Aerial sample counts of large game in northern Namibia

M. LINDEQUE * AND P.M. LINDEQUE

Ministry of Environment and Tourism,
Private Bag 13306, Windhoek

* To whom correspondence should be addressed

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ABSTRACT

Simulated samples from total aerial censuses in Etosha National Park were used to assess inexpensive sample count methods designed for most large game species in northern Namibia. Random transect samples yielded population estimates with greater precision than systematic or weighted transect samples. Relatively low densities and extreme clumping in the distribution of populations within census zones resulted in imprecise sample count estimates. The precision of population estimates could be enhanced by using the number of groups sighted instead of the number of individuals per group, and after-the-event stratification. This combination of treatments has made a sample aerial design feasible for areas with highly aggregated game distributions but overall low game densities, but extensive stratification of aerial counts will be essential to further improve precision of population estimates of virtually all large game species.

INTRODUCTION

Total coverage of protected areas by aerial transects has thus far been the most important method used to monitor population trends of large game in northern Namibia. Several major sources of error and bias can occur in a total aerial census (Norton-Griffiths 1978) and total censuses are often not easy to repeat or standardize. The Namibian Ministry of Environment & Tourism has nevertheless accepted these limitations and has attempted to maintain its long-term schedule of censusing parks in this way. We have, however, finally reached the point where the cost of the census schedule is unaffordable. The need for better and more frequent censuses is ironically greater than ever before, as recent changes in conservation philosophy have emphasized the harvesting of game in or around parks to the benefit of rural communities. Better, more frequent, and more efficient monitoring of population trends, are required if interventive management of game populations is to be successfully applied on a sustainable basis. Alternative census methods therefore have to be developed, in order to find a compromise between our data requirements and financial resources.

A major censusing problem applicable to all conservation areas in northern Namibia is that game densities are lower and game distribution is more clumped than in those parts of Africa where the classic aerial census methods were developed (eg. Sinclair 1972, Norton-Griffiths 1973, Pennycuick *et al.* 1977). These methods do not necessarily yield adequate estimates of population size if applied to a different censusing environment. The process of refining and validating a census technique is problematical, particularly when the direction of development is towards a less intensive counting technique. Each method used to derive a population estimate has its own inherent sources of error, and can often not be used to validate an alternative method (Norton-Griffiths 1978). The accuracy of estimates derived from "total censuses" has never been assessed and these consequently have limited use in the validation of any new method, particularly as previous total censuses were usually not standardized. We are thus left with individual sample characteristics such as variance, as the only objective assessment of the validity of population estimates, derived from sample count methods.

The lack of funds to do total aerial censuses of several parks in 1990 forced us to use a sample count method, the development of which was based on sample simulations of previous total censuses. The aim of this paper is to evaluate the feasibility of aerial sample counting as a possible future standard census method for some parks in northern Namibia.

MATERIALS AND METHODS

No additional time or funds were available to do an experimental census, but the flight plans for total area coverage aerial censuses of elephants (*Loxodonta africana*) in Etosha National Park (hereafter referred to as Etosha), were modified to allow sample simulations. A sampling system was investigated by using a series of routine elephant censuses in Etosha. This was done by selecting a sample in various ways from a series of finite transects which had to be flown in any event. Two strata were defined, the eastern woodlands where transects were spaced 2 km apart (thus 2 km wide) from a randomly chosen starting point, and the western shrubland with transects at 4 km intervals. A maximum number of 186 transects was thereby established, represented as a double row of north-south transects in two broad vegetation strata.

The feasibility of a sample estimate is assessed by determining the appropriate sampling intensity (Norton-Griffiths 1978). Optimal sampling intensity yields the minimum variance of the estimate in terms of effort expended (time, cost) and is estimated by step-by-step increasing the sample size until additional sampling units do not increase the precision of the estimate (Jolly 1969; Norton-Griffiths 1978). Jolly's (1969) method 2 for unequal sized sampling units was used to calculate the population estimate (Y) and 95% confidence limits (CL) of Y (this means there is a 95% certainty that the true number of entities lies within 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, and

R = ratio of animals counted to area searched $= \frac{y}{z}$

and the population total Y = Z R

and population variance $\mathrm{Var}(Y) = \frac{N(N-n)}{n} s^2y - 2Rs_{zy} + R^2 s_z^2$

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

and 95% confidence limits (CL) of $Y = \pm\, t_{(n-1\ df)} SE(Y)$

Precision of the estimate Y is expressed as the 95% CL of Y as a percentage of Y and is used to indicate optimal sampling intensity. An alternative indication of optimum sampling intensity and intra-sampling variation is obtained by expressing the homogeneity between sampling units as the percentage similarity (PS) (Gauch 1982) where:

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

where 200 = denominator if samples are expressed as a percentage

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

A computer program was written where series of transect samples were chosen at increasing sampling intensities, according to a systematic, random and weighted random sampling system.

A combined fixed-wing and helicopter census done in September 1987 was used to determine sampling intensities for other large game in Etosha. The park was divided into a helicopter and fixed-wing aircraft stratum, corresponding to predetermined "high" and "low" game densities. Three series of north-south transects were flown, using roads and fences as boundaries. Sample counts were simulated for each species separately in the two strata, as described for the elephant simulations above.

Aerial transect sample counts were done in Etosha, Khaudom Game Reserve (hereafter referred to as Khaudom) and eastern Bushmanland, in August-September 1990. A sample intensity of 30% area coverage was used and transects were randomly allocated in the three series of north-south transects previously used in Etosha, and in similar units in Khaudom and eastern Bushmanland using features such as dry rivers and fences as boundaries. All transects were flown using a Maule four-seater fixed-wing aircraft, at an altitude of c. 100 m, speed of 100 km/h, and transect widths of 2 km. We could not stratify the census area into zones of homogeneous game densities prior to the census. High density zones were demarcated during census flights, where intensive flying was used to count game concentrations. Such areas were excluded from transect areas. The distance between aircraft and game observed was estimated for as
many sightings as possible, using markers on the wing struts to indicate half-transect width for each side of the aircraft.

