Comparative assessment of fixed wing based aerial wildlife census techniques: A case study of Maswa and Moyowosi Game Reserves, Tanzania.

Kaaya, J. [1]*, B.K. Reilly [2], P. Funston[2] and V. Harley[3]

1. *Wildlife Division, Ministry of Natural Resources and Tourism, P.O. Box 9372 Dar es Salaam, Tanzania.*

2. *Department of Nature Conservation, Tshwane University of Technology, Private Bag X680, Pretoria, 0001, Republic of South Africa.*

3. *Department Biodiversity and Conservation, Cape Peninsula University of Technology P.O. Box 652 Cape Town 8000.*

*corresponding author: kaayaje12@yahoo.com

Abstract: *Effective management and conservation of wildlife populations require reliable estimates of population size, which can be difficult and costly to obtain. This study investigates and discusses the two aerial counting techniques currently used in estimating wildlife populations in Tanzania: Systematic Reconnaissance Flight (SRF) and Aerial Distance Sampling (ADS). We evaluated their precision, perceived accuracy and cost effectiveness. The study further assesses the impact of the sampling designs and intensities on estimates of population parameters. The study reveals that precision in estimates improves with increasing sampling intensity. The SRF has better coefficients of variation (CV) than ADS. Direct cost differences were negligible for any selected area. The analysis of two statistical procedures shows that there were significant differences between the two methods. The selection of appropriate techniques in counting wildlife should therefore depend on the objectives of the survey, the properties of the population to be sampled, the number and type of quantities to be measured, the auxiliary information available, and the limitations of funds, equipment and manpower.*

Keywords: Census, systematic reconnaissance flight, precision, cost effectiveness.

Introduction

Up-to-date information on the size and distribution of animal populations is crucial for conservation and proper management of tropical savanna ecosystems. There is growing recognition among conservation practitioners and scientists that effective protected area management is integrally linked to well designed monitoring and evaluation systems (Margoluis *et al*. 2005). Similarly, effective conservation action depends on practitioners being able to evaluate cost benefits of available conservation strategies and techniques. Such information can be generated rapidly and at acceptable cost through airborne surveys (Norton-Griffiths, 1978; Wint, 1998). Effective management and conservation of wildlife populations requires reliable estimates of population size to monitor the timing, direction and extent of changes in animal abundance so that the underpinning causal processes can reliably be identified, evaluated and understood. Accurate estimation of abundance should thus be an integral and operational component of all effective conservation and management activities to promptly detect and mitigate unacceptable levels of population change. Decision makers require cost-effective estimates of abundance as part of the need to prioritize the investment of finite conservation effort and financial resources (Ogutu *et al*., 2004).

The use of aerial surveys as a tool in the manage ment of large ungulates can be traced back as far as 1935 (Cahalane, 1938; Melton, 1978; Van Lavieren & Esser, 1979; Collinson, 1985; Beasom *et al.*, 1986; Bothma *et al.*, 1992; Eiselen, 1994). On the African continent light aircraft have been used to assess the abundance of wildlife since the mid-1950s. The first attempts aimed at total counts of animals of all species in a particular area. It was not until the mid-1960s that these expensive total counts were gradually replaced by more efficient sampling techniques in east Africa. Because of the vastness and remoteness of many wildlife areas in Africa, aerial counts continue to be an important tool for wildlife management (Jachmann, 2001).

Total counting of large mammals from the air has become a standard practice on smaller provincial reserves and private game ranches in South Africa but has now been replaced by sample counting in places, for example, in the Kruger National Park (Reilly; 2000). Both sampled and total surveys, however, have drawbacks, being of unknown accuracy and relatively expensive, and therefore difficult to adopt for many developing countries like Tanzania. Only in South Africa has the total count been retained as a standard technique, in part due to the small size of properties and their hard boundaries (Caughley & Sinclair 1994, Reilly, 2000).

