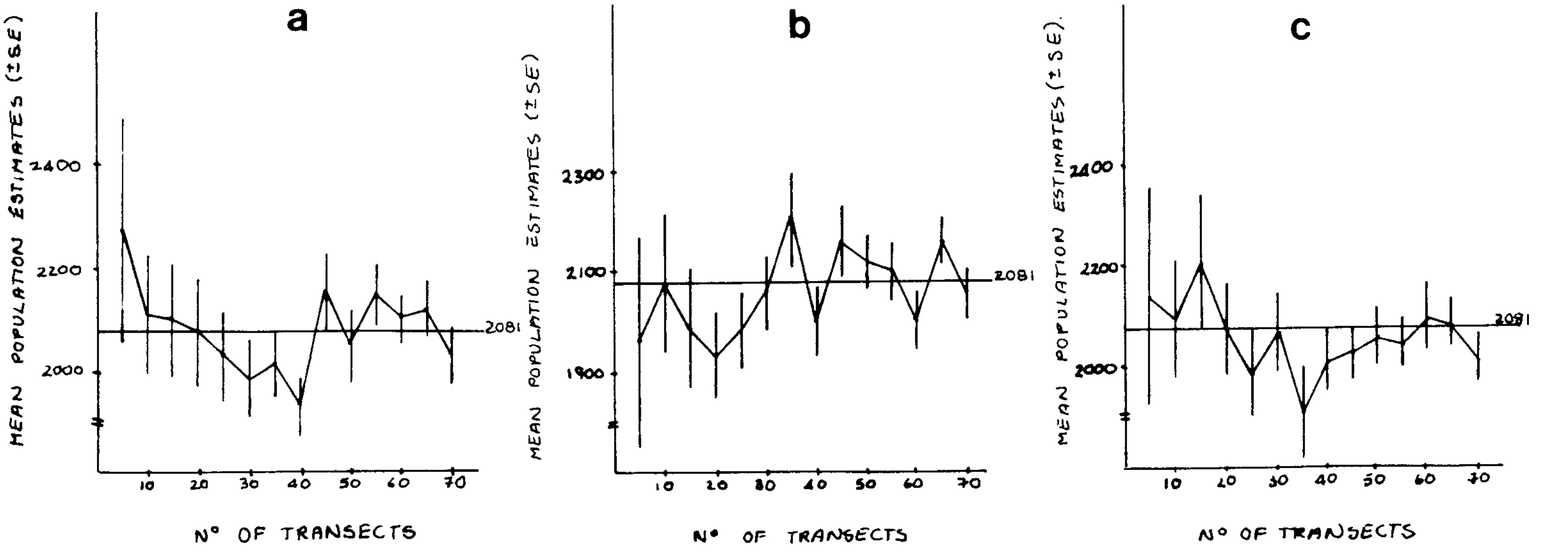


Figure 16 (a-c). Three additional estimates of elephant population size (Y+-SE) from 40 groups of 5,10,15....70 random transects for the December 1984 census.

are that:

1. It is not possible to calculate an explicit standard error of the population estimate (it can only be estimated by calculating SE as if the sample had been random).

2. Transect spacing may quite easily interact with periodicities in the distribution of animals, which in most cases are unpredictable and undetectable.

3.14.3 Figures 17a-d and 18a-d illustrate the percentage similarities and population estimates of systematic samples from the four most recent censuses. It is apparent in all four situations, that the greater the spacing between transects (and consequently the smaller number of transects used) the greater the variation in PS and population estimate. This is misleading, however, since with higher sampling intensity, fewer replicate runs could be chosen for proper comparison.

The spread of points on fig. 17 and 18, if not saying much about appropriate sampling intensity, does indicate the deep waters one will face when trying to interpret the results, for there is in reality no sound method, without numerous assumptions, to calculate the variance.

3.15 Block sampling

Block sampling is a real alternative to transect sampling in the case of Etosha, since the obvious navigational difficulties of transect sampling will be eliminated.

