
Participatory wildlife surveys in communal lands: a case study from Simanjiro, Tanzania

Fortunata U. Msoffe^{1,2,3}, Joseph O. Ogutu¹, John Kaaya⁴, Claire Bedelian¹, Mohammed Y. Said¹, Shem C. Kifugo¹, Robin S. Reid⁵, Moses Neselle¹, Paul van Gardingen² and Simon Thirgood^{6*}

¹International Livestock Research Institute, PO Box 30709, 00100 Nairobi, Kenya; ²Centre for the Study of Environmental Change and Sustainability, University of Edinburgh, Edinburgh EH9 3JN, U.K.; ³Tanzania National Parks, PO Box 3134, Arusha, Tanzania; ⁴Tanzania Wildlife Research Institute, PO Box 661, Arusha, Tanzania; ⁵Center for Collaborative Conservation, Colorado State University, Fort Collins, CO 80523, U.S.A. and ⁶Aberdeen Centre for Environmental Sustainability, Macaulay Institute, Craigiebuckler, Aberdeen AB15 8QH, U.K.

Abstract

It is widely accepted that protected areas alone are not sufficient to conserve wildlife populations particularly for migratory or wide-ranging species. In this study, we assess the population density of migratory species in the Tarangire–Simanjiro Ecosystem by conducting a ground census using DISTANCE sampling. We focus on the Simanjiro Plains which are used as a dispersal area by wildebeest (*Connochaetes taurinus*) and zebra (*Equus burchellii*). We demonstrate that DISTANCE sampling can provide precise estimates of population density and is an affordable method for monitoring wildlife populations over time. We stress the importance of involving local communities in monitoring programmes across landscapes that incorporate communal lands as well as protected areas.

Key words: CBNRM, census, DISTANCE, migration, rangeland, ungulate

Résumé

On reconnaît généralement que les aires protégées ne suffisent pas, seules, à préserver les populations de faune sauvage, particulièrement celles d'espèces migratrices ou très largement distribuées. Dans cette étude, nous évaluons la densité de population d'espèces migratrices de l'Ecosystème Tarangire-Simanjiro en réalisant un recensement au sol recourant à l'échantillonnage par distance. Nous nous concentrons sur les plaines de Simanjiro qui sont utilisées comme aire de dispersion des gnous *Connochaetes taurinus* et des zèbres *Equus burchellii*. Nous montrons que

l'échantillonnage par distance peut donner des estimations précises de la densité d'une population et que c'est une méthode accessible pour suivre des populations sauvages dans le temps. Nous soulignons l'importance d'impliquer les communautés locales dans les programmes de suivi, dans des paysages qui intègrent des terres publiques aussi bien que des aires protégées.

Introduction

There is a growing need for reliable monitoring of wildlife populations in the communal lands of Africa (Gaidet *et al.*, 2005). Monitoring is a crucial source of information for determining conservation priorities and evaluating ecosystem responses to management activities particularly in areas where wildlife is not formally protected (Georgiadis, Hack & Turpin, 2003; Waltert *et al.*, 2006). Management can be more effective if based on a sound understanding of ecological processes including migratory movements and wildlife harvesting (Fryxell & Sinclair, 1988; Msoffe *et al.*, 2007). Reliable estimation of population size represents an essential first step in monitoring the consequences of management activities.

Despite the fact that wildlife populations occur seasonally on communal lands adjacent to protected areas, most wildlife monitoring programmes are conducted only in the protected areas (Nelson, 2007). These communal lands are important for conservation as they provide seasonal foraging and calving areas for many species. The long-term conservation of these areas requires the participation of local communities in management. One way to ensure that communities are actively involved in conservation is

*Correspondence: E-mail: s.thirgood@macaulay.ac.uk

to engage them in monitoring and resource protection activities so that they can generate benefits from having wildlife on their land (Gross, 2007). Long-term monitoring of wildlife populations require precise and unbiased methods for estimating population size and related parameters so that temporal changes in these population characteristics can be reliably established.

In common with other communal land in Africa, the Maasai Steppe in Tanzania is threatened by anthropogenic factors affecting all aspects of biodiversity from species to communities (Borner, 1985; Mwalyosi, 1991). Within the Maasai Steppe, the Tarangire-Simanjiro Ecosystem (TSE) is one of the most species-rich wildlife areas in Tanzania and is also an important tourism destination (Prins, 1987). The TSE incorporates a number of protected and unprotected areas subject to different forms of natural resource use. At the heart of the ecosystem is the Tarangire National Park (TNP), which contains the only perennial source of water in the dry season. This coincides with the time of year when majority of large mammals, including the migratory herbivores, congregate along the Tarangire River (Lamprey, 1963). At the onset of the rains, these animals disperse north and east away from TNP into the surrounding ecosystem (Lamprey, 1964). The factors driving these migrations are not fully understood but likely include mineral nutrition and the availability of green forage and surface water (Kahurananga & Silkilwasha, 1997; Gereta *et al.*, 2004). Once outside the TNP, the migrants occupy unprotected areas where they come in contact with people, livestock and farming (Borner, 1985; TAWIRI, 2001).