Several sampling strategies have been used in aerial surveys, but a modification of systematic sampling approach known as SRF (Systematic Reconnaissance Flight) has been adopted by several surveying organizations in east Africa because of its low cost per sampled unit compared to other sampling methods. Furthermore, navigation with SRF is relatively easy and fatigue among the crew is minimized (Norton-Griffiths, 1978). This method is also used to collect spatial and temporal environmental data suitable for explaining the relationship between animals and their environment and for long-term monitoring purposes.

In east Africa several scientists were involved in developing SRF, leading to a wealth of information on the technique and its use (Dasman & Mossman, 1962; Jolly, 1969; Norton-Griffiths, 1978). Elsewhere in Africa, for example in South Africa, the subject has also been well covered by several individuals, (Hirst, 1969; Goodman, 1977; Bothma *et al*., 1992; Eiselen, 1994; Reilly, 2000; Reilly, 2002).

There are many sources of bias in aerial counts, some of which can be mitigated with a proper survey design. Others cannot be remedied, almost always leading to incomplete counts (Khaemba, 2002). In the past, several techniques have been proposed to eliminate biases from aerial counts (Caughley & Goddard, 1972; Caughley *et al.*, 1976; Cook & Jacobson, 1979; Grier *et al.*, 1981; Caughley & Grice, 1982). Unfortunately, many of these proposed techniques are impractical and expensive (Barnes *et al.*, 1986). Generally, detection and counting problems represent the most important source of bias in aerial techniques (Norton-Griffiths, 1978).

The objective of this study was to assess the effectiveness and efficiency of the SRF against the newer ADS techniques ((Buckland *et al.*, 1993) for counting wildlife populations in Tanzania. The comparative evaluation was done using relative precision for each species. Since the actual size of the target wildlife populations are unknown, the assumption was that ADS would provide approximately unbiased estimates of abundance and so these derived estimates obtained from ADS could be used as a benchmark against which the accuracy performance of SRF could be assessed. Even though precision is more important than accuracy in showing population change over time external pressures on conservation agencies in east Africa are demanding more accurate estimates of populations, particularly where quota setting is involved. Also the component of cost involved in executing the two count techniques was assessed. The relatively high cost of game counting has recently resulted in a re-evaluation of the results obtained for the money spent (Reilly & Haskins; 1999).

Materials and methods

Of the surveyed areas (Maswa Game Reserve) encompasses 2,765 km^2 of predominantly *Acacia* spp. open woodland whilst the Moyowosi (12,432 km^2) consists primarily of Miombo woodland (typified by *Julbernardia globiflora, Soberlina tormentosa* and *Brachystegia spp*.) and bushland thickets and scrub (*Combretum, Commiphora* and *Acacia spp*.). The Maswa game reserve is within Serengeti ecosystem which supports the largest herds of migrating ungulates in the world (Sinclair & Arcese, 1995), and Moyowosi is also remarkable known for harbouring large groups of herbivores especially buffalo, topi and bohor reedbuck (TAWIRI, 2000). Several monitoring program has been implemented in these areas including monitoring as a key component of conserving the large mammal diversity of Tanzania as it helps in identifying the nature and extent of population change and hence management interventions. .

Data was collected using a Cessna 206 aircraft at a speed of 220km/hr in both study areas on consecutive days in September 2005. The team consisted of a pilot and a data-capturer, seated next to each other, and an observer sat behind each. Distance markers fixed to the wing struts allowed the observers to allocate each observation to one of four distance intervals, 0-50, 50-100, 100-200 and 200-400 meters on either side of the plane when flying at 250 feet above ground level. A map of each study was overlaid with 25 km^2 grid cells, which were numbered sequentially by rows or columns, to distribute transects over the selected area using systematic random sampling (Cochran, 1977). Each transect was a minimum of 2 km apart and of varying length. Forty-five transects resulting in 40% coverage for Maswa (1215 km), and 78 transects with 38% coverage for Moyowosi (2494 km), were flown. When sighting the animals the observers reported the number and distance category (alfa = 0 – 50m, beta 50 -100m, charlie 100 – 200m and delta 200 – 400m) to the data capturer and the information was entered directly into a laptop computer connected to the aircraft's Global Position System (GPS). The pilot and data capturer assisted the observers with observations directly below the plane.