A number of possibilities may be considered, including random or systematic selection of blocks, stratified or not, quadrats (equal sized blocks), unequal sized blocks with a probability to be drawn proportional to size, or standard irregularly shaped blocks.

The absence of great topographical variance in Etosha will make the use of any grid square-quadrat type sample very difficult. Assessments were therefore confined to irregularly shaped blocks. Similarly, stratification could not be used sensibly, as the number of blocks in each stratum is too low. Systematic selection of blocks would also be difficult to apply to the irregularly shaped Etosha and was not considered here.

The remaining procedures therefore are:

1. Random selection of unequal sized blocks without replacement of which the number must be indicated by a sampling intensity assessment.

2. Random selection of unequal sized blocks with replacement (to give greater weight to larger blocks) with a probability to be drawn proportional to size. Sampling intensity must also be assessed separately.

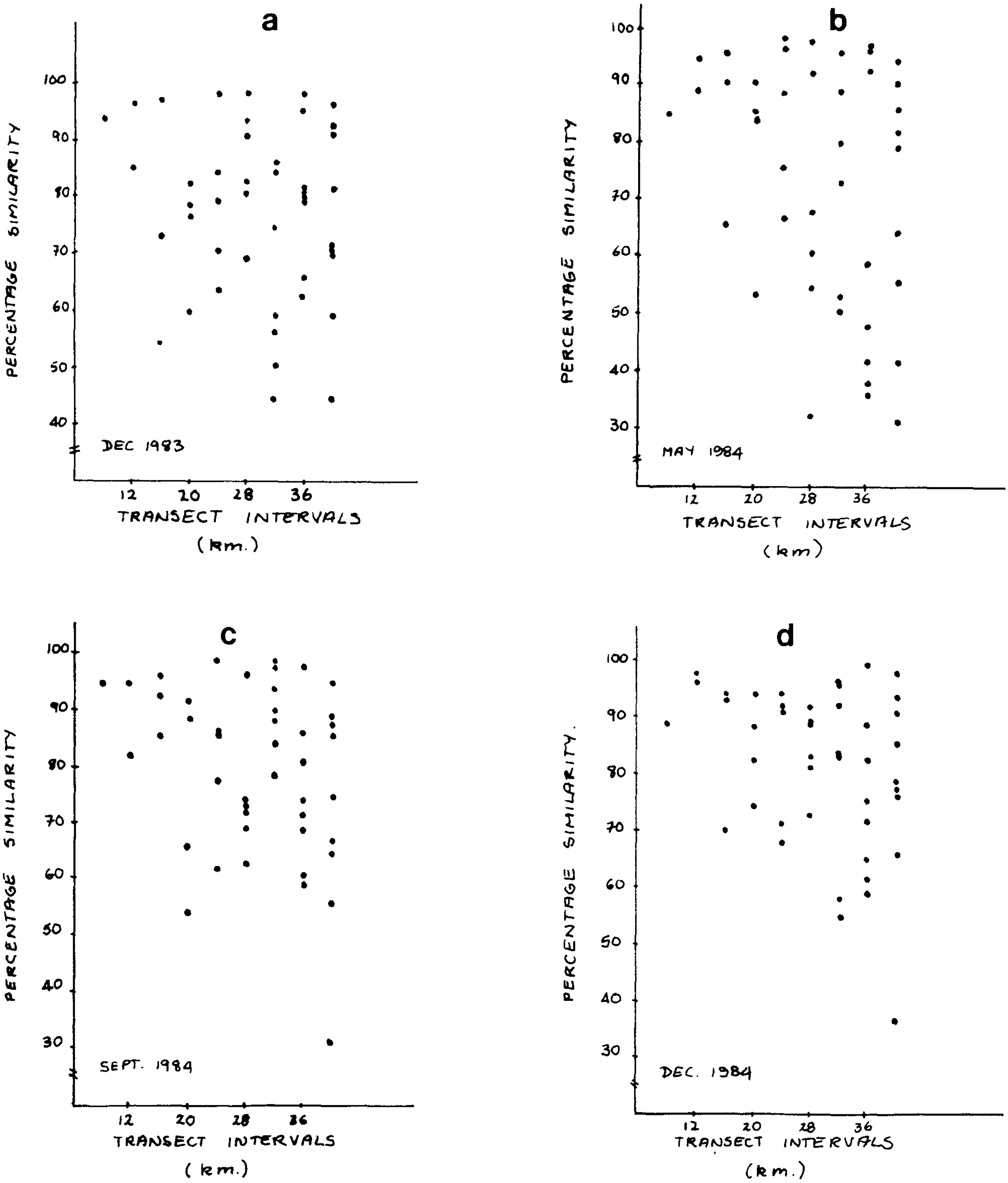


Figure 17 (a-d). Percentage similarities of systematic transects at progressive intervals of 4,8,12.....40 km for the four most recent censuses of elephants.