Large mammal censuses in Tanzania are usually conducted using aerial surveys, typically using the Systematic Reconnaissance Flight (SRF) technique (Norton-Griffiths, 1978). Population estimates from SRF surveys may have large confidence limits making it difficult to ascertain population trends (TAWIRI, 2001). Moreover, only four aerial surveys have been conducted in the TSE during the wet season in the past 25 years. These aerial surveys were conducted as components of donor-funded projects. Without such external funding it is unusual for the Tanzania Wildlife Division (WD) to conduct aerial surveys incorporating communal lands because of the high costs involved. However, in each year, hunting quotas are set in the TSE and elsewhere in Tanzania. Setting hunting quotas without reliable information on population trends can endanger population viability especially if the species concerned is already threatened by illegal hunting (Msoffe *et al.*, 2007).

Given the limitations of aerial survey, it is important to test alternative approaches for conducting wildlife censuses in the communal lands of Africa. One approach that is becoming increasingly popular for counting wildlife distributed across large areas is ground-based DISTANCE sampling (Buckland *et al.*, 2001). Here, we test the reliability of ground-based DISTANCE sampling for counting large mammals in the TSE. The objectives of the study were threefold: (i) develop and test a survey method that can be used to monitor wildlife populations outside protected areas; (ii) obtain baseline estimates of wet season density for migratory species and livestock in the TSE and (iii) compare the costs and logistics of ground-based DISTANCE sampling with aerial survey.

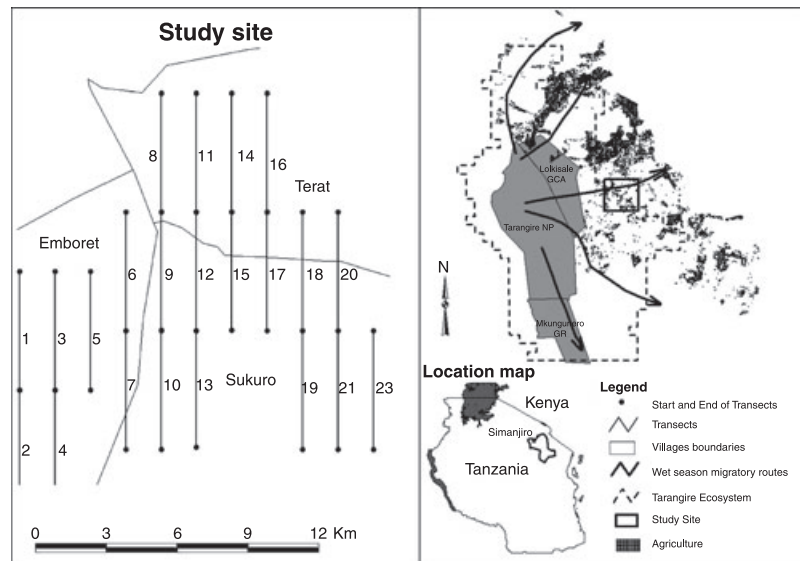
Methods

The study was conducted on the Simanjiro Plains in the TSE in Tanzania (Fig. 1). We focused on a 589 km² area located 40 km east of the TNP, which constitutes one of the wet season dispersal areas for migratory wildebeest and zebra. We used DISTANCE sampling from ground surveys to count wildlife, livestock and people during the 2007 wet season (28 April to 12 May 2007). A team of 18 counters, comprising the team leader, six experienced counters, two district officials and eight community members, supported by one driver, conducted the counts based on the theory, assumptions and design considerations in Buckland *et al.* (2001).

The survey team was trained for 5 days on DISTANCE sampling methodology. Training focused on ensuring the following assumptions would be met: (i) objects on the centre of the line are detected with certainty so that the detection probability on the line is 1, i.e. $g(0) = 1$; (ii) objects do not move towards or away from the transect line in response to the observer before distances are measured and (iii) distances from the centre line to each object are measured accurately. Training also covered the use of maps, geographical positioning system (GPS), laser range finders, binoculars and data sheets.