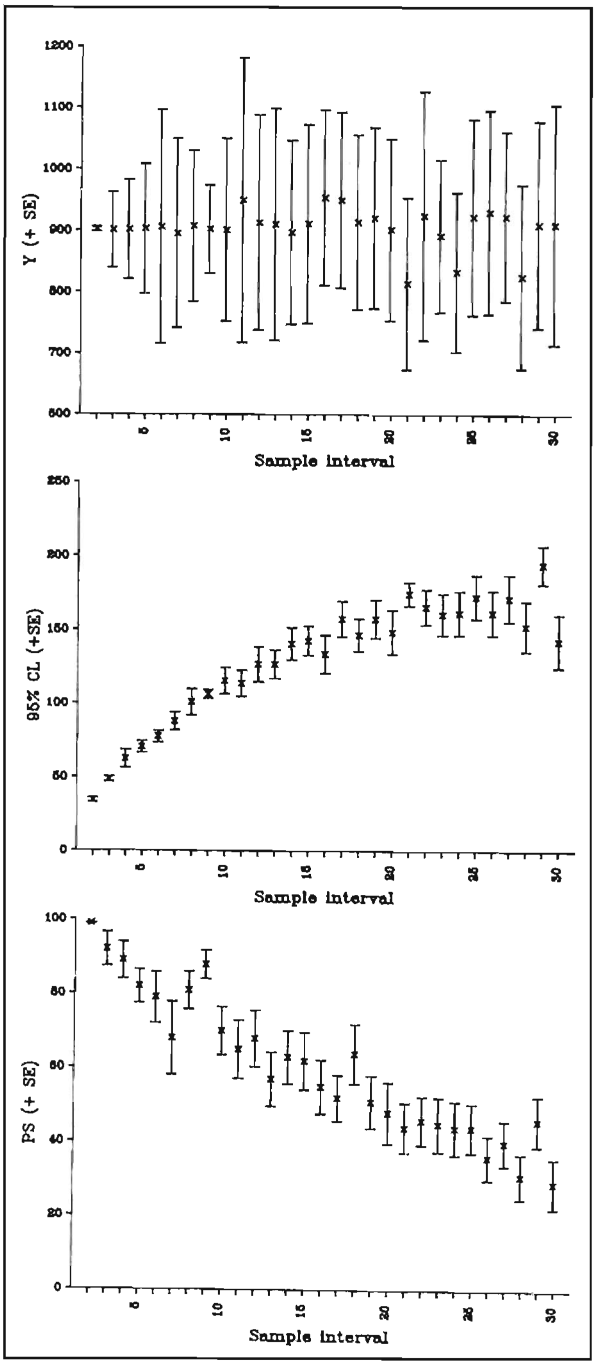

FIGURE 1: Mean (± SE) population estimates (Y), 95% confidence limits (CL) as a percentage of Y and the percentage similarity (PS) for simulated systematic transect sample counts of elephants in Etosha National Park. (Transects were not replaced in the sample, and the number of simulations are equivalent to the sample interval).

Effective transect widths were determined as in Lindeque & Lindeque (1997), and population estimates calculated as above. A separate set of estimates was calculated for each census area excluding transects with zero counts and using the number of groups instead of actual totals observed. Population estimates in the latter instance were produced using mean group sizes for species per area. Final estimates were produced by adding the total per species observed in non-transect zones to sample estimates (Norton-Griffiths 1978).