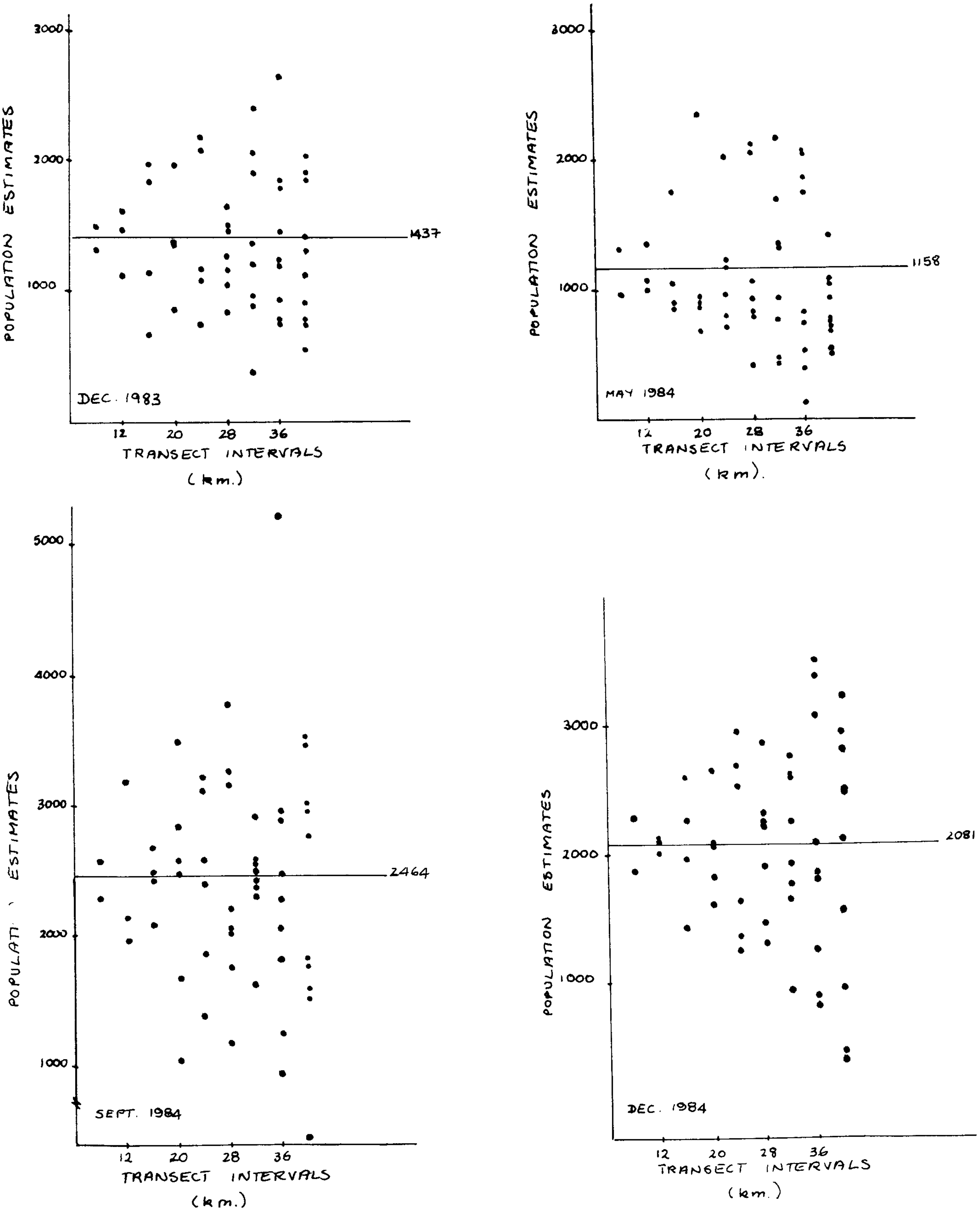


Figure 18 (a-d). Population estimates of elephants calculated from systematic transects at progressive intervals of 4,8,12....40 km for the four most recent censuses of elephants.

3.15.1 Random blocks without replacement

Figure 19 illustrates the mean percentage similarity of groups of 20 of 5,10,15.......40 blocks. Essentially, blocks are treated as "transects" as with transect sampling and the analysis is identical. Population estimates in relation to increasing sampling intensity is illustrated in fig.20.

Acceptable similarity levels are reached at > 50% sampling intensity, the variance in population estimates at this level is rather high, but improves with higher sampling intensity.

3.15.2 Random blocks with replacement

Caughley (1977a,b) suggests a selection of blocks using pairs of random numbers representing map coordinates, but in order to computerize the analysis, a different method was used. The area of each block was expressed as a percentage of the total survey area and from a series of 100, where each point represents a percentage of the total survey area, identified as a particular block, a random sample was drawn.

Mean percentage similarities of 20 groups of 5,10,...40 blocks and population estimates are illustrated in fig. 21 and 22.

3.16 Summary of investigation into alternative census methods.