The SRF counts were conducted from the 14th to 20th of October 2005 using a Maule aircraft at a speed of 210km/hr and a crew of four. Low-level SRF's were conducted according to the methodology described by Norton-Griffiths (1978). Observations were limited to a 150 m strip of land visible between two markers attached to the wing struts on each side of the aircraft at a known distance and height from each of the individual observer's positions. Strip calibration involved flying several passes perpendicularly over an airstrip at known altitude and recording the number of ground markers seen by the two rear seat observers. The nominal flying altitude was 350 ft a.g.l. (actual range approximately 91.4 – 122 meters (200-400 feet), speed of 200 km hr^{-1} (or 120-130 knots).

Data were analysed using DISTANCE version 4 .1 (Laake *et al.* 1993) for the ADS technique. Estimates of herd size (n) and total abundance, standard errors (SE), effective strip width, (ESW) and coefficients of variation (% CV) were generated for buffalo, impala, ostrich, Thomson's gazelle, warthog, and zebra in Maswa Game Reserve as well as bushbuck, reedbuck, topi and warthog for Moyowosi Game Reserve. Species with less than fifty observations were discarded from the analysis due to the minimum sample sizes required in the DISTANCE analysis.

In the SRF, data were analyzed using Herd Count (2000), software developed specifically for SRF surveys at Tanzania Wildlife Research Institute (TAWIRI)[1]. Counts of wildlife and domestic stock made during the survey were extrapolated for the whole census zone using Jolly's method two for unequal sized units (Jolly 1969) as outlined by Norton-Griffiths (1978) including the 95% confidence level (CL) of the estimates. The combined total area of the observation strips flown for all the sampled transects covered only about 15% of the total study area. Geo-referenced data were combined with the GIS database to present estimated densities and distribution of all wildlife, domestic stock and other human activities in 5 km^2 grid squares.

Amount of bias between methods and observers normally varies (Downing, 1980). Although composition surveys are commonly used in wildlife management, their precision is poorly understood. For most surveys to be reliable, relative precision and bias of the techniques must be understood. Comparison of two techniques were therefore made aiming to evaluate the relative precision and bias in estimates of population abundance derived from DISTANCE sampling and systematic reconnaissance surveys

RESULTS AND DISCUSSION

In aerial distance sampling and based on Akaike's Information Criterion (AIC) and likelihood ratio tests the hazard rate key function without adjustment terms was selected as the best approximating model for the detection functions for buffalo, zebra and ostrich, whilst the negative exponential was the best model fit for impala (*Aepyceros melampus*), Thomson's gazelle (*Gazella thomsonii*) and warthog (*Phacocoerus aethiopicus*) in the Maswa Game Reserve survey (Table 1). In Moyowosi Game Reserve, the best approximating model for bushbuck and warthog was again the hazard rate whilst the negative exponential key function best approximated data for topi (*Damaliscus lunatus*) and reedbuck (*Redunca redunca*) (Table 2).

Plots of detection functions fitted to frequency histograms of distance data showed that in all cases detections declined rapidly with increasing distance. For all ten species, precision in estimates increased markedly and consistently with increasing sample size, as expected, but at rates that differed between species.

. The comparison of the two techniques results in 2004 and 2005 respectively involved six animal species. The counts were all done in the same area in the same season but with a one year time interval. Thus, we expect that the bias was not entirely constant, and therefore one should be cautious when using these results. The median coefficient of variation (CV) for selected species on a reserve was used to gauge the techniques relative precision. This was similar to work conducted by Harley (2006) in protected areas of the North West Province, South Africa.