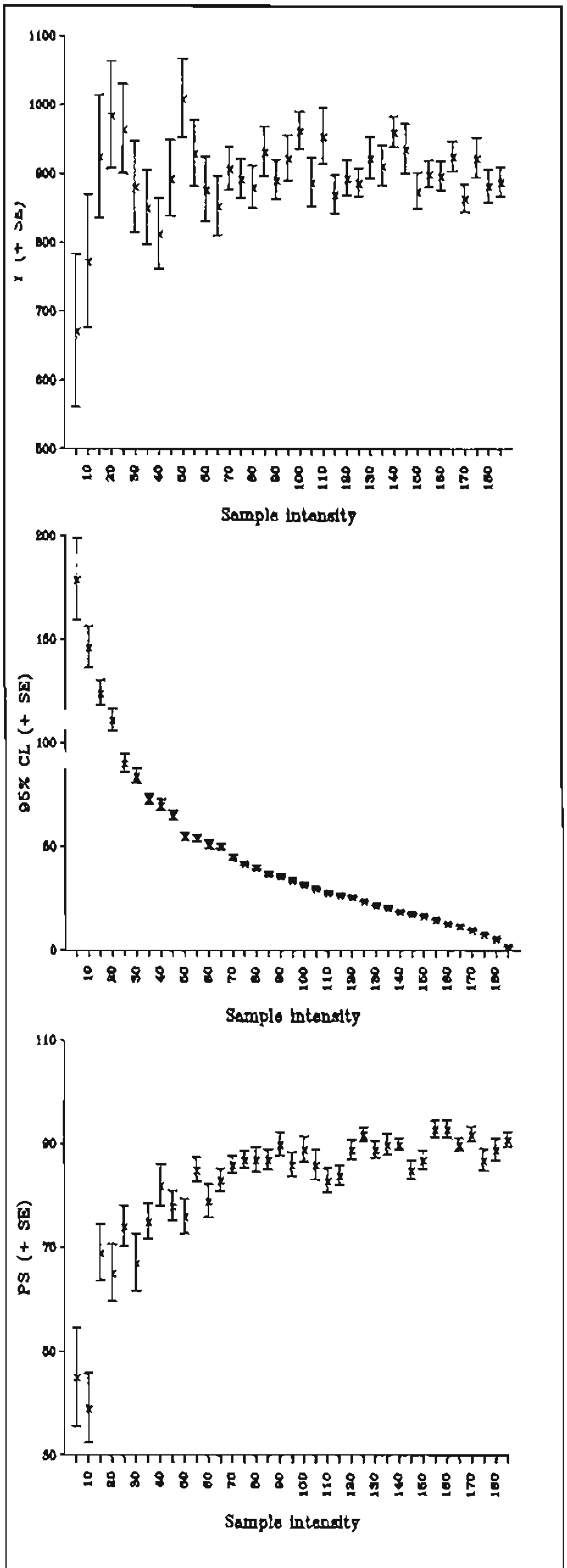

FIGURE 2: Mean (± SE) population estimates (Y), 95% confidence limits (CL) as a percentage of Y and the percentage similarity (PS) for 20 simulated random transect sample counts of elephants in Etosha National Park.

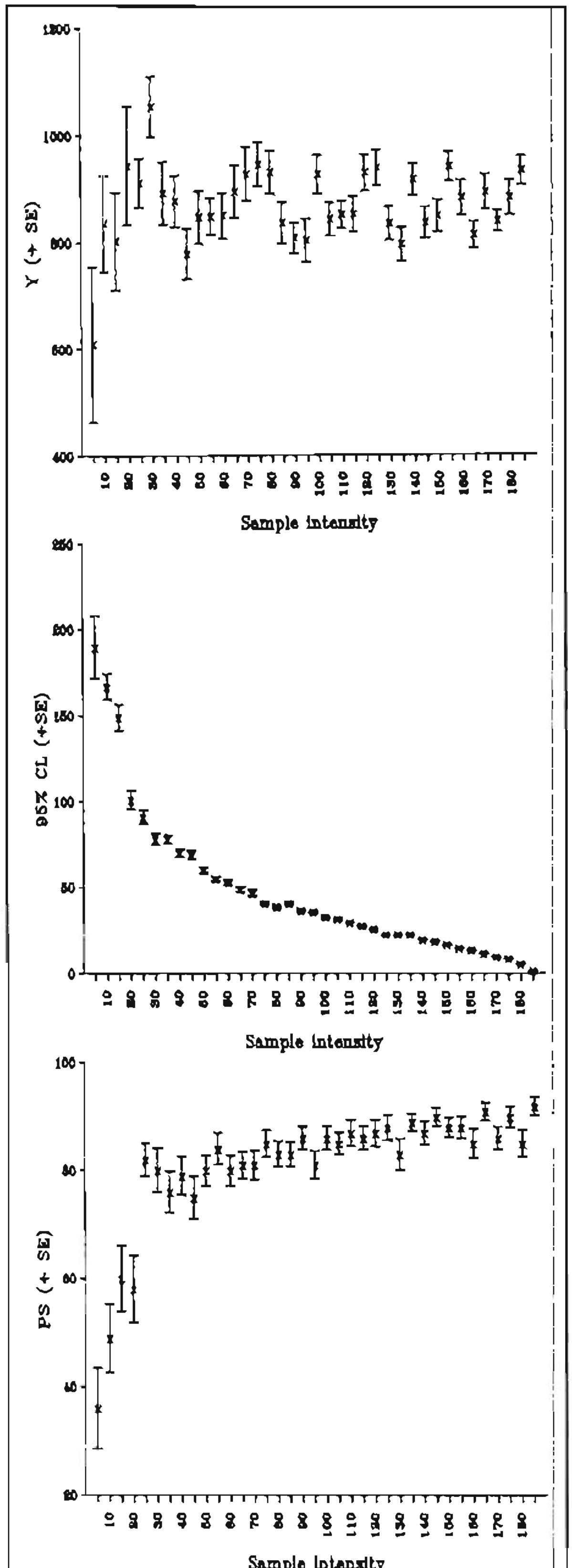

FIGURE 3: Mean (± SE) population estimates (Y), 95% confidence limits (CL) as a percentage of Y and the percentage similarity (PS) for 20 simulated weighted random transect sample counts of elephants in Etosha National Park.