The team was divided into five groups for the survey with each group comprising an observer, navigator and recorder. Each group had at least one community member and one experienced counter. The survey lasted for 10 days (3–12 May 2007) and covered a total of 50 transects (25 transects each sampled twice) each of 5 km length. Transects were oriented north–south, following grid lines on 1 : 50,000 topographic maps and spaced a

Fig 1 Map showing the location of the Tarangire-Simanjiro Ecosystem in Tanzania and line transect layout in Terat, Emboret and Sukuro villages of the Simanjiro Plains



minimum of 1.5 km apart to minimize the probability of overlapping counts between transects, based on preliminary surveys (Fig. 1). The minimum separation distance of 1.5 km between transects ensured that the range finder, which was accurate to 1 km from the transect centre line, recorded distances to groups of animals along the target transect and enabled comprehensive coverage of either side of the transect.

The survey employed walked line transects following Buckland *et al.* (2001). Each group was given a map of the area with transects marked with GPS coordinates and overlaid with landmarks such as roads, village boundaries and habitat types. Each team used a GPS to navigate. The observer and recorder noted the date and time, sighting angles (using the GPS compass), sighting distance (using the laser range finder) and habitat characteristics of all observations of wildlife, livestock and people. Binoculars were used to assist in species identification. The counts started at ~07.00 hours with each transect requiring 3 h to complete and each team sampling one transect per day.

DISTANCE v5.3 (Thomas *et al.*, 2006) was used to model detection functions and calculate estimates of density. Sighting distances and angles were transformed to perpendicular distances to the geometric centres of groups prior to analysis using the trigonometric relation: Perpendicular distance = $x \sin(\theta)$ with x = sighting distance (in meter) and θ = sighting angle (in degrees). The perpendicular distances were right truncated at 600 m for wildebeest, zebra and cattle, 500 m for people and 400 m

for Grant's gazelle (*Gazella granti*). We plotted frequency histograms of perpendicular distances for each species and fitted models to the histogram based on the key function and series expansion approach in Buckland *et al.* (2001). The models, including the uniform, half-normal and hazard rate key functions and associated series adjustments were fitted to the data for all species. Information-theoretic model selection, in particular the corrected Akaike information criterion (AICc), was used to select the detection function model with the best support in the data. The goodness-of-fit of the AICc-selected model was then assessed using chi-square and Cramer von Misses tests and special attention paid to model fit close to the transect line, where a goodness-of-fit test is crucial (Buckland *et al.*, 2001). Model selection revealed that models allowing for observers as covariates had less support than models excluding observers.

We estimated the group size, encounter rate, density and numerical abundance and the coefficients of variation for each species using DISTANCE v5.3. We regressed the logarithm of cluster size against the detection probability to correct for size-bias in cluster size as a function of sightability and adjusted the expected cluster size for sightability if the slope of the regression was significant at 0.15 (Buckland *et al.*, 2001). We examined the percentage contribution of variation in each of the three components of density (group size, encounter rate and detection function) to establish factors influencing the precision of the estimated population abundance (Ogutu *et al.*, 2006).

Transects were counted twice thus the estimated density was halved (Thomas *et al.*, 2006).

Results

Survey implementation

The survey covered 589 km² and the distance walked on transects was 250 km. The time taken on transects was 150 h with an additional 40 h required for the initial period of training. These distances and times do not include the distance and time spent travelling from the field camp to the transects. The cost of implementing the survey (15 days including 5 days for training and 10 days of counting for a team of 18 people) was USD 10,000 or USD 40 km⁻¹. The costs were distributed as follows: salaries and per-diems for participants USD 4500; food and accommodation USD 3600; vehicle hire and fuel USD 1350; vehicle maintenance USD 150; GPS and range-finder batteries USD 200; and other field equipment USD 200.

The cost of the current ground survey can be compared to the cost of aerial surveys in Tanzania. SRF surveys using a Cessna 182 fixed-wing aircraft cost USD 11 km⁻¹ inclusive of all aircraft and staff costs (Honoré Maliti, pers. comm.). Aerial surveys are typically flown over large areas and costs are therefore not strictly comparable to the current ground survey. DISTANCE sampling techniques can also be applied over smaller areas using helicopters but the costs of such surveys average USD 70 km⁻¹, and are higher than the costs for fixed-wing aircraft surveys (Jachmann, 2002).

Density estimates

Twenty species were observed during the survey but only five were sufficiently abundant to estimate using DISTANCE. The five most abundant species were wildebeest, gazelle, zebra, cattle and people. Based on AICc and the chi-square goodness-of-fit tests, the half-normal key function with one cosine adjustment term was selected as the best approximate model for the detection functions for wildebeest, zebra and people. The uniform key function with one cosine adjustment term was selected as the best model for gazelle and cattle. The uniform key function without any series expansion was used with the wildebeest data and the same right-truncation distance of 600 m as used for the line transect to obtain a strip-transect estimate of wildebeest density for comparison with the line-transect method (Table 1). Precision in line-transect estimates of abundance is influenced by the variance in group size, encounter rate of groups and the effective strip width (Ogutu *et al.*, 2006). Plots of theoretical detection functions fitted to the observed frequency histograms of perpendicular distances showed that the probability of detection declined rapidly with increasing distance from the transect line at around 100–150 m (Fig. 2a–e).