3.16.1 Field experimentation will be necessary to assess the potential of alternative census methods, as each method has its own advantages and disadvantages. As discussed by Caughley(1977a), the eventual selection of a particular method may depend on the ease of practical implementation, not necessarily the method which allows the most stringent statistical evaluation. I believe that further investigation into some of the sampling methods will be well worthwhile, since the present total count method is both comparatively expensive, inaccurate and imprecise. If any one of these factors will be improved by a different type of census, it will be clearly advantageous to adopt that method. There is absolutely no reason to continue with the present " total count" censuses, of both elephants or mixed species, if better results can be obtained by alternative methods or equivalent results at a lower cost.

With regard to the investigation in this report, which can not be used to make a final decision to change our precent system,the following:

1. Factors other than the immediately apparent advantages or disadvantages of a census method should be considered. Firstly, a choice between a total count and a partial count (sample count) has to be made, and then if required, a choice of several sampling systems. The chief advantage of total counts is that

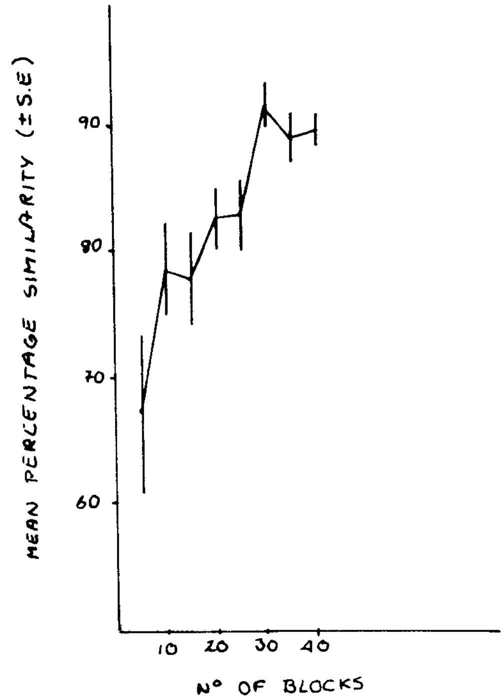


Figure 19. Mean percentage similarity (+-SE) of 20 groups of 5,10,15.....40 random blocks (without replacement) in December 1984.