The ADS has a higher median CV than the SRF under the same conditions. For example, with buffalo the CV was more than twice as much (42%) in the ADS when compared to SRF (16%) in the same area (Table 4). The CV in this case implies a best minimum estimate of a techniques ability to show change in the population (Ogutu,2004) Coefficients of Variation that exceed the desired magnitude of population change to be detected indicate that the source of change is unknown and could be either population change (real change) or within technique variation. Conversely low CV's that are smaller than the magnitude of population change to be detected have a high probability of reflecting real change.

The analysis of six species suggests that precision is correlated to sampling intensity. We thus concur with Ogutu *et al.* (2003) in Mara reserve, Kenya where high sampling intensity led to improved precision in counts of ungulate species. This is also borne out by findings from the Kruger National Park (Kruger *et al. in prep).* As with all sampling the increase in intensity will lead to an improvement in precision up to a point and undoubtedly if the ADS sampling is increased it may eventually approach or surpass that of SRF. Motivation for the increase in effort, hence cost, lies with being able to reduce the confidence limits around the estimate. This may be explained by the fact that in the SRF the observer is restricted to a narrow strip during counting, while in the ADS there is a wider strip to be covered. Theoreticaly the narrow strip counted in the SRF under the assumption of detection of all animals within the strip should have lower precision than ADS where this assumption is held only for the line of movement. Another study conducted in similar habitat pointed out undercount as a major problem in aerial counts (Jachmann, 2002). Because our counts were conducted in open woodland savanna, and because bias varies by habitat type, aerial counts done in wide-open terrain may generate estimates that are potentially more accurate.

Recent surveys conducted in Kruger National Park (KNP) shows median CV's of 14% which is lower than results obtained in Maswa game reserve. This may be attributed to the type of aircraft used in KNP (Partenavia - Observer) being slower with more maneuverability as opposed to the Cessna 182 used in this study. High running costs have however, forced KNP to return to the single engined option. The differences in the results from two counts held in Kruger and Maswa may call for need to revisit the type of aircraft to be used in aerial distance sampling in Tanzania (Reilly *pers.comm*). The Partenavia seems to have better results than Cessna 182 which is commonly used in Tanzania.

The total cost of implementing both methods was US$ 4600 ($2 per km of transect), and was distributed such that fuel costs accounted for US$ 2400 (52%), consumables US$ 200 (4%), food and accommodation for US$ 2000 (44%). The costs of the methods were very similar contrary to many perceptions. This is similar to Reilly & Haskins (1999) count conducted in Suikerbosrand Nature Reserve, where two methods yielded the same result and concluded that monitoring techniques should be chosen according to the goal to be measured.

Generally the evaluation of the accuracy performance of distance and systematic sampling theory would require information on the actual numbers or objectives present in an area (White *et al.*, 1989; Otto & Pollock, 1990; Anderson & Southwell, 1995). It is therefore difficult to compare estimates of abundance directly and hence accuracy between techniques if the numbers of animals present are not actually known. Precision may be increased by increasing sample size, improving sample tally and by rigid standardization of sampling method (Eberhardt 1978; Krebs 1989; Caughley & Sinclair 1994). The findings are concurrent with other studies conducted in Kenya (Ojwang, 2000; Ogutu 2003) where results from validation of three counting techniques shows that increase of sampling intensity leads to improvement in precision.