Table 2 presents the results of estimates of abundance for the five species from DISTANCE and compares precisions of line-transect and strip-transect estimates of wildebeest density. Although abundance and density estimates for wildebeest were larger under the strip-transect than the line-transect method, estimates for the latter method were more precise (compare D-CI and D-CV in Table 2). The

Table 1 The selected key functions and series expansions (model) for the detection function based on AICc values for each of the five species analysed by program DISTANCE

Key	Series expansion	Wildebeest	Grant's gazelle	Zebra	Cattle	People	Wildebeest ^a
Uniform	Cosine	2,499.36	729.51	536.75	444.38	839.28	2,584.36
	S-poly	2,499.36	729.51	****	445.24	****	
	H-poly	****	****	536.89	446.99	****	
Half-normal	Cosine	2,498.86	729.68	536.15	444.43	837.65	
	S-poly	2,498.88	729.68	536.15	444.43	****	
	H-poly	2,498.88	****	****	444.43	****	
Hazard-rate	Cosine	2,500.80	****	****	447.21	****	
	S-poly	2,500.80	****	****	****	****	
	H-poly	2,500.80	****	****	****	****	

S-poly means simple polynomial while H-poly means hermite polynomial; **** means the likelihood optimization algorithm failed to converge to an optimal value hence parameter estimates of models and fit statistics could not be computed.

^aThe same data for wildebeest collected using line-transect was re-analyzed here using strip-transect method for comparison.