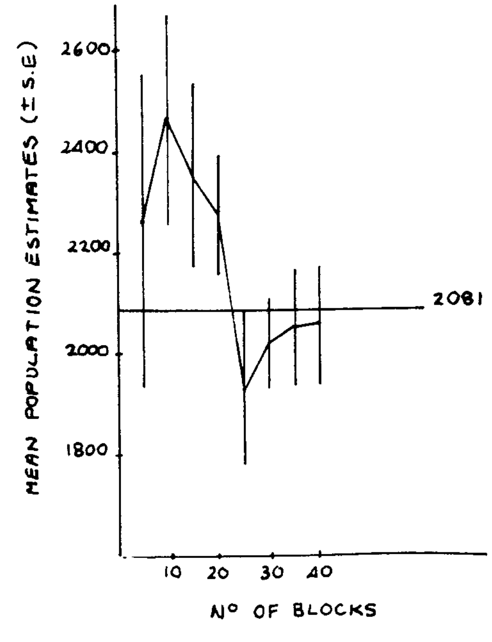


Figure 20. Mean population estimate (+-SE) of elephants calculated from 20 groups of 5,10,15.....40 random blocks (without replacement) in December 1984.

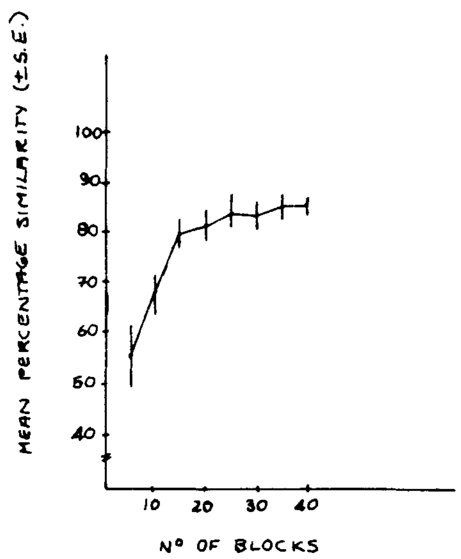


Figure 21. Mean percentage similarity (+-SE) of 20 groups of 5,10,15.....40 random blocks (with replacement) in December 1984.

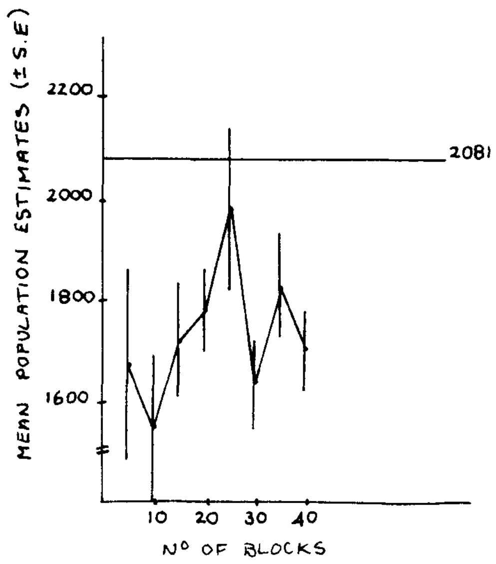


Figure 22. Mean population estimate (+-SE) of elephants calculated from 20 groups of 5,10,15.....40 random blocks (with replacement) in December 1984.

the whole survey area is flown, making it possible to collect additional data on the vegetation, burning, rainfall and to plot animal distribution accurately. Some sampling methods, notably systematic sampling come close to a total count with regard to the collection of this type of information. The chief disadvantage of a total count of an area the size of Etosha, is the excessive costs and effort required.

The ease of implementation of a method, be it a total count or sample count is imperative, but a compromise between ease of implementation and expected benefits will have to be reached. The easiest method generally yields the most imprecise results. Some of the better methods however, require intricate navigation procedures and a strict time schedule which may prove too complicated in practice.

2. Overall indications are that future efforts should be concentrated on transect sample methods. The final choice between random and systematic transect sampling can only be done after careful experimentation, as both methods offer exclusive advantages.

4. PROPOSALS FOR FUTURE CENSUSES OF ELEPHANTS IN ETOSHA

4.1 The proposals here stated should be considered in terms of the respective investigations into bias and alternative census methods, summaries of which can be found in this report (3.7 and 3.16). It may also be better not to test too many variables all at once, but rather spread the experiments over the next two aerial censuses of elephants.

4.2 Practical improvements

1. Use of the shadowmeter by pilot for more accurate altitude control (a copy of Pennyquick's (1973) paper will be sent to the pilot).

2. Use of streamers attached to wing struts for more accurate delineation of transect width (described by Pennyquick and Western,1972).

3. Use of overlap photography of all herds, using a motordriven camera.

4. Use of methods to lessen fatigue and stress, such as improvements to two additional runways (Mopani and Etosha fontein) to result in less ferrying time (discussed with the Etosha Management Committee) and pilot-observer intercom (already available).

5. Use of better quality maps than existing 1:500000 type (copies of 1:100000 Government Surveyers Topographical maps have been ordered, and a new 1:500000 map is being drawn at present. Limited cockpit space limits the size and scale of maps which can be used).

6. Additional improvements may not be applied due to the insecure financial position and the ownership issue of the Piper Supercub. These include :

a. Fitting of a radio/radar altimeter (expensive)

b. Fitting a cameraport on the floor of the aircraft for vertical photography (aircraft ownership, civilian aircraft regulations?).

c. Using a multi-exposure filmroll (eg. 500 exposures on one roll), camera motor drive, timed exposure controls, or alternatively a smallish video camera (expensive).

d. Removal of portside observer window and starboard door to improve visibility, as the perspex panes are scratched, fuzzy in some areas, and reflect light back onto the observer (aircraft ownership , civilian aircraft regulations?).

4.3 Experimental procedures to be considered for May 1985 census.

At present it takes about 80 hours flying over 14 days to count the whole of Etosha. If experimental procedures are too involved, accumulative fatigue will bias results of the last days of flying, whether experiment or census. The plan is therefore to opt for a strategy which would rapidly assess the following points:

1. Bias : Two areas can be found in Etosha where North-South transect lines will pass through strata D,E and F. These are marked on fig.23 . Another area comprised of strata D,E and F is south of Ekuma-Natukanoaka Pan, but elephant densities in strata E and F in this region are always very low.

Six treatment combinations (100m altitude: 1/2/4 km transect width; and 130 m altitude : 1/2/4 km transect widths) can be repeated five times in each of the three strata, using the combined seventeen transects of the two areas (where transects run North-South, as in fig. 7). The two areas would not have to be counted again.

2. Transect sampling : The remainder of Etosha can be divided into two areas, one where it is essential not to count using transect width wider than 2 km, and the other where 4 km transects can be used (provisionally). In order to test systematic and random transect sampling (while obtaining a total count) it is proposed that the rest of Etosha be counted using

continuous N-S transects, 2 or 4 km in width, as in fig. 23. This allows full statistical analysis after the census, and comparisons between the two methods.

Not a single block will be flown twice, and flying time could even be less, if this schedule is followed.

4.4 Experimental procedures to be considered for September 1985 census.

Essentially the same method as in 4.3 will be followed, except that the survey area will be stratified and procedures changed to conform with the optimum way of counting in each stratum.