The diversity and mobility of animals and observer bias results in these surveys tending to be inaccurate and sometimes unreliable (Caughley, 1974; Smith, 1981). A rigorous analysis of such inaccuracies using field tests is not possible because the sampling methods used are also subject to similar biases. This leaves simulation as a viable option to investigate and validate different sampling techniques used in aerial surveys of wildlife (Khaemba, 2000). Simulation allows the study of systems that are expensive, difficult or impossible to observe in the field (Robinson, 1994). It also allows replication where only single surveys have been possible, thereby giving the investigator more control when considering different scenarios. A systematic reconnaissance flight has been adopted as a sampling design for most surveys in the tropics because of its low cost per sampled unit (Norton – Griffiths, 1978; Ottichilo, 2000). Common sampling intensities lie between 3% for a low – resolution survey and 15% for a high – resolution survey. Aerial distance sampling in the Kruger National Park varies in sampling intensity between 12 and 27% (Reilly *pers comm.*[2]). The results of this study reveal that the median CV's were 31% for ADS and 20% for SRF (Figure 2).

Only a few cases have been documented where the estimate of an aerial count was compared with a control estimate obtained by an assumedly more accurate method. In nearly all cases, aerial counts produced underestimates. For example, only 29% of a black rhino (*Diceros bicornis*) population, of which numbers were known exactly, was counted from the air (Goddard 1967). An aerial count of eight African large herbivore species returned only 23% of known numbers (Spinage *et al*. 1972). Aerial counts of non-African game returned similar results, such as 47% for brown bear *Ursus arctos* (Erickson & Siniff 1963), 57% for red kangaroo *Megaleia rufa* (Bailey 1971) and 56% for Indian rhino *Rhinoceros unicornis* (Caughley 1969). Only one case documents aerial total counts of elephants exceeding ground counts in four out of six occasions (Eltringham 1972).

The results also reveal that population estimates were higher in all cases for ADS than SRF. Although SRF seems to be favoured in terms of CV (precision) it restricts the counting in a manner that animals observed outside sampling units during the survey are not counted. Although this gives unbiased estimates, it is a waste of potential sampled information (Khaemba 2000). Assuming random distribution in the same area and all other factors constant a significant difference between the two count techniques is evident ($H = 3.1$; $df = 1$; $p > 0.001$).

Cost effectiveness

Clearly the value of wildlife has to enter into determination of monitoring efficiency, effectiveness and budgeted cost (Reilly & Reilly; 2003). Wildlife monitoring actions are derived from objectives and operational goals within a decision support framework or management plan (Harley; 2006). These monitoring actions must be designed and developed with consideration for (a) ecological limits of the operation, (b) available funding, (c) audit requirements and (d) statistical power of the monitoring action (Reilly 2000; Reilly & Reilly 2003)

Following the issue of cost, the two surveys cost nearly the same amount of money. The time spent for actual counting was not differing and one may therefore assume that given a target goal, similar sampling intensity and even parameters the two counting techniques can have the same budget. (Reilly,1999) observed that the cost of methods are very similar and a strong demonstrations has been made that monitoring techniques should be chosen according to the goal to be measured and thereafter experimentally tested in their ability to show real change, thus avoiding decision making based on Type 1 and Type 11 errors. With an increasing number of counting techniques that can be applied in a given situation, protected areas managers must weigh the advantages and disadvantages of adopting one procedures over another, with consideration such economies in mind.

The variation on CV and population estimates for the two techniques, suggests that distance sampling is not ideal for estimating abundance of browsers or small cryptic species (Reilly, 2000). This can be explained in relation of type of aircraft used in data collection. We used Cessna 182 and 206 which have high speed of 200km from ground (60km/hr). With speeds of > 100 knots, it is not always easy to determine when animals are perpendicular to the aircraft which is also results in errors when assigning groups of animals to different distance intervals (Jachmann 2001). Distance requires slow aircraft which can maneuver. For example the aerial count in Madikwe game reserve in South Africa showed that count with a Cessna 182 recorded 36.3% of known numbers while those completed using a Partenavia returned 45.3% (Reilly, 2003). Thus, counting inanimate objects from a slow and low flying aircraft like a helicopter that is easy to maneuver in different habitat cannot be compared with counting animals that are always on the move, from an aircraft that flies at 60km/hr and cannot be maneuvered to search the strip beneath. Therefore the use of a helicopter is a pre-requisite for obtaining accurate estimates, although the cost of helicopter is roughly five to six times more expensive than cost of normal fixed wing aircraft (Jachmann, 2000) which is a handicap for many developing countries. Another study conducted by using helicopters in estimating kangaroo (Pople et al., 1998) revealed that an obvious shortcoming of helicopter surveys been the cost which prohibits their use across large areas. They are approximately three times the cost per kilometre of a fixed-wing aircraft.. Ultralight aircraft offer a cheaper alternative capable of similar accuracy to helicopters (Grigg *et al.* 1997).