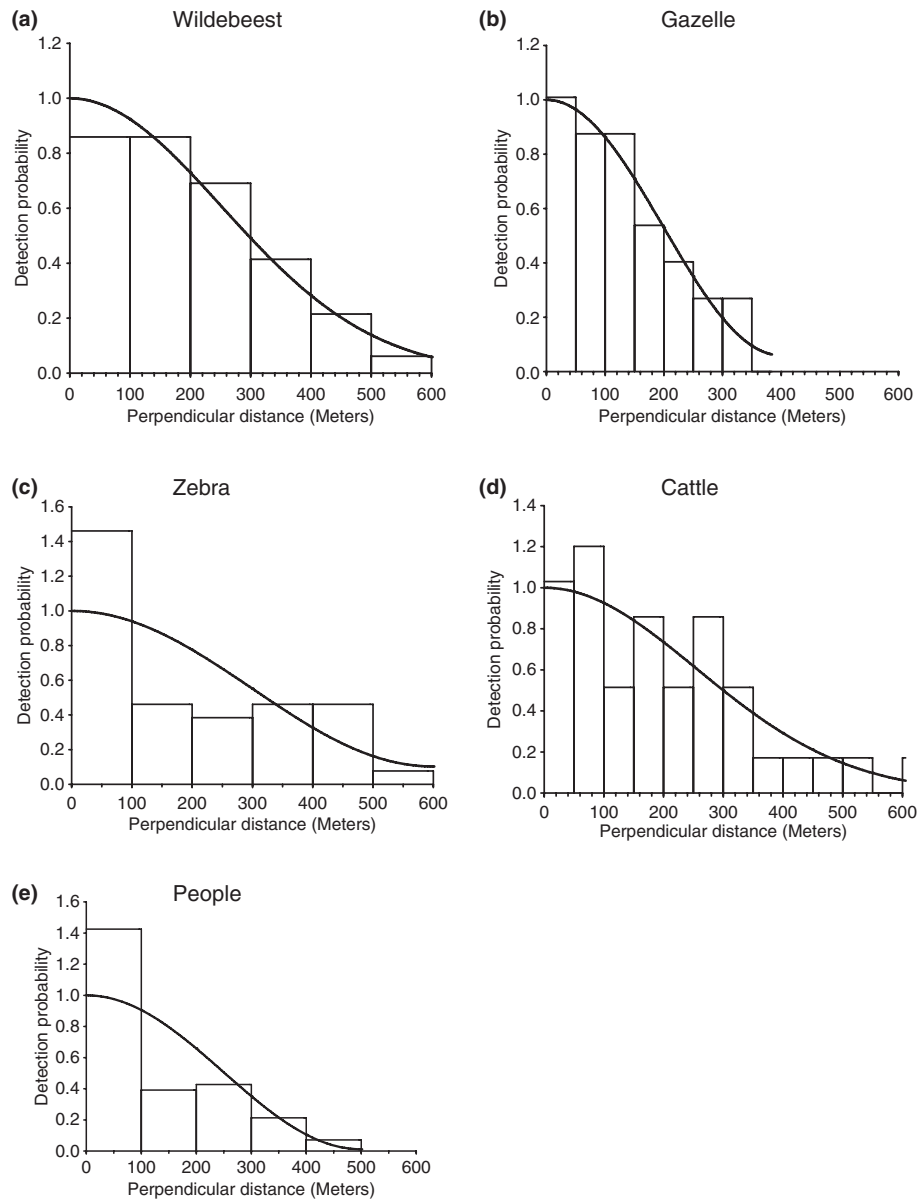


Fig 2 The observed frequency distributions of perpendicular distances (in meters) and fitted detection probability for wildebeest, gazelle, zebra, cattle and people

strip-transect estimate of density was based on a strip half-width of 600 m, whereas the line-transect estimate was based on an effective strip half-width of 310 m, resulting in more groups being included in the strip-transect than the line-transect analysis. This could partly account for the slight upward bias in the estimated strip-transect density relative to the line-transect density. The mean group sizes were the largest for cattle and wildebeest followed by zebra,

gazelle and people (Fig. 3a–e). Conversely, the encounter rates were higher for cattle, followed by zebra, people, gazelle and wildebeest. Variance in encounter rates made a greater contribution to variance in the estimated density for all species but wildebeest. Variance in group size made the next highest contribution to the variance in density whereas variation in the detection probability made the least contribution (Table 3).

Table 2 The observed number of clusters (*n*), estimated density (\hat{D}) and abundance (\hat{N}) and the 95% confidence limits (D-CI) and percent coefficient of variation (% CV) for people, cattle and the three-common species of wildlife counted in the Simanjiro plains from 3 to 12 May 2007

Species	Observations (<i>n</i>)	Density (\hat{D})	Abundance (\hat{N})	D-CI (95%)	% CV	Cluster size (<i>E</i> _s)	ESW
Wildebeest	202	9.4	5531.9	5.8–15.3	20	14.5	310.1
Grant's gazelle	63	2.0	1177.0	1.4–3.0	20	6.9	211.9
Zebra	43	1.7	1000.5	0.9–3.2	30	12.9	324.1
Cattle	36	16.9	9945.7	9.6–29.7	30	145.1	309.1
People	71	0.8	470.8	0.5–1.4	30	2.5	222.9
Wildebeest	202	10.7	6297.0	5.8–19.7	30	31.8	600.0

ESW is the estimated strip half-width on either side of the transect centreline in metres.