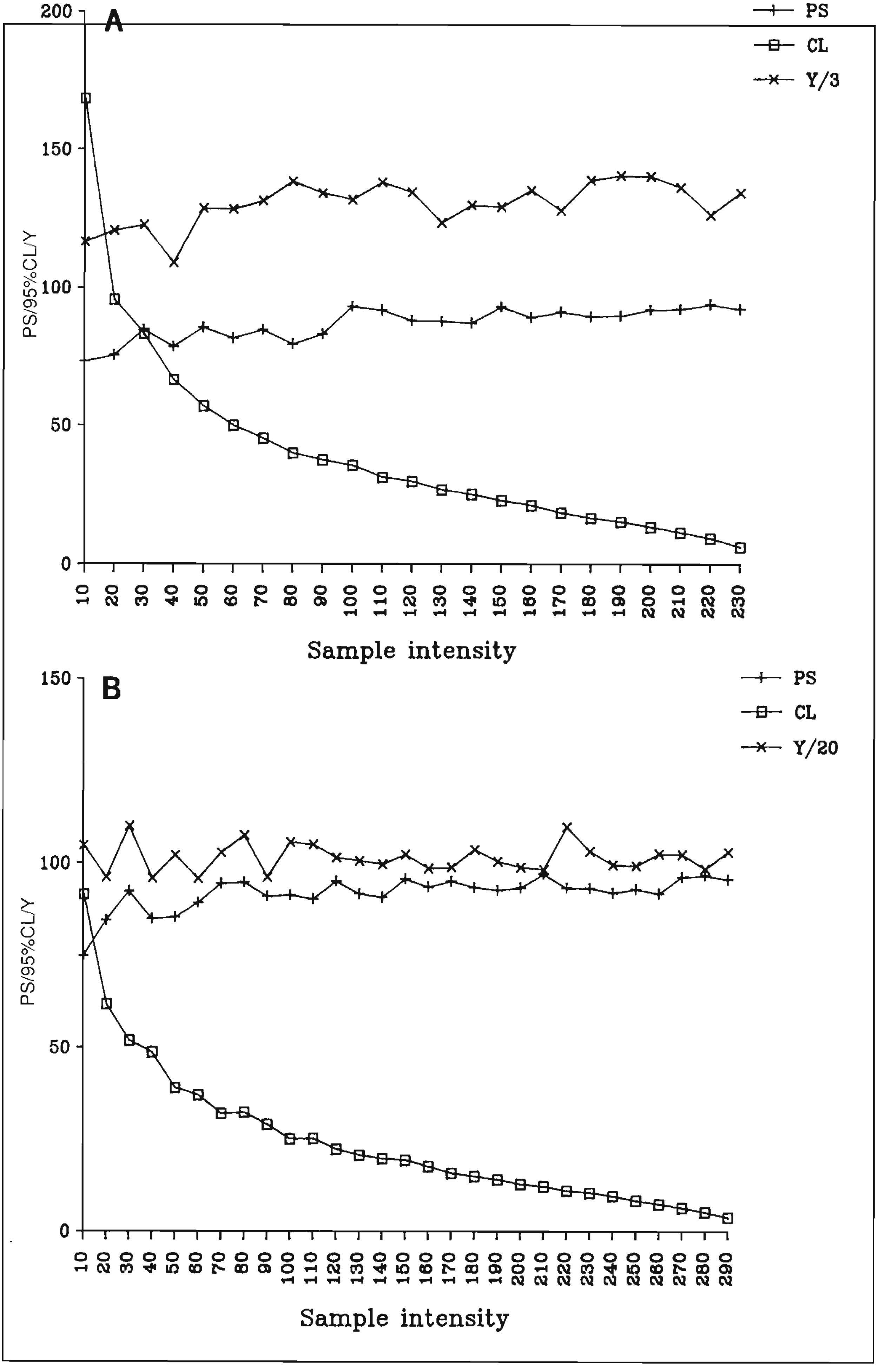

FIGURE 4: Population estimates (Y), percentage similarity (PS) and 95% confidence limits as a percentage of Y (CL) for a simulated random transect sample count of gemsbok in the low (A) and high density (B) strata in Etosha National Park.

RESULTS

Elephant census simulations

The mean (± SE) of the population estimate Y (n = 40), 95% CL (n = 40) and PS (n = 20) of random transect samples (weighted and unweighted) and systematic transect samples for the entire unstratified census area in Etosha in May 1985 are illustrated in Figures 1-3, as an example. Simulations were performed for the shrubland and woodland zones separately, but stratification did not reduce the variances associated with each estimate significantly. Simulations were also performed for an identical census in August 1985, and were similar to the May results and are not illustrated.

Population estimates derived from simulated samples in Figures 1-3 remained acceptably close to the estimate of population size obtained from the total count, but the 95% CL values only reached the <20% range of the population estimate at near maximum sampling intensity. Designing a sample census based on this simulation might therefore yield an accurate population estimate with wide confidence limits and consequently low precision. Random transect sampling (weighted and unweighted) shows a levelling off in precision at 30-40% sampling intensity. About 60-70 transects will therefore be adequate in terms of sampling efficiency, should precision not be an overriding factor. Systematic transect sampling shows greater variance in parameters and should not be used in favour of random sampling, particularly where the danger exists of coincidence with systematically distributed environmental features such as dunes and boreholes.

Multi-species census simulation

Figure 4 A & B illustrates a single simulation of a random sample count for gemsbok (*Oryx gazella*) in the 1987 multi-species census in Etosha as an example. Systematic transect samples were more variable for all species, and are not illustrated. Table 1 presents minimum sampling intensity per species in order to achieve population estimates with confidence limits of not larger than 20% of the population estimates. Low density stratum counts required greater sampling intensity than in the high density stratum for all species. Adequate sampling intensity did not correlate with our ranking of species according to relative visibility. Highly gregarious species seem to require more intensive sampling than those occurring in smaller groups.

Random transect sample censuses in 1990.

Population estimates were more precise than predicted by the simulations performed for a multi-species census when using a sampling intensity of 30% (Table 2). Confidence limits in all cases exceeded the 20% of Y cut-off point, and the population estimates are consequently of little value. Most species occurred in a small portion of the total number of transects flown and their distributions were highly clumped. Only Hartmann's zebras (*Equus zebra hartmannae*) and black-faced impalas (*Aepyceros melampus petersi*) have restricted distribution ranges in Etosha, as determined by habitat and/or range extension since re-introduction. All other species, except gemsbok, occurred in less than 50% of the transects flown (Table 3).

TABLE 1: Percentage transects required to yield population estimates (Y) with 95% confidence limits of ≤ 20% of Y, and a percentage similarity ≥ 80%, in a simulated random transect sample census of Etosha National Park.

	Sampling intensity at 95% CL ≤ 20% of population estimate, and PS ≥ 80%	
Species[1]	Low density stratum	High density stratum
La	78	67
Sc	59	41
Ct	87	76
Og	65	59
Eb	89	69
Ab	91	88
To	-	97
Am	87	72
Gc	76	55
Ts	87	60
Db	91	71

La = elephant (*Loxodonta africana*), Sc = ostrich (*Struthio camelus*), Ct = blue wildebeest (*Connochaetes taurinus*), Og = gemsbok (*Oryx gazella*). Eb = Burchell's zebra (*Equus burchelli*), Ab = red hartebeest (*Alcelaphus buselaphus*). To = eland (*Taurotragus oryx*). Am = springbok (*Antidorcas marsupialis*), Gc = giraffe (*Giraffa camelopardalis*). Ts = greater kudu (*Tragelaphus strepsiceros*), Db = black rhinoceros (*Diceros bicornis*).

1 Species subjectively rated in descending order from most visible to least visible.

TABLE 2: Population estimates (± SE) and 95% confidence limits (CL) of large game in the transect zone in Etosha National Park in August 1990, using 2 km wide transects, and a sampling intensity of 30%.

Species***	Pop. est. Y ± SE	95% CL as a % of Y	Approx. 95% CL as % of Y predicted by simulations at 30% sampling intensity*
La	1160 ± 208	35.2	40 - 60
Sc	636 ± 91	28.1	30 - 45
Ct	1281 ± 301	46.1	55 - 80
Og	2513 ± 272	21.3	30 - 45
Eb	2664 ± 584	43.0	40 - 70
Ezh**	279 ± 108	75.8	-
Ab	389 ± 111	55.9	60 - 95
To	123 ± 60	95.9	65 - 85
Am	3498 ± 605	33.9	50 - 65
Gc	659 ± 94	28.0	30 - 65
Ts	487 ± 93	37.5	40 - 80
Amp**	212 ± 110	101.4	-
Db	107 ± 20	35.7	50 - 75

* low and high estimates correspond to simulations of counts in high and low game densities respectively, using the 1987 multi-species census in Etosha.

** Ezh = Hartmann's zebra (*Equus zebra hartmannae*), Amp = black-faced impala (*Aepyceros melampus petersi*).

*** See Table 1.

TABLE 3: Sightings per transect of each species during the 30% random transect sample count in Etosha National Park in 1990. (A total of 162 transects were flown).

Species***	2 km transect width*			1 km transect width**		
	no. (%) transects with sightings	total number counted	total number of groups	no. (%) transects with sightings	total number counted	total number of groups
	A	B	C	A	B	C
La	34(21.0)	498	44	22(13.6)	258	24
Sc	75(46.3)	273	121	55(34.0)	187	77
Ct	25(15.4)	550	44	19(11.7)	382	33
Og	103(63.6)	1079	222	83(51.2)	631	140
Eb	57(35.2)	1144	90	37(22.8)	560	48
Ab	16(9.9)	167	18	7(4.3)	63	7
Ezh	7(4.3)	120	17	6(3.7)	78	10
To	6(3.7)	53	6	5(3.1)	51	5
Am	50(30.9)	1502	91	38(23.5)	1003	64
Gc	47(29.0)	283	92	31(19.1)	172	57
Ts	32(19.8)	209	49	24(14.8)	146	37
Amp	5(3.1)	91	5	2(1.2)	51	2
Db	21(13.0)	46	27	12(7.4)	30	15

* using all sightings within c. 1 km from the aircraft
** using all sightings within c. 500 m from the aircraft
*** See Tables 1 & 2

The effects of a clumped distribution on sample estimates is demonstrated by hypothetical samples of 100 individuals counted in 10 equal-sized transects (Table 4). Population estimates derived from transect distributions representing three different degrees of clumping remained constant, but the standard errors and 95% confidence limits declined drastically with increasing homogeneity within a sample. Most species counted in Etosha showed distributions similar to A and B in Table 4, while case C represents an ideal case where eg. stratification had ensured that transects with uniform game densities were sampled together.

TABLE 4: Population estimates (Y ± SE, ± 95% CL as % of Y) of hypothetical sample distributions of 100 individuals in 10 transects of a 33% sample count, representing variable degrees of clumping.

	A	B	C
Transect no.	Total counted	Total counted	Total counted
1	0	0	11
2	0	50	9
3	0	0	10
4	0	0	11
5	100	0	9
6	0	0	8
7	0	30	9
8	0	0	10
9	0	0	11
10	0	20	12
Total	100	100	100
Pop. est. Y	300	300	300
± SE	245	137	10
95% CL as % of Y	185	103	7

The same distributions used in Table 4 are presented in Table 5 but with the number of groups sighted instead of the number of individuals. Population estimates and variances were calculated using the mean group sizes in each sample and were similar in all three cases, as well as to corresponding population estimates and variances in Table 4. Using the number of groups as the sample unit thus did not reduce the variance of the sample. Using sightings of groups instead of actual totals counted, allows correction factors to be used in cases where it is impossible to count groups accurately, eg. densely packed elephant herds or giraffe (*Giraffa camelopardalis*) herds partly concealed by clumps of trees, using independently obtained data on mean group sizes at the time of censusing.

Discarding transects with zero sightings improved the variance of the estimate without biasing the population estimate itself. Table 6 presents two hypothetical samples where population estimates and variances were calculated with and without transects with no sightings of the hypothetical species. In both cases, using case B from Tables 4 & 5, both estimates of variance were reduced following exclusion of transects with no sightings. This procedure is similar to after-the-event stratification discussed in Yates (1960), Sinclair (1972), Bell *et al.* (1973) and Norton-Griffiths (1973, 1975, 1978), and might be useful as an alternative estimator of variance associated with sample estimates of population size. Alternative population estimates with generally reduced sample variances can also be calculated by using the effective strip widths as opposed to intended strip widths (Lindeque & Lindeque 1997), group sizes rather than individuals and excluding transects with zero sightings as in Tables 7-9.

TABLE 5: Population estimates (Y ± SE, ± 95% CL as % of Y) of hypothetical sample distributions of 100 individuals in 10 transects of a 33% sample count, using the number of groups sighted.

		Transect no.	A	B	C
		1	0	0	1
		2	0	2	1
		3	0	0	1
		4	0	0	2
		5	2	0	1
		6	0	0	1
		7	0	1	1
		8	0	0	2
		9	0	0	2
		10	0	1	3
Total number		10	2	4	15
Mean group size			50.0	25.0	6.7
	Y		6	12	45
Groups	± SE		4.9	5.5	5.5
	± 95% CL as % of Y		184.7	102.1	27.5
	Y		300	300	302
Total	± SE		244.9	135.4	36.7
	± 95% CL as % of Y		184.7	102.1	27.5

TABLE 6: Population estimates (Y ± SE, ± 95% CL as % of Y) of hypothetical sample distributions of 100 individuals in 10 transects of a 33% sample count, using all transects and excluding those with no sightings.

Transect No.	B* Total counted	B* Total groups counted	
1	0	0	
2	50	2	
3	0	0	
4	0	0	
5	0	0	
6	0	0	
7	30	1	
8	0	0	
9	0	0	
10	20	1	
Total	100	4 (Mean group size 25.0)	
Y(n trans. 10)	300	12	300
± SE 137	5	135	
± CL as % of Y	103	102	102
Y(n trans. 3)	300	12	300
± SE 65	3	61	
± CL as % of Y	93	88	88

* Corresponding distributions used in Tables 4 & 5 respectively.

TABLE 7: Population estimates (Y ± SE and 95% confidence limits as % of Y) in the random transect sample census of Etosha National Park (A), corrected population estimate based on effective strip widths (B), and an alternative population estimate (C) based on the exclusion of transects with zero sightings, effective transect widths and using group sizes instead of individuals.

Species *	A Y ± SE; 95%CL as % of Y	B[1] Y ± SE; 95%CL as % of Y	C Y ± SE; 95%CL as % of Y	Non-[2] Transect counts
La	1469 ± 208; 35.2	1469 ± 208; 35.2	1556 ± 88 ; 14.4	309
Sc	681 ± 91 ; 28.1	921 ± 183; 41.1	840 ± 57 ; 14.4	50
Ct	2014 ± 301; 46.1	2532 ± 549; 60.4	2950 ± 331; 31.3	733
Og	2789 ± 272; 21.3	3220 ± 484; 32.2	3514 ± 226; 14.0	276
Eb	4445 ± 584; 43.0	4389 ± 750; 56.4	5405 ± 313; 17.7	1781
Ezh	451 ± 108; 75.8	535 ± 174; 93.6	844 ± 192; 73.3	172
Ab	493 ± 111; 55.9	493 ± 111; 55.9	604 ± 51 ; 21.9	104
To	206 ± 60 ; 95.9	(206 ± 60 ; 95.9)[3]	—	83
Am	5870 ± 605; 33.9	7043 ± 966; 40.5	8456 ± 866; 29.1	2372
Gc	761 ± 94 ; 28.0	897 ± 179; 44.1	818 ± 133; 38.1	102
Ts	516 ± 93 ; 37.5	709 ± 191; 55.2	669 ± 86 ; 27.9	29
Amp	215 ± 110; 101.4	(215 ± 110; 101.4)[3]	—	3
Db	111 ± 20 ; 35.7	144 ± 40 56.4	313 ± 40 ; 26.8	4

* See Tables 1 & 2.

1. Effective transect widths determined following Lindeque & Lindeque (1993) with effective sampling intensities consequently either 30% or 15%. The effective transect width for elephants and red hartebeest was 2 km and 1 km for all others.
2. Additional sightings in non-transect areas were added to the population estimates from transect strata in estimates A, B and C (Norton-Griffiths 1978).
3. Data insufficient to determine effective counting strip width.

TABLE 8: Population estimates (Y ± SE and 95% confidence limits as % of Y) in the random transect sample census of Khaudom Game Reserve based on effective strip widths (B), and an alternative population estimate based on the exclusion of transects with zero sightings, effective transect widths and using group sizes instead of individuals (C).

Species *	B[1] Y ± SE ;95%CL as % of Y	C Y ± SE ;95%CL as % of Y	Non-[2] Transect counts
La	1208 ± 420; 82.6	918 ± 88 ; 40.4	169
Sc	35 ± 16 ; 92.9	36 ± 5 ; 38.5	0
Ct	190 ± 101; 124.8	296 ± 51 ; 79.6	26
Og	12 ± 12 ; 207.2	44 ± 10 ;280.7	0
Gc	201 ± 55 ; 61.7	230 ± 31 ; 32.7	19
He[3]	220 ± 198; 186.5	212 ± 1 ; 6.9	3
Dl[4]	—	—	8
Ra[5]	—	—	5

* See Tables 1 & 2.
1. Effective transect widths determined following Lindeque & Lindeque (1993) with effective sampling intensities consequently either 30% or 15%. The effective transect width for elephants and red hartebeest was 2 km and 1km for all others.
2. Additional sightings in non-transect areas were added to the population estimates from transect strata in estimates B and C (Norton-Griffiths 1978).
3. Roan (*Hippotragus equinus*)
4. Tsessebe (*Damaliscus lunatus*)
5. Reedbuck (*Redunca arundinum*)

TABLE 9: Population estimates (Y ± SE and 95% confidence limits as % of Y) in the random transect sample census of eastern Bushmanland based on effective strip widths (B), and an alternative population estimate based on the exclusion of transects with zero sightings, effective transect widths and using group sizes instead of individuals (C).

Species *	B[1] Y ± SE ;95%CL as % of Y	C Y ± SE ;95%CL as % of Y	Non-[2] Transect counts
La	301 ± 188; 173.7	237 ± 90 ; 172.5	13
Sc	371 ± 185; 107.5	372 ± 65 ; 36.7	8
Ct	234 ± 145; 131.1	179 ± 1 ; 0	5
Og	216 ± 162; 158.8	364 ± 70 ; 61.4	8
Ab	18 ± 9 ; 103.0	79 ± 1 ; 0.7	14
Gc	92 ± 44 ; 100.8	96 ± 26 ; 66.2	4
Ts	1443 ± 133; 53.8	496 ± 77 ; 34.4	31
He	—	—	1
Dl	—	—	5
Scaf[3]	—	—	14

* See Tables 1 & 2.
1. Effective transect widths determined following Lindeque & Lindeque (1993) with effective sampling intensities consequently either 30% or 15%. The effective transect width for gemsbok was 0.4 km and 1km for all others.
2. Additional sightings in non-transect areas were added to the population estimates from transect strata in estimates B and C (Norton-Griffiths 1978).
3. Buffalo (*Syncerus caffer*)

DISCUSSION

For a conservation agency such as the Namibian Ministry of Environment & Tourism, which is used to working with purportedly exact population estimates derived from "total" aerial censuses, sample estimates might seem vague. Single estimates of population sizes have invariably been produced from "total" censuses, simply because there is no way of measuring bias, variance or error in such censuses (Norton-Griffiths 1978). Sample counts done in northern Namibia in 1990 required only about 10% of the expenditures in finances and effort of total coverage aerial censuses done previously. The price for this reduction in effort required is extensive data processing and manipulation. Population estimates and variances calculated from sample censuses are inevitably more complex and intuitively seem more vague than "total" census arithmetic, but such estimates give numerical estimates to probable ranges, previously recognized to exist but never quantified.

Sample aerial counts are widely used in African conservation areas and elsewhere in the world, and are suitable for most animal species except the very cryptic ones. The methodology and theory of sample counts have been explored exhaustively in Yates (1960), Cochran (1963), Jolly (1969), Norton-Griffiths (1973, 1978), Caughley (1977), Eberhardt & Simmons (1987) and others. Commonly used techniques might, however, require modifications to be suitable for local conditions and different species. Without modifications, sample techniques result in unusable population estimates with unacceptably high confidence limits in censuses of species occurring at low density and/or in a clumped distribution. A critical modification required in future sample counts of virtually all large mammals in northern Namibia is considerable improvements in stratification, where stratification prior to a census should aim to improve the homogeneity of samples. The cost of doing stratification of the census zone by air would probably not exceed the cost of the sample count, and would thus still be much less expensive than a total count. Minor increases in the sampling intensity of a survey will in most cases not reduce the homogeneity of the sample, as predicted by the simulations presented in Figs. 1 - 4 and Tables 1 and 2. A 30% sampling intensity as used in 1990 in northern Namibia already exceeds sampling intensities in large game censuses in neighbouring countries and east Africa.

We have presented population estimates from sample counts subjected to two procedures aimed at reducing variance associated with the estimates, namely removing transects with zero sightings and using groups instead of individuals. Both procedures might be considered questionable, and reducing the heterogeneity of transect samples due to the presence of a majority of transects with zero sightings should rather be attempted through improvements in stratification. Using groups instead of individuals should only be attempted if mean group sizes are determined independently and the variance in group sizes is included in the overall estimate of variance.

By using such modifications, and recognizing that technologies not available to us at present would further improve estimates, we feel that population estimates derived from aerial sample counts in northern Namibia may be at least as good as total count estimates. It is, however, clear that locally rare species or highly aggregated species might require alternative counting procedures. The bias in total aerial counts has not been determined, and population estimates based on such counts cannot be used uncritically to validate sample counts. Recent population estimates of large game in the three census areas are nevertheless presented in Tables 10-12, as well as an indication of which species would require special counting techniques in future, other than a general improvement in stratification. Aerial counting techniques are regarded as unsuitable for only two large game species in Etosha, namely eland (*Taurotragus oryx*) and black-faced impala (other than non-target species such as the large predators). The density of eland in Etosha has reached such a low level that special methods such as mark-resighting will be required, despite the fact that eland are usually adequately visible from the air. Protracted total area coverage censuses will not necessarily be a viable alternative, as eland are highly mobile and groups are unstable in Etosha. Black-faced impalas are not adequately visible from the air and ground counting is required for this species.

Giraffe and kudu (*Tragelaphus strepsiceros*) are both marginally countable from the air, the problem being that observers do not seem to count entire groups, due to partial concealment and differential sightability of different age groups and sexes. Both species usually "freeze" when approached by a fixed-wing aircraft, with kudu bulls and senior adult giraffe bulls often appearing more visible due to the presence of horns or their darker coat colour. Most observers feel that with more time available more individuals will eventually be spotted. It is thus recommended that independent data on group sizes be obtained during a census in order to use mean group size as a correction factor for these two species.

TABLE 10: Recent population estimates based on total aerial censuses inEtosha National Park, compared to an aerial sample count.

Species[1]	Total aerial censuses[2]			15-30% Random transect sample estimate ± 95% CL		Future improvements[4]
	1982	1984	1987	1990 B[5]	1990 C[5]	
La	2202	2464	2021	1469 ± 408	1556 ± 180	Stratify
Sc	1835	1311	1460	921 ± 358	840 ± 114	Stratify
Ct	2195	2253	2617	2532 ± 1087	2950 ± 694	Stratify
Og	5081	3248	2191	3220 ± 948	3514 ± 453	Stratify
Eb	7970	5332	4761	4389 ± 1471	5405 ± 642	Stratify
Ezh	2665	620	449	535 ± 340	844 ± 494	Stratify
Ab	396	486	548	493 ± 218	604 ± 110	Stratify
To	692	353	259	(206 ± 118)	—	Mark-resighting
Am	16011	10722	8162	7043 ± 1892	8456 ± 1770	Stratif
Gc	1184	1376	1129	897 ± 351	818 ± 273	Correct. factor
Ts	1041	1061	970	709 ± 375	669 ± 179	Correct. factor
Amp	93	164	180*	(215 ± 215)*	—	Ground counts
Db	121	150	142**	144 ± 79**	313 ± 83	Ground counts
Total	41486	29540	24889	22773 ± 7860	25969 ± 4992	
Crude Density[3] (n/km^2)	(2.3)	(1.6)	(1.4)	(1,3 ± 0.4)	(1.4 ± 0.3)	

1 As in Tables 1 & 2
2 Unpublished data, Ministry of Wildlife, Conservation & Tourism
3. Using c.18000 km^2 of savanna in Etosha.
4. See text.
5. See Table 7.
* Single-species ground counts indicate a population of 500-1000 in Etosha (F.G. Joubert, pers. comm.)
** Waterhole counts of known individuals indicate a population of c.300 in Etosha (A.D. Cilliers, pers. comm.).

TABLE 11: Recent population estimates based on total aerial censuses using a helicopter in Khaudum Game Reserve compared to an aerial sample count by fixed-wing aircraft.

Species[1]	Total aerial census[2]			15% Random transect sample estimate ±95% CL		Future improvements
	1984	1985	1987	1990 B[4]	1990 C[4]	
La	395	377	593	1208 ± 858	918 ± 303	
Sc	34	72	30	35 ± 33	36 ± 14	
Ct	439	199	160	190 ± 205	296 ± 215	Stratify and increase
Og	225	141	186	12 ± 25	44 ± 124	sampling intensity
Gc	236	495	665	201 ± 112	230 ± 69	
He	237	159	410	220 ± 405	212 ± 14	
Dl	24	36	2	8		Mark-resighting
Ra	3	10	2	5		Mark-resighting
To	36	14	35	0		Mark-resighting
Ab	1	18	0	0		Mark-resighting
Total	1630	1521	2083	1879 ± 1638	1736 ± 739	
Crude Density[3] (n/km²)	(0.4)	(0.4)	(0.5)	(0.5 ± 0.4)	(0.5 ± 0.2)	

1 As in Tables 1, 2 & 8
2. Unpublished data, Ministry of Wildlife, Conservation & Tourism
3. Area of Khaudom Game Reserve = c.3840 km²
4. See Table 8

TABLE 12: Recent population estimates based on total and sample aerial counts of eastern Bushmanland, using fixed-wing aircraft.

Species[1]	Total aerial censuses[2]		c. 15% Random transect sample estimate ± 95% CL		Future improvements
	1984	1988	1990 B[4]	1990 C[4]	
La	395	401	301 ± 500	237 ± 386	
Sc	53	147	371 ± 390	372 ± 134	Stratify and increase
Ct	368	59	234 ± 300	179 ± 0	sampling intensity
Og	267	198	216 ± 330	364 ± 219	
Ab	116	65	18 ± 4	79 ± 1	Mark-resighting
Gc	425	233	92 ± 89	96 ± 61	
Ts	875	325	1443 ± 760	496 ± 160	
Dl	0	0	1		Mark-resighting
He	108	56	5		Mark-resighting
Scaf	40	11	14		Mark-resighting
To	17	8	0		Mark-resighting
Total	2664	1503	2695 ± 2373	1823 ± 961	
Crude Density[3] (n/km²)	0.7	0.4	0.7 ± 0.6	0.5 ± 0.2	

1. As in Tables 1, 2, 8 & 9
2. Unpublished data, Ministry of Wildlife, Conservation & Tourism
3. Area of eastern Bushmanland census zone = c.4000 km²
4. See Table 9

Hartmann's zebra only occur in a limited part (c. 1200 km^2) of Etosha (c. 23000 km^2) (Joubert 1972), which in future should be stratified to contain more sampling units than at present. Counting springbok (*Antidorcas marsupialis*) presents the most difficult monitoring problem in Etosha. The species shows a highly aggregated or clumped distribution pattern and poor visibility from the air. We recommend that springbok be counted during the short wet season in Etosha, when the bulk of the springbok population occurs on the short grass plains (c. 2000 km^2) of Etosha and with a green background contrast. Burchell's zebra (*Equus burchelli*) and blue wildebeest (*Connochaetes taurinus*) likewise concentrate on the plains during the wet season and should also be counted at this time. All three species form large aggregations at this time and a photographic technique will be necessary (Norton-Griffiths 1974, Collinson 1985).

Population estimates and sample counts in Khaudum and eastern Bushmanland are less precise than in Etosha. Game densities in these two areas are less than half the density in Etosha, both areas are unfenced and most species are migratory-nomadic. A greater degree of variation in sequential counts can thus be expected than in Etosha. Severe clumping in the distribution of the major species is the prime reason for lower precision. As both areas are much smaller than Etosha, it would be cost-effective to do a systematic preliminary search immediately prior to a scheduled sample census in order to facilitate stratification. The small number of sightings per species in each area furthermore does not allow accurate determinations of effective strip widths and visibility bias, at present. Stratification to improve sample homogeneity based on reconnaisance flights would reduce sample variance, and 30% sampling intensity versus 15% would do likewise. Rare species will have to be monitored using a mark-resighting method (Collinson 1985).

We have presented in this paper a contribution to the development of inexpensive aerial census methods adequate for monitoring major game populations in three regions in northern Namibia. Frequent monitoring of these populations is essential in view of pressures on populations due to harvesting and changes in land use patterns in northern Namibia.

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