Similarly the Systematic sampling method which used Jolly's 2 has criticism of giving large standard errors due to differences in the size of sample units and observed counts in species with large group sizes and therefore an uneven distribution. Systematic reconnaissance flight underestimate the population but have small coefficient variance while aerial distance sampling overestimate but have large coefficient variance. Under such circumstances one may argue that biologically underestimate might be better than over estimate. In Tanzania for example, in allocating quota of various species, the technique which gave the overestimation may mislead the managers by allowing them to harvest more animals than the actual population.

There will be a need to strike a balance between reliable (high precision) information and cost benefits (Ojwang, 2000). Total costs of surveys depend on many factors-such as salaries of pilots and observers, aircraft operating costs, proportion of area sampled, time spent in training observers, and the cost of ground support and the transport of fuel. Typical costs in Kenya, for instance, a sample survey covering 5 to 10% of a rangeland area, fall in the range of US$1 to 3 per km^2 of total area under investigation. The largest cost component is usually salaries, especially when allowance is made for data processing and report writing: aircraft hire costs are secondary.

Conclusion

Our work shows that we cannot reliably compare the accuracy of the two techniques because we don't know the number of animals but precision shows that there is some potential in knowing each technique in certain circumstances. Despite the precautions stated before, our results should be treated only as speculative, as they involve censuses carried out in two geographical area at different years, and involve techniques that have inherent measurement error. There is a need therefore for confirmatory studies where surveys are made on populations of known size or where several surveys methods are compared on the same population (Focardi *et al*., 2002). Nevertheless, they do provide a worthwhile comparison of the two counting techniques, which are used in assessing mammal populations in Tanzania at the present time. As with any other research tool, the future use of any aerial survey will depend not only on its value in terms of accuracy and precision, but also on its costs and benefits in relation to stated objectives and to the relative merits of alternative techniques.

The results revealed that the two techniques are significantly different in most cases. This implies that no method is generally superior. A method may perform well in certain situations but poorer under other circumstances. In most cases the technique with the least (cost) X (variance) product is the technique that offers optimal efficacy. There is a general aim to maximize precision and accuracy in wildlife ecology but often a trade-off needs to be made between accuracy and precision to answer a particular question (Caughley and Sinclair 1994).

This study therefore shows that the commonly method used in Tanzania, the systematic reconnaissance flight is still a valid technique but this is not conclusive. It would be imprudent to rely on this technique for the time being as the other technique execution calls for more cost especially the reason to use helicopter which is expensive and therefore unaffordable to many African countries.

It is concluded that distance method have potential to be suitable for estimating the density of large mammals in various ecosystem ranging from open savanna to closed miombo woodland. However, some authors elsewhere recommended this method sometimes to be supplemented by other sampling approaches, such as systematic reconnaissance flight, total count, to efficiently estimate the full spectrum of densities typical of rare, highly clustered, or multi-species assemblage of African savanna mammal (Ogutu, 2004). It was recommended elsewhere that distance sampling from air should be done with a helicopter or a slow and low flying micro light plane. Several surveys although costly may improve the detection of change and can increase the precision and accuracy of survey (Harley, 2006).