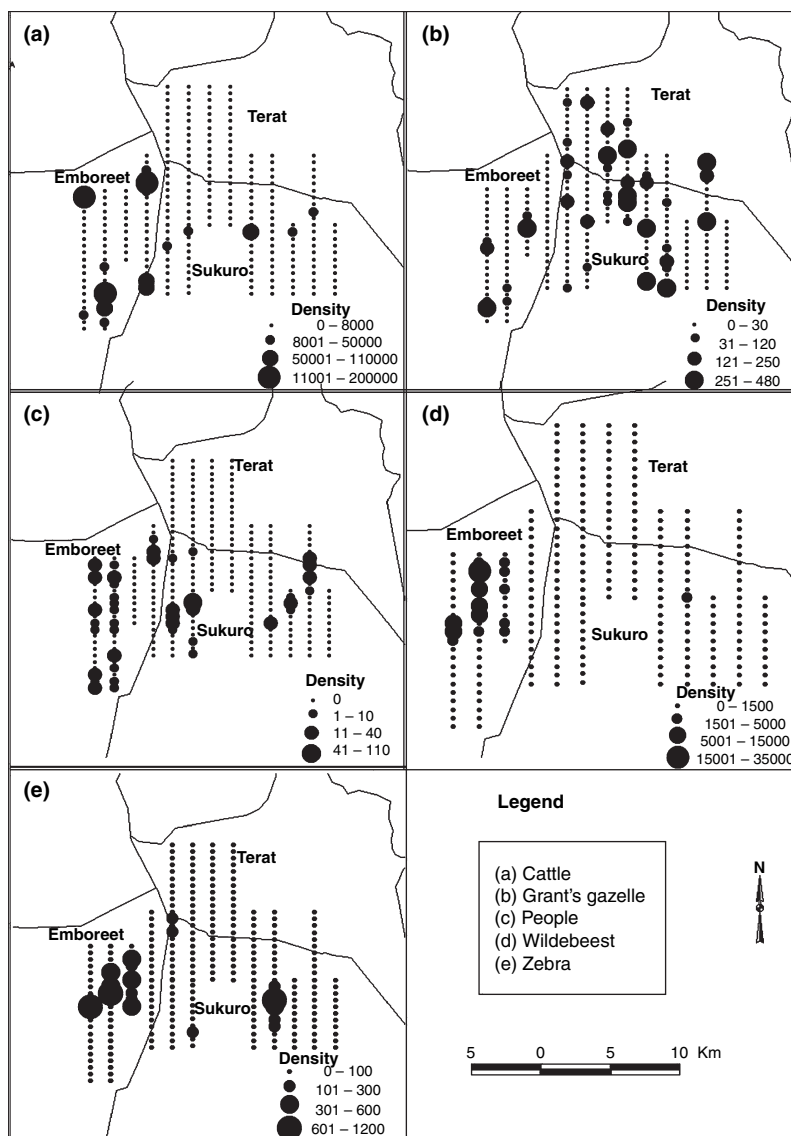


Fig 3 Spatial distribution of the observed groups for (a) cattle (b) gazelle (c) people (d) wildebeest and (e) zebra based on DISTANCE sampling in the Simanjiro Plains

Table 3 Component percentages of the variance of density [$\text{var}(\hat{D})$]: Cluster size, encounter rate and detection probability and their percent coefficients of variation (%CV)

Species	Cluster size (E (s))	% CV	Encounter rate (n/l)	% CV	Detection probability (\hat{f}_0)	% CV
Wildebeest	62.2	19.1	32.1	14.1	15.7	6.0
Grant's gazelle	34.8	11.1	53.4	13.8	11.8	6.5
Zebra	23.2	15.3	62.2	25.1	14.6	12.2
Cattle	30.9	16.1	63.7	23.2	5.4	6.7
People	36.6	17.3	54.5	21.1	8.9	8.5

Discussion

This study has demonstrated that it is possible to design and implement a ground survey using DISTANCE sampling to obtain reliable estimates of density for migratory ungulates and livestock in the communal lands of the TSE. Here, we evaluate the financial and logistic implications of the survey, the precision of the density estimates derived from DISTANCE sampling compared to aerial surveys, and the extent to which local communities can be active participants in such surveys.

The cost of the current survey was USD 10,000 which equates to USD 40 km⁻¹ of transect walked. A financial comparison suggests that DISTANCE sampling using ground surveys is four times more expensive per kilometre than the costs of aerial survey using SRF techniques. However, such a simple comparison is misleading for four reasons. First, aerial surveys typically have a low intensity of spatial coverage making it difficult to reliably estimate density for small but important wildlife habitats. Second, aerial surveys strictly require DISTANCE sampling techniques to correct for sighting bias, which when implemented with a helicopter, which can fly slowly and at lower heights to facilitate reliable observation and distance measurements, cost six times more than a fixed-wing aircraft. This makes aerial DISTANCE sampling prohibitively expensive in most circumstances (Jachmann, 2002). Third, aerial surveys require the use of aircraft with specialized personnel and equipment which are often unavailable for communal lands. Such surveys also preclude participation by community stakeholders in monitoring programmes. Finally, important ancillary information such as age and sex structure can be obtained during ground-based but not aerial surveys. It follows that the development and evaluation of ground-based survey methods that require inexpensive low technology equipment and allow the widest participation of community stakeholders could enhance conservation goals on communal lands.

Ground-based wildlife surveys in Tanzania have traditionally adopted strip-transect sampling rather than line-transect sampling. The financial costs of implementing strip-transect surveys are identical to those for line-transect surveys. Strip-transect and line-transect surveys are special cases of DISTANCE sampling and both require estimation of the perpendicular distance of animals from the transect centreline. However, while line-transects account for changing detection of animals with covariates, strip-transects assume that all animals within the strip are sighted with certainty. This assumption is violated under most field conditions, with observed sighting probabilities declining with distance, as confirmed for all species in our study.

Our analyses revealed that precision in density estimation for DISTANCE sampling was more sensitive to variation in encounter rate than in group size and sighting probability. Although reducing the variance in encounter rate in order to increase the precision of the estimated density is desirable, this can be hard to achieve if animals are intrinsically highly clumped in their distribution. Achieving the minimum recommended sample size of 60–80 groups required to reliably estimate density with DISTANCE sampling in a single ground survey may prove difficult for many ungulate populations (Ogutu *et al.*, 2006). This problem can be overcome by pooling data from repeat surveys to estimate a common detection function and then using the pooled detection function to obtain density estimates for the different surveys. For long-term population monitoring this introduces no additional financial and logistic costs but ensures unbiased estimates of density relative to strip-transects.

One of the advantages of DISTANCE sampling is that it allows for the widespread observation that detection decreases with increasing distance from the transect line (Buckland *et al.*, 2001). Assuming a constant sighting probability is unrealistic even for landscapes as open as the

Simanjiro Plains. This partly explains why the density estimate for wildebeest based on the strip-transect method was biased high relative to the line-transect estimate. The strip-transect estimate of density was also less precise than the line-transect estimate, as has been found in other studies (Newey *et al.*, 2003; Bardsen & Fox, 2006).

Estimates of population abundance for wildebeest, gazelle and zebra derived from our DISTANCE sampling survey were an order of magnitude more precise than estimates derived from SRF aerial surveys in the same ecosystem. For example, the 2001 Wet Season SRF survey counted 309 wildebeest on the Simanjiro Plains resulting in a population estimate of 5257 with standard error of 2616 and 95% confidence interval of 5–10,489 (TAWIRI, 2001). Whilst there is superficial concordance between the population estimates derived from the two surveys, the coefficient of variation of the SRF estimate was 201% which compares unfavourably to the coefficient of variation of the DISTANCE estimate of 20%. Population estimates derived from the SRF aerial survey for gazelle and zebra also had large coefficients of variation and confidence intervals (TAWIRI, 2001). The estimated densities from our DISTANCE survey can therefore provide more reliable baseline data to assess the population status of key species in the TSE than estimates from the aerial surveys. In addition, because DISTANCE sampling on walked transects can focus on small discreet areas, it is possible to conduct censuses in hunting blocks and communal areas to provide valuable information to guide management activities (Waltert *et al.*, 2006).

Reliable and cost-effective monitoring of wildlife populations is becoming increasingly important in the development of community-based natural resource management (CBNRM) in Tanzania (Nelson & Ole Makko, 2003; Kibebe, 2005). There is also increased interest and debate concerning the decentralization of management of wildlife resources (Gaidet *et al.*, 2006; Nelson, 2007). The move towards CBNRM will require wildlife enterprises such as community-based organizations, tourism operators and hunting companies to accurately monitor wildlife populations to be able to set sustainable hunting quotas and monitor trends of key species over time.

This study has demonstrated that ground surveys based on DISTANCE sampling can provide accurate estimates of density for key wildlife species in communal lands. It is also clear that aerial surveys using SRF techniques often produce estimates of abundance which are too imprecise to reliably establish population trends. With a small

investment of time and money, members of local communities can be trained to collect DISTANCE data with acceptable levels of accuracy. With support and encouragement, community members can plan and implement ground-based surveys on communal lands where it is logistically and financially unfeasible to conduct aerial surveys. External technical advisors will need to supervise data collection and analysis until such activities are within the skills of local communities. As such, the present survey represents an intermediate level of community involvement in natural resource monitoring where local people participate in monitoring activities but require technical input to interpret the resultant data (Danielsen *et al.*, 2009). This active participation in monitoring activities helps to develop support from community stakeholders for CBNRM programmes.

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References

- BARDSEN, B.J. & FOX, J.L. (2006) Evaluation of line transect sampling for density estimates of chiru in the Aru Basin, Tibet. *Wildl. Biol.* **12**, 89–100.
- BORNER, M. (1985) The increasing isolation of Tarangire National Park. *Oryx* **19**, 91–96.
- BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., LAAKE, J.L., BORCHERS, D.L. & THOMAS, L. (2001) *Introduction to DISTANCE SAMPLING: Estimating Abundance of Biological Populations*. Oxford University Press, Oxford.
- DANIELSEN, F., BURGESS, N., BALMFORD, A., DONALD, P., FUNDER, M., JONES, J., ALVIOLA, P., BALETE, D., BLOMLEY, T., BRASHARES, J., CHILD,