5. IMPLICATIONS FOR CENSUSES OF OTHER SPECIES

5.1 It is recognized that the current censusing of elephants and other species in Etosha National Park is at best a trade-off between several limiting factors. Although several aspects are not always optimal, such as the type of aircraft, number of observers, personal psyche, absolute precision and absolute accuracy, the objective is to optimize according to local constraints.

5.2 The ultimate objective of a census is to arrive at an estimate of population size, as opposed to a general survey where numbers, distribution data and environmental data are recorded. The confidence one places on the ultimate estimate of Y can only be founded on thorough analysis of data following sensitive statistical procedures, to have any value at all. To simply sum the total number of individuals counted in each block or transect and arrive at a total while conceeding that some degree of error is involved, is simply meaningless and a grand waste of time and money.

5.3 To elaborate further, if the population estimate is to be used to establish trends in population status (increase or decrease in numbers) then the accuracy of the estimate is critical. An estimate with an estimated 10% standard error of the mean will not show a population change of 5%. An estimate with a 50% SE, which is still very, very optimistic in censuses where bias, precision and accuracy were not tested, will only show a population change of 5% after 10 years of censusing. It is not possible to manage, harvest, cull, translocate sensibly with this type of data base.

5.4 Several lucrative options exist to enable one to place more confidence in the estimation of population size derived from a typical "total" census. These options will not necessarily apply to all types of censusing or all types of areas or all species, but there are some procedures which could be used with any one

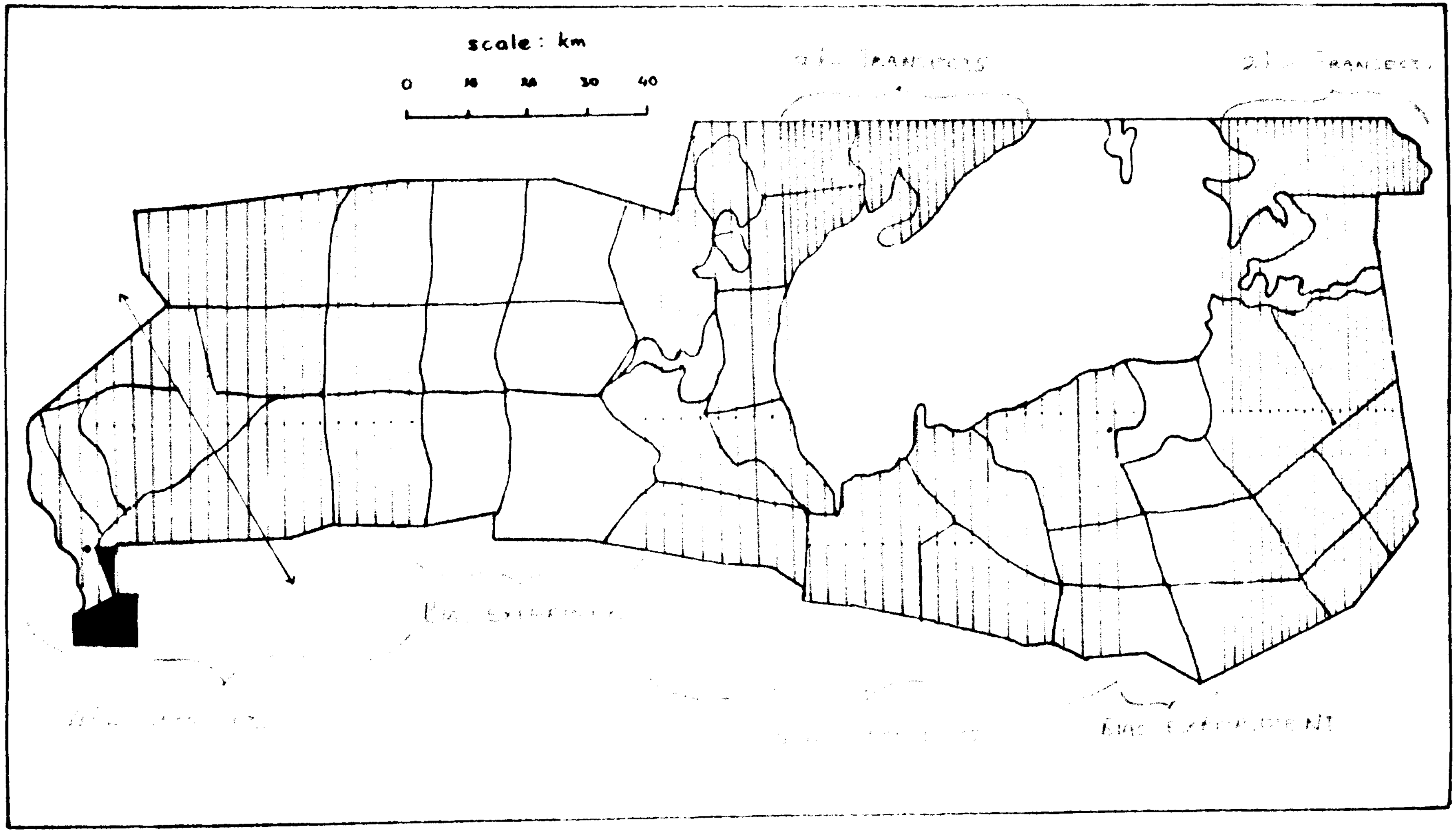


Figure 23. Proposed census schedule for counting elephants in May 1985.

set of circumstances. This report has dealt with exactly that, to test some of the options and estimate the optimum procedures under local conditions of counting elephants. Before any other species, or community of species can be approached in this way, similar investigations will have to be done. This very fact has scared people off this approach, as the statistical procedures are intimidating.

5.5 But look at the potential benefits. For example, if a "total" count yields a Y value of 2000 individuals of species x, with an unknown variance, the standard error(SE) must then be regarded as at least +- Y

∴ Y +- Y

or a guessed SE of +- 5/10/15/20% which must still be interpreted as at least +-Y

∴ Y +- Y

or a confident estimate of SE +- 49%,

∴ Y +- 49%

then the only estimate which under any circumstances should feature in any management assessment should be the Y +- 49%

∴ 2000 +- 49% = 2000 +- 980

and although this estimate is not accurate enough to describe population growth in terms of harvesting etc., it is indicative of trends, which although the population is changing gradually, will eventually be discovered after a number of years.

This might be the best possible use of an estimate, and the only one, unless further steps are taken to increase the precision of this estimate with known variance in accuracy (by refining counting techniques).

5.6 In some instances, however, a different census method may yield far superior results. Let us consider the example again:

2000 individuals are counted in a "total" census using 100 hours flying time.If initial procedures were followed, the variance at least will be confidently known, ie. +- 49%.

The estimated total is therefore Y (+- SE) 2000 +- 980

: if a transect sample count had been done at the 50 % level of sampling intensity (50% of survey area counted) the result could have been:

Y (+- SE) 2100 +- 11%

Not only is the variance less (since sample counts are notoriously more accurate) but only half of the flying time was required at half of the costs of a "total" census.

If this approach is ever considered for counting large areas in South West Africa, such as Etosha, then it must be realized that census design will have to begin at the beginning. The cost/benefit ratio is nevertheless favourable.

6. ACKNOWLEDGEMENTS

I thank all the personnell in Etosha who at various times gave physical and mental assistance in the completion of censuses and analysis of data. The pilot of the Piper Supercub in three of the four censuses discussed, Gino Noli, forms an integral part of the census and his flying skills and ever-increasing familiarity with the area are vital. His enthusiasm and patience are much appreciated.

Miss P.Rankin wrote numerous complex computer programmes for simulation and data analysis. Her general numerical skills and assistance are much appreciated. She also typed this report.

Dr J. Dippenaar assisted with the photogrammetrical survey and photographic counts of elephants.

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