In overall, the study revealed that the two techniques are different in sampling animal distribution, the cost of executing each method are almost the same, increase of sampling intensity provides high population estimates, systematic sampling has relative low coefficient variance than distance sampling and therefore selection of appropriate technique in counting wildlife should depend on the objectives of the survey, the properties of the population to be sampled, the number and type of quantities to be measured, the auxiliary information available, and the limitations of funds, equipment and manpower.

REFERENCES

Bailey, P.T. (1971) The red kangaroo, *Megaleia rufa* (Desmarest), in northwestern New South Wales. CSIRO Wildlife Research, 16, 11–28.

Bothma, J Du P., Peel, M.J.S., Pettit, S. & Grossman, D. (1992). Evaluating the accuracy of some commonly used game- counting method. S. Afr. J. Wild. Res. 20(1): 26-32.

Buckland, S.T., Anderson, D.R., Burnham, K.P. & Laake, J.L. (1993). 'DISTANCE SAMPLNG' – Estimating abundance of biological populations. Chapman & Hall, London.

Cahalane, V.H. (1938). The annual north Yellowstone elk herd count. Trans. North Am. Wildl. Conf. 3: 388-389.

Caughley, G. and Sinclair, A.R.E. (1994). Wildlife Ecology and Management. Blackwell Science: Cambridge.

Cochran, W.G. (1977). Sampling Techniques, 3rd edition. John Wiley and Sons: New York.

Collinson, R.H.F. (1985). Selecting wildlife census techniques. Monogr. 6, Inst. Of Nat. Res., University of Natal, Pietermaritzburg.

Downing, R.L (1980). *Vital statistics of animal population. Wild. Manage.techniques manual*. The wildlife society, Washington, D.C.

Eiselen, R . (1994). Estimating the trends in herbivore numbers in the southern district of the Kruger National Park. S. Afr. J. Wildl. Res. 24(4): 95-100.

Grigg, G.C., Pople, A.R. and Beard, L.A. (1997). Application of an ultralight aircraft to aerial survey of kangaroos on grazing properties. Wildl. Res. 24: 359-72.

Harley, V. (2006). *An Optimized monitoring programme for Ungulate numbers in the North West Parks, South Africa*. MSC Thesis. Tshwane University of Technology, Pretoria, South Africa.

Jachmann, H. (2001). Zambian's Wildlife Resources: A Brief Ecology. Wildlife Resources Monitoring Unit Handbook No.2, Environmental Council of Zambia, Lusaka, Zambia

Jachmann, H. (2002). Comparison of aerial counts with ground counts for large African herbivores. J. Appl. Ecol. 39(5): 841-852.

Jolly, G.M (1969a). Sampling methods for aerial censuses of wildlife populations. E. Afr. Agric. and For. J. 34: 46-49.

Khaemba, W.M (2000). *Development and application of Spatial and temporal statistical methods for improved sampling of wildlife*. PHD Thesis. International Institute of Aerospace surveys and earth sciences, Enschede, the Nertherlands.

Khaemba, W.M, Stein, A., Rasch, D. (2000). An empirically simulated investigation and validation of aerial wildlife sampling methods. Afr. J. Ecol.

Khaemba, W.M. & Stein, A. 2002. Improved sampling of wildlife populations using airborne surveys. Wildl. Res. 29: 269 – 275.

Krebs C.J. (1989). *Ecological Methodology*. Harper Collins, New York.

Melton, D.A. (1978). Undercounting bias of helicopter census in Umfolozi Game Reserve. Lammergeyer 26: 1-6.

Norton-Griffiths, M. (1978). *Counting animals. Handbooks on Techniques currently used in African Wildlife Ecology, No. 1*. Nairobi: African Wildlife Leadership Foundation.

Pople, A.R., Cairns, S.C., Clancy, T.F.. Grigg, G.C., Beard, L.A. and Southwell, C.J. (1998). An assessment of the accuracy of kangaroo surveys using fixed-wing aircraft. Rangel. J. 20(1): 92-103

Ogutu, J.O., Bhola, N., Reid, R.S.,Piepho, H (2004). *Efficiency, bias and cost- effectiveness of strip and line transect survey of African savannah mammals*. International livestock Research Institute. Arusha, Tanzania.

Ojwang, G.O. (2000). *On sampling variability of wildlife cropping-quota allocated on the basis of airborne sample surveys. MSC Thesis. International Institute of Aerospace surveys and earth sciences*, Enschede, the Nertherlands.

Reilly, B.K. (2000). *The statistics of helicopter total counts of large ungulates in sourish mixed bushveld, northwest arid bushveld and mopane veld, Republic of South Africa*. PhD Thesis. University of Stellenbosch, Stellenbosch

Reilly, B.K. & Reilly, Y. (2003). Auditing wildlife. Koedoe, 46(2): 97-102

Reilly, B.K. & Haskins, C.I. (1999). Comparative efficiency of two game counting techniques as applied to Suikerbosrand Nature Reserve. *S.Afr.J Wildl.Res*. 29(3): 89-97

Robinson, S (1994). *Successful simulation: A practical approach to simulation projects.* McGraw-Hill Book Company, London, 246pp.

TAWIRI (2000). Aerial census in the Moyowosi-Kigosi Game Reserves, Dry Season 2000. TAWIRI Aerial Survey Report, Arusha

White, G.C., Bartmann, R. M., Carpenter, L.H., & Garrot, R.A. (1989). Evaluation of aerial line transects for estimating mule deer densities. J. Wildl. Manage. 53: 625-635.

Table 1: Wildlife population estimates for Aerial Distance Sampling (ADS) in Maswa game reserve, September 2004.

Species	Estimate	Variance	SE	CV (%)
Buffalo	8,147	11,573,604	3,402	42
Ostrich	2,571	1,034,289	1,017	40
T. Gazelle	19,326	24,890,121	4,989	26
Zebra	31,437	80,856,064	8,992	29
Warthog	4,930	1,447,209	1,203	24
Impala	36,818	151,486,864	12,308	33

Table 2: Wildlife population estimates for Aerial Distance Sampling (ADS) in Moyowosi game reserve, September 2004.

Species	Estimate	Variance	SE	CV (%)
Bushbuck	5,581	1,240,996	1,114	20
Topi	32,882	65,141,041	8,071	25
Reedbuck	28,705	15,413,476	3,926	14
Warthog	3,308	652,864	808	24

Table 3: Wildlife population estimates for Systematic Reconnaissance Flight (SRF) in Maswa game reserve, October 2005.

Species	Estimate	LCL	UCL	SE
Bushbuck	80	34	126	46
Buffalo	20876	17638	24114	3238
Baboon	1111	828	1394	283
Duiker	40	22	58	18
Eland	247	112	382	135
Elephant	1031	498	1564	533
Grants Gazelle	73	37	109	36
Greater Kudu	53	8	98	45
Giraffe	482	327	637	155
Impala	4291	3513	5069	778
Kongoni	502	255	749	247
Ostrich	803	654	952	149
Reedbuck	60	28	92	32
Roan Antelope	180	72	288	108
Topi	395	212	578	183
Vervet Monkey	20	6	34	14
Waterbuck	508	309	707	199
Warthog	582	462	702	120
Zebra	4385	3444	5326	941

Table 4: Comparative results of Aerial Distance Sampling (ADS) and Systematic Recconaissance Flights (SRF) in Maswa between September 2004 and October 2005

	ADS			SRF		
Species	**Estimate**	**SE**	**CV (%)**	**Estimate**	**SE**	**CV (%)**
Buffalo	8147	3402	42	20876	3238	16
Ostrich	2571	1017	40	803	149	19
T.gazelle	19326	4989	26	4720	1126	24
Zebra	31437	8992	29	4385	941	21
Warthog	4930	1203	24	582	120	21
Impala	36818	12308	33	4291	771	18