- B., ENGHOFF, M., FJELDSA, J., HOLT, S., HUBERTZ, H., JENSEN, A., JENSEN, P., MASSAO, J., MENDOZA, M., NGAGA, Y., POULSEN, M., RUEDA, R., SAM, M., SKIELBOE, T., STUART-HILL, G., TOPP-JORGENSEN, E. & YONTEN, D. (2009) Local participation in natural resource monitoring: a characterization of approaches. *Conserv. Biol.* **23**, 31–42.
- FRYXELL, J.M. & SINCLAIR, A.R.E. (1988) Causes and consequences of migration by large herbivores. *Trends Ecol. Evol.* **9**, 237–241.
- GAIDET, N., FRITZ, H., MESSAD, S., MUTAKE, S. & LE BEL, S. (2005) Measuring species diversity while counting large mammals: comparison of methods using species accumulation curves. *Afr. J. Ecol.* **43**, 56–63.
- GAIDET, N., FRITZ, H., BOURGAREL, M., RENAUD, P., POILECOT, P., CHARDONNET, P., COID, C., POULET, D. & LE BEL, S. (2006) Cost and efficiency of large mammal census techniques: comparison of methods for a participatory approach in a communal area in Zimbabwe. *Biodiv. Conserv.* **15**, 735–754.
- GEORGIADIS, N., HACK, M. & TURPIN, K. (2003) The influence of rainfall on zebra population dynamics: implications for management. *J. Appl. Ecol.* **40**, 125–136.
- GERETA, E., MEING'ATAKI, G.E., MDUMA, S. & WOLANSKI, E. (2004) The role of wetlands in wildlife migration in the Tarangire ecosystem, Tanzania. *Wetl. Ecol. Manage.* **12**, 285–299.
- GROSS, M. (2007) Mapping hidden resources. *Curr. Biol.* **17**, 340–341.
- JACHMANN, H. (2002) Comparison of aerial counts with ground counts for large African herbivores. *J. Appl. Ecol.* **39**, 841–852.
- KAHURANANGA, J. & SILKILWASHA, F. (1997) The migration of zebra and wildebeest between Tarangire National Park and Simanjiro Plains, northern Tanzania, in 1972 and recent trends. *Afr. J. Ecol.* **35**, 179–185.
- KIBEBE, J.D.N. (2005) *Socio-economic and ecological impacts of safari hunting and commercial farming on key stakeholders, Simanjiro District, Tanzania*. MSc Thesis, Noragric University, Norway.
- LAMPREY, H.F. (1963) Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. *East Afr. Wildl. J.* **1**, 63–92.
- LAMPREY, H.F. (1964) Estimation of large mammal densities, biomass and energy exchange in the Tarangire Game Reserve and the Maasai Steppe in Tanganyika. *Afr. J. Ecol.* **2**, 1–46.
- MISOFFE, F.U., MTURI, F.A., GALANTI, V., TOSI, W., WAUTERS, L.A. & TOSI, G. (2007) Comparing data of different survey methods for sustainable wildlife management in hunting areas: the case of Tarangire-Manyara ecosystem in northern Tanzania. *Eur. J. Wildl. Res.* **53**, 112–124.
- MWALYOSI, R.B.B. (1991) Ecological evaluation for wildlife corridors and buffer zones for Lake Manyara National Park, Tanzania, and its immediate environment. *Biol. Conserv.* **57**, 171–186.
- NELSON, F. (2007) Are large mammal declines in Africa inevitable? *Afr. J. Ecol.* **46**, 3–4.
- NELSON, F. & OLE MAKKO, S. (2003) *Communities, Conservation and Conflicts in the Tanzanian Serengeti. A Case Study Prepared for the Third Annual Community Based Conservation Network Seminar. Turning Natural Resources into Assets*, Georgia, U.S.A.
- NEWAY, S., BELL, M., ENTHOVEN, S. & THIRGOOD, S. (2003) Can distance sampling and dung plots be used to assess the density of mountain hares *Lepus timidus*? *Wildl. Biol.* **9**, 185–192.
- NORTON-GRIFFITHS, M. (1978) *Counting Animals*. African Wildlife Foundation, Nairobi, Kenya.
- OGUTU, J.O., BHOLA, N., PIEPHO, H.P. & REID, R. (2006) Efficiency of strip-and line-transect surveys of African savanna mammals. *J. Zool. Lond.* **269**, 149–160.
- PRINS, H.T.T. (1987) Nature conservation as an integral part of optimal land use in East Africa: the case of the Masai Ecosystem of Northern Tanzania. *Biol. Conserv.* **40**, 141–161.
- TAWIRI (2001) *Tarangire Ecosystem: Wet season Systematic Reconnaissance Flight Count, May 2001*. Tanzania Wildlife Research Institute, Arusha.
- THOMAS, L., LAAKE, J.L., STRINDBERG, S., MARQUES, F.F.C., BUCKLAND, S.T., BORCHERS, D.L., ANDERSON, D.R., BURNHAM, K.P., HEDLEY, S.L., BISHOP, J.R.B. & MARQUES, T.A. (2006) *DISTANCE, Vers. 5.3*. University of St. Andrews, U.K.
- WALTERT, M., MEYER, B., SHANYANGI, M.W., BALOZI, J.J., KITWARA, O., QOLLI, S., KRISCHKE, H. & MUHLENBERG, M. (2006) Foot surveys of large mammals in woodlands of western Tanzania. *J. Wildl. Manage.* **72**, 603–610.

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