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Cost and efficiency of large mammal census techniques: comparison of methods for a participatory approach in a communal area, Zimbabwe

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Abstract. The comparison of precision is often advocated for the selection of an appropriate census and/or monitoring method for wildlife, but little attention is generally paid to their cost effectiveness, a crucial criterion given budgetary and logistical constraints. We present six direct count methods conducted in a communal area of the Zambezi Valley, Zimbabwe, and compare them in terms of (1) effort and cost to survey an area (sampling efficiency), and (2) efficiency in data collection (detection efficiency). Methods ranged from c.US\$0.2 to over US\$6.0/km^2 and needed from 0.1 to 5.0 human-h/km^2. The comparison of efficiencies showed the advantages of simple ground methods: foot counts and particularly bicycle counts appear well adapted to the ecological and human context of our study. The relative benefits and constraints of the different methods are discussed in the context of a community-based wildlife management programme.

Introduction

With the growing concern for the conservation of biodiversity, the economic exploitation of wildlife as an indigenous resource (Hudson et al. 1989; Child and Child 1991) has been proposed as an appropriate approach to reconcile conservation and development goals (Jacobs and Munro 1987). The sustainable use of wildlife strongly depends on the monitoring of population status and trends, and the definition of appropriate harvesting quotas (Kremen et al. 1994). Many techniques have been developed and employed to monitor large terrestrial mammal populations (Norton-Griffiths 1978; review from Van Hensbergen and White 1995). These survey techniques have often been compared in terms of accuracy and precision of results (Jachmann and Bell 1984; Koster and Hart 1988; Knott and Venter 1990; Jachmann 1991; Klinger et al. 1992; Mandujano and Gallina 1995; Peel and Bothma 1995), with special emphasis on the undercounting bias in aerial survey (see reviews from

Caughley 1974; Hone 1988; East 1998; Jachmann 2002). However, little attention has been paid to their cost effectiveness (Van Hensbergen and White 1995; Reilly and Reilly 2003), although some measures of costs and efforts have been published recently (Jachmann 1991; Mourão et al. 1994; Kraft et al. 1995; Reilly and Haskins 1999; Walsh and White 1999; Hochachka et al. 2000; Walsh et al. 2001). In this paper, inspired by Reilly and Reilly (2003), we consider effectiveness as being output orientated, and a measure of productivity in relation to resources invested and in terms of long term profitability, whereas efficiency is concerned with the performance of a given method at the minimum cost of the undertaking. Only measures of cost efficiency can allow for adequate planning (people and time allocated, sample size) within budgetary and technical constraints. This is particularly true in the context of community-based conservation programmes with restricted funding (Hackel 1999), and cost effectiveness should be a key criterion in the choice of the appropriate counting/monitoring method to ensure its successful implementation and sustainability (Van Hensbergen and White 1995; Walsh and White 1999).

In this paper we compare different wildlife census methods used within the Biodiversity Project, which operated in 1996 in a communal area of the Zambezi Valley, in Zimbabwe, aimed at promoting the sustainable use of natural resources for the benefit of local communities (Biodiversity Project 2001). Among other objectives, the project had to assess the status of large mammal populations and implement a long term monitoring programme, involving members of the local communities (Gaidet et al. 2003). This project supported the Zimbabwean CAMPFIRE programme (Communal Area Management Programme for Indigenous Resources) that organises the involvement and empowerment of rural communities in the management of natural resources, hence benefiting directly from them (Martin 1986; Murindagomo 1989).

Five ground census methods were used in the project area: daylight and night car counts, bicycle counts, foot counts and water point counts. We examined cost effectiveness of these surveys, and compared the results with aerial surveys conducted in the same area by the World Wildlife Fund for Nature (WWF) (Mackie 1998; Davies 1999). As the quality of population estimates and the detection of trends depends on the number of sightings (Kraft et al. 1995; Plumptre 2000; Walsh et al. 2001), which is in turn related to area covered, sampling effort and detection efficiency of the census method, we first describe the sampling efforts and costs induced by the logistical constraints of each method, and then compare the results obtained with these methods in terms of efficiency in data collection. Finally we discuss their suitability for use at the community level in Africa through the comparison of their cost effectiveness in relation to the general monitoring goals in communal areas.

Methods

Study area

The study area is located in the middle Zambezi Valley, in Zimbabwe, between 30° and 31° longitude East and 15°30 and 16°20 latitude South. It is communal land, comprised of three Wards (2, 3 and 4) of the Dande Communal Area, in the rural Guruve District. The area corresponds to former floodplains of the Zambezi river basin, at an altitude of c. 400 m, and has three main rivers. The climate is dry tropical, with low and variable annual rainfalls (on average 750 mm/year), and a mean annual temperature of 25 °C. Two seasons are clearly defined: a rainy season from December to March, and a long dry season from April to November. Re-growth of the woody vegetation occurs in early November.

People and wildlife coexist in this communal land of 2044 km^2 which is characterised by two contrasting habitats: a dense human settlement with croplands, and a wooded savanna. A total of 13,000 habitants live in this area, primarily settled along the main rivers, where farming is their dominant activity (mostly cotton and maize) (Biodiversity Project 2001). Livestock populations are relatively low and localised around settled areas, and although cattle numbers have been increasing recently, overgrazing does not appear to be a problem yet. The uninhabited areas still cover a large proportion of the valley (c. 80%), and contain remarkable species richness, with more than 40 large mammal, 200 bird and 700 plant species (Biodiversity Project 2001). The natural land cover is deciduous dry savanna, dominated by mopane trees (*Colophospermum mopane*) mainly associated with *Combretum apiculatum*, *C. mossambicense*, *Commiphora* spp., *Dalbergia melandoxylon*, *Diospyros kirkii*, *Kirkia accuminata*, *Sclerocarya birrea*, *Terminalia brachystemma*, *T. stuhlmannii*, *T. stenostachya*, and *T. sericea*. The grass stratum is dominated by *Digitaria milanjiana*, *D. eriantha*, *Heteropogon contortus*, *H. melanocarpus*, *Loudetia flavida*, *Schmidtia pappophoroides* and *Aristida* spp. (Biodiversity Project 2001). The composition and structure of each vegetation type varies with the type of soils, and forms a mosaic of woodland and shrubland varying from 4 to 18 m in height.

Protocol and field study

All methods presented are from direct counts based on sightings and these were restricted to medium to large size mammals of more than 200 g (Skinner and Smithers 1983). Sampling units of each census protocol were spread over the same study area. Details of protocols and sampling designs are presented in Table 1.

Table 1. Details of protocols and sampling designs of methods (unit of sampling area is km^2).

Method	Year	Month	Day/Night	*N* agents	*N* sample units	Sampling area	*N* replicates
Aerial census	1997/1999	Sep.–Nov.	Day	4	2	186/170.2	2
Car day count	1997	Jun.–Oct.	Day	3	12	15.6	96
Car night count	1997	Jun.–Oct.	Night	4	12	12.6	24
Bicycle count	1999	Sep.–Dec.	Day	1	10	19.4	304
Foot count	1999	Jun.–Nov.	Day	1	18	5.9	108
Water point count	1997	May–Oct.	Day–night	2	27	–	46

Aerial census

The World Wildlife Fund (WWF-Zimbabwe) carried out aerial censuses in selected Communal Areas, including the Guruve communal lands area, in support of the CAMPFIRE Programme (Mackie 1998; Davies 1999). A stratified systematic sampling methodology (Norton-Griffiths 1978) was used with various sampling designs. The study area was covered by two sample strata, where transects were spaced from 2 to 5 km. A total of 24 and 17 transects covering 563 and 455 km were flown in 1997 and 1999, respectively. Censuses were carried out in the late dry season (September 97, November 99), early morning (97) and late afternoon (99), from a Cessna 206 aircraft flying between 140 and 180 km/h, at a height of 90 m above ground level. The survey involved four people; a pilot, a recorder/navigator, and two observers. Observers identified and recorded all animals (without sex or age details, except for elephant *Loxondota africana*) found within a calibrated strip of 300 m, defined by streamers attached to the wing struts.

Car count

These counts were conducted from June to October 1997 during day and night surveys. Animals were counted along transects established on four-wheel-drive roads opened up by the Regional Tsetse and Trypanosomosis Control Program (RTTCP). This network of roads was established to cover the area for maintenance and control of tsetse fly targets, regardless of human activities or vegetation units. These roads were thus considered to provide a representative sample of the area. A total of 12 road transects were spread over the whole study area, away from villages and permanent human disturbances. The transects were between 6.6 and 17.8 km long, and covered a total length of 138 km. They were driven four times in the early morning (starting at 6:30 h), four times in the late afternoon (starting at 16:30 or 17:00 h depending on transect length) and twice at night (starting 21:30 h).

Daylight car counts involved a driver and two experienced observers, standing up in the platform of a pick-up truck, identifying and counting animals with binoculars. The direct distance to an individual animal, or the centre of a group, was measured with a range-finder and the angle was estimated so that the perpendicular distance from the transect could be calculated (Buckland et al. 1993). At night an additional observer was employed to shine the 1000-W spotlight on both sides of the road while observers looked for reflections from animal's eyes, and took the same records as during the day.

Bicycle counts

Bicycle counts used the same network of RTTCP roads as the car counts, but 10 transects were established between 3.7 and 23 km long, covering a total length of 121.3 km. Monitoring took place in the mornings, and transects were repeated on average 30 times each (min. 17, max. 47) from September to December 1999 (Gaidet et al. 2003). Animals were counted with the naked eye by one observer riding a bicycle at slow speed. Step counts were used to directly measure the perpendicular distance from the transect to the detected animal (individual or centre of a group). Even in thick bush, four-wheel-drive roads were straight, wide and good enough to ensure easy riding and allow the observer to concentrate on the detection of animals. A total of 33 different observers were involved, with each observer normally covering a single transect, but sometimes up to three.

Foot counts

The foot counts comprised eighteen 1.8 km transects. Each transect originated on a RTTCP road some distance from areas of human activity and extended into the bush with the route being marked with red paint. In the early morning, an observer cycled to the beginning of the transect and then walked the transect slowly. He identified and counted animals without the aid of binoculars and visually estimated the perpendicular distance to the point where animals were first sighted. Three observers were in charge of six transects each, which they walked once in a month from June to November 1999.

Water point counts

Twenty-seven of the 49 water points in the area were selected on the basis of remoteness from human activity, probable permanence and distribution within the project area. These were monitored twice in 1997, once during the cool season (May–July) and once in the hot dry season (August–October). Since some water points were dry by the end of the season, only 19 were monitored in the late dry season. Because of the lack of observers, all selected water points could not be monitored at the same time. Monitoring took place during 2–3 days over the full moon period to allow clear observations and identification at night with normal binoculars. Observations were made continuously over a 24-h period by two observers working from a blind built in a tree, offering a clear and safe view of the water point.

Survey crew

Observers involved in ground counts were local agents from Anti-Poaching Units, the Natural Resources Monitors from the District Council and local technicians called 'Barefoot Biologists', trained by the Biodiversity Project. They were all conversant with patrolling in the study area and had a good knowledge of local wildlife. Except for foot counts, different observers were used from one replicate to another. For aerial censuses, the observers were highly qualified and experienced technicians, from Department of National Parks and WWF. Car and aerial counts also required a licensed driver and pilot, respectively.

Period of the survey

The censuses were conducted in 1997 and 1999. Rainfalls recorded in the Zambezi Valley (Muzarabani station) from 96–97 and 98–99 rainy seasons (November to March) were high, 1140 and 1650 mm, respectively. These are two of the three wettest seasons of the last decade recorded at this station (mean 830 mm, range 310–1650 mm). During the hottest months of the study period (September–December), mean monthly maximum temperature recorded in 1997 and 1999 were similar, ranging from 34.0–37.6 °C to 34.3–37.0 °C, respectively. The two dry seasons were therefore considered to be very similar in terms of water resource availability and climate condition.

The counts were spread over several months from June to December. These months correspond to the dry season, with a cool (June–August) and a hot period (September–December). The census period was extended to the first major rains, i.e. the end of November in 1997 and the end of December in 1999. Night and day surveys were analysed separately for drive counts. Data recorded during the continuous 24-h counts at water point were not analysed according to night and day observations, but were pooled, as many animals visited the water points at dusk and dawn.

Sampling efficiency

Sampling efficiency depends on time, people and cost required to cover a sampling area. These varied with methods used, so in order to be able to compare the different sampling methods we created two indexes the sampling effort index (SEI) and the sampling cost index (SCI) [see calculation below].

Sampling area

In ground transect counts, sighting distances were systematically recorded to calculate the area in which animals were visible along each transect. However, only bicycle counts provided enough records per transect (>60 sightings) to calculate the sampling area using a line transect analysis. For bicycle counts, we used the DISTANCE software programme (Buckland et al. 1993) to build a model of detection function on each transect using data from all animals observed. We multiplied the 'effective strip width' (Buckland et al. 1993), calculated by the programme, by the transect length to calculate the transect area surveyed during the census.

For car and foot counts, a complementary protocol was used to estimate the area sampled: an observer standing on the back of a pick-up truck or on the road (for car and foot protocols, respectively) estimated, on both side of the track, the maximum distance at which an agent walking perpendicular to the edge of the transect was still visible (Cumming 1975). At night, the same measurement was made with an agent holding a reflector to simulate animal eyes detected by the spotlight. Distances were measured with a rangefinder every 400 and 75 m (for car and foot protocols, respectively) along each transect at the beginning of the dry season (July). The area covered by each transect was calculated as the product of the transect length by the mean visible distance.

The area covered by aerial censuses is calculated from a calibrated transect width (Mackie 1998; Davies 1999). For the water point survey, effective sampling area was impossible to estimate because the area of influence of each water point could not be assessed.

Observation time

We only considered the effective time to carry out counts during the survey from the start point to the end point of a transect. The time needed to reach the starting point was excluded since it is less rigorously calculated than observation time. A mean observation period was calculated for each transect, from records of the time spent in the field. The difference in observation time between transects was used to calculate a variance (expressed as %CV). Survey design, field implementation (the marking and measurement of transects, the building of blinds at water points), complementary measures of visibility, tests of protocol and co-ordination or training of observers, were not taken into account in the measure of effort and cost of methods. All these activities are always costly for the implementation of a monitoring programme, both in terms of material and time consumed. However we considered these activities to be an initial cost and effort that would not be repeated during the monitoring programme.

Sampling effort index

A SEI was calculated as the number of human-hours required to sample one km^2. We used the transect as the unit of analysis and calculated for each transect:

$$\mathrm{SEI} = H \times P/A$$

where H is the transect observation period (hours), P the number of people involved to monitor the transect, and A the transect area (km^2). For each method, we calculated the mean SEI and a %CV over the transect indices. In most of the protocols, transects were of varying length. To integrate the relative contribution of each transect to the whole sampling design, transects were weighted by their respective length in the calculation of the mean SEI. The transect length was considered to be representative of the implementation effort, independent of the visibility factor (transect width) attached to the transect area.

For aerial censuses, sampling data on each transect was not available (Mackie 1998; Davies 1999), so we calculated the mean SEI over two identified strata, weighted by their respective total transect length. For the water point survey, we estimated sampling effort by assuming a total simultaneous count over the whole study area. The survey was conducted in the late dry season restricting counts to permanent water points and needing limited labour intensity. At this time of the year, we assumed that the 19 permanent water points would allow a survey of the whole study area (excluding crops, fallows and human settlements, i.e. 1848 km^2), although we know it is likely to be an underestimate. We therefore calculated a SEI over all these water points.

Sampling costs index

We calculated a cost per hour or per km for each sampling method used. All costs were expressed in US dollars ($). Estimates were obtained on the basis of observer's salaries, trip and material costs (fuel, material maintenance and depreciation). We considered standard Zimbabwean duties of 8 h a day and 5 days a week. The salary of local agents involved in ground counts was 0.6$ per hour (100$ per month), and 0.7$ per hour (125$ per month) for the local driver. For the aerial census, fees were 6.2$ per hour (50$ per day) for experienced technicians, and 31.2$ per hour (250$ per day) for the pilot/consultant. Trip costs were calculated from fees of 0.3$ per km for a car and 200$ per hour for an aircraft. Car counts included costs of a Rangefinder (220$, 10 years guarantee), Binoculars (250$, 10 years guarantee), and for the night survey a Spotlight (50$, 2 years guarantee). For the bicycle count, the cost based on material maintenance and depreciation was estimated at 0.1$ per km (a 200$ bicycle + 100$ material, for 3000 km). Continuous monitoring costs during 24 h at water points, included salary, night allowance, binoculars, meals and sleeping materials and were estimated at 9.0$ per 24 h.

We generated a SCI of the monitoring methods for each transect:

$$\mathrm{SCI} = (H \times \text{per hour cost rate} + l \times \text{per km cost rate})/A,$$

where H is the transect observation time (hours), l the transect length (km) and A the transect area (km^2). We summed the costs per hour and per kilometre to account for the fact that costs are estimated independently on either the distance covered or the time spent basis. We calculated a mean SCI and a %CV over all transects, weighted by their respective length (see above SEI). For aerial censuses and water point surveys, we used the same approach developed for SEI.

Detection efficiency

The detection efficiency is defined here as the average number of animals observed within the area covered during the count (i.e. the product of the transect sampling area by the number of transect replicates). We considered observations of all species recorded. Animals were observed in groups of different sizes since social organisation of species varies from solitary to social. To avoid group size bias, we used sightings rather than individual numbers to estimate the observation efficiency. We used the mean number of sightings collected on each transect as the unit of analysis. We calculated a detection efficiency index (DEI) for each transect:

$$\mathrm{DEI} = N/A \times R,$$

where N is the total number of sightings of all species over replicates, A the transect area (km^2) and R the number of replicates. We calculated a mean DEI and a %CV between transects, weighted by their respective length (see above SEI).

To test for the importance of bias linked to differences in sampling design between methods (transect location and survey period), we conducted an additional comparison of detection efficiency restricted to counts that were all run by the different methods over the same roads, during the same time-period (September and October). We considered two contrasting sub-sites, an open shrub woodland and a densely wooded shrubland. We selected transects and their replicates that belonged to these two sub-site roads, and time-period. We calculated a mean site-specific detection efficiency index ($\mathrm{DEI_{SS}}$) and %CV for each method at each sub-site. However, these detection efficiency indices could only be generated for ground transect counts. No index was calculated for water point surveys since the area of influence of each water point (i.e. the effective sampling area) could not be measured.

For aerial censuses, the detailed number of sightings were not available (Mackie 1998; Davies 1999), but we had access to the number of individuals counted. To compare the ground and aerial counts, we then built an animal detection efficiency index based on the number of individuals observed from a single species. We restricted the comparison to the two largest animals observed, elephant and buffalo (*Syncerus caffer*), which are the target species of aerial censuses (Davies 1999). We used the transects as units of analysis and calculated an elephant and a buffalo detection efficiency index ($\mathrm{DEI_E}$ and $\mathrm{DEI_B}$ respectively):

$$\mathrm{DEI_{E\ or\ B}} = n/A \times R,$$

where n is the total number of elephants or buffaloes counted along a transect over replicates, A the transect area (km^2) and R the number of replicates. We calculated a mean index and %CV for each method as for the SEI (see above). For aerial censuses, we calculated a mean index between the two strata areas, weighted by their respective total transect length.

Results

A total of 10,368 animals were counted during this survey, from the 27 different species ranging in size from genet (*Genetta tigrina*) to elephant. The sampling effort varied greatly according to count methods, as well as the number of animals detected (Table 2). Ungulates represented most of the observations, with common duiker (*Sylvicapra grimmia*), impala (*Aepyceros melampus*) and kudu (*Tragelaphus strepsiceros*) being the more frequently seen animals.

Sampling effort and cost

In ground counts, the average speed to monitor a transect during our surveys (including observation stops) was 11.6 km/h for car counts, 5.5 km/h for bicycle counts, and 1.3 km/h for foot counts. The mean visibility distances measured were 46 m for car night counts, 56 m for car day counts and 91 m for foot counts. The average effective strip width was 79 m for bicycle counts. When comparing manpower and cost to cover 1 km, bicycle counts appeared to be the best method in both respects. The effort index was 0.26, 0.35, 0.18 and 0.79 human-h/km for car day, car night, bicycle and foot counts, respectively; and the cost index was 0.48, 0.53, 0.20 and 0.45 $/km for car day, car night, bicycle and foot counts, respectively. Combining visibility distance and effort to travel 1 km showed that bicycle counts were the most efficient methods to sample an area among ground transect counts (Table 3).

Table 2. Sampling effort for each method: observation time (h) and area covered (km^2), and detailed results of counts, with number of sightings, individuals and species observed.

Method	Total sampling area	Total observation time	*N* sightings	*N* individuals	*N* species
Aerial census	356.2	6.5	–	348	8
Car day count	124.6	95.1	54	239	12
Car night count	25.2	23.8	60	170	16
Bicycle count	595.2	669.0	1328	7938	26
Foot count	35.3	153.8	189	1054	12
Water point count	–	1104.0	110	619	21

Table 3. Summary of performances of each protocol expressed in terms of effort, cost and detection efficiency.

Method	SEI		SCI		DEI		Elephant DEI		Buffalo DEI	
	Mean	%CV	Mean	%CV	Mean	%CV	Mean	%CV	Mean	%CV
Aerial census	0.07	–	4.54	–	–	–	0.25	–	0.60	–
Car day count	2.46	25.99	4.58	25.97	0.39	93.53	0.10	275.44	0.52	203.97
Car night count	3.97	22.70	6.35	30.22	2.09	62.53	0.17	323.46	1.21	377.32
Bicycle count	1.32	96.25	1.46	60.28	2.79	131.23	1.15	136.73	4.76	326.31
Foot count	4.80	44.76	2.74	44.76	5.83	58.84	1.96	167.25	1.85	259.26
Water point count	0.49	–	0.18	–	–	–	–	–	–	–

SEI was defined as the number of human-hour required to sample 1 km^2, SCI was defined as the cost (US$) to sample 1 km^2, and DEI was defined as the average number of sightings detected within the area covered during counts. Elephant and buffalo detection efficiency index (DEI_E and DEI_B, respectively) were defined as the average number of animals detected within the area covered during the count. We present for each index a mean and %CV, calculated over the transect units, weighted by the transect respective length.

Foot counts also benefited from single observer involvement per transect and high visibility but were not so useful because of the slow travelling speed. At night, car counts required more effort to sample an area because of the combination of reduced visibility and high people involvement. Aerial census was classically the lowest effort consuming technique to sample an area (human-h/km^2). It is far less labour intensive compared to other techniques (Table 3) thanks to a high cruising speed (140–180 km/h) and a wide visible strip (300 m). Variance between transects was high in bicycle and foot counts, and was probably related to different in local condition of roads (slope, sandy ground), whereas car counts could maintain a constant speed over various terrain.

Results on sampling costs also show large differences between methods (Table 3). Among transect counts, costs varied from 1 to 4 times. The lowest costs were logically found in ground-based techniques that involved local agents and required low labour and material expenses per sample unit, such as foot and bicycle counts. These simple methods were around half the cost of aerial censuses. Surprisingly, aerial censuses were however not the most costly: with a high labour and material requirement but short visibility distances, car counts were an expensive method to conduct, with costs especially pronounced for night counts. Water point surveys were one of the least labour intensive methods and by far the cheapest one. This method is highly efficient at the end of the dry season when water availability is reduced to a few pools, but it is based on a very constraining hypothesis that the count is exhaustive for the whole area considered. Moreover, unless it is repeated several times, this method cannot provide any value of the precision of population estimates. It is, however, probably adequate to assess trends and collect information on the structure of various animal populations.

Detection efficiency

Efficiency to detect animals within the sampling area varied widely according to methods used. Considering data from all species, the average number of sightings collected per unit of area increased from car, bicycle and foot counts (Table 3). The simplest ground transect methods therefore presented the highest detection efficiency index. It should be noted that for car counts, night surveys were more efficient than day ones, probably because of a greater detection of animal from eye reflection by spotlight, a better distribution of animals moving out of thick bush at night, and the additional observation of nocturnal species.

When we restricted comparison to similar sampling periods and area, i.e. the site-specific index, we observed the same tendency in the order of detection efficiency between methods (Table 4). Foot counts had however a higher detection rate compared to bicycle counts, while car night counts showed the highest efficiency of one site. Site-specific comparison also allowed observation of differences in efficiency between open and dense habitats. Car counts were more efficient in open woodland during both day and night surveys than in thick shrubland, whereas we observed the opposite result for foot counts.

No detection efficiency index could be calculated for water point surveys, but values of sighting frequency gave us a point of comparison with other ground count methods. The average number of sightings (mean and SE over sample units) for each method were: one sighting for every 10 h of observation at a water point (mean (CV, n) = 0.10 (0.73, 27) sighting/h), while 1–2 sightings were collected per hour during bicycle, foot and car night counts (mean (CV, n) = 1.99 (0.31, 10), 1.28 (0.48, 18) and 2.27 (0.73, 12) sighting/h), respectively. Car day counts still had the lowest sighting frequency (mean (CV, n) = 0.53 (1.04, 12) sighting/h). Though water point counts are potentially a very efficient method to sample an area (see sampling effort and cost index), they presented a very low efficiency of collecting animal observations. To ensure an exhaustive

Table 4. Site specific detection efficiency index (DEI_{SS}) for each ground transect methods, defined as the average number of sightings detected within area covered during counts restricted to two sites: a shrub woodland (open) and a thick wooded shrubland (dense). We present a mean DEI_{SS} (sightings/km^2) and %CV, calculated between replicates of transect (n).

Method	DEI_{SS}					
	Open			Dense		
	Mean	%CV	n	Mean	%CV	n
Car day count	1.36	54.71	4	0.00	0.00	12
Car night count	8.73	–	1	1.59	125.53	3
Bicycle count	1.72	45.10	13	1.39	63.51	14
Foot count	4.12	84.84	4	6.74	31.53	4

count, this method requires continuous observation over long periods, including mid-day hours when sighting probabilities are low.

The comparison between ground counts and aerial counts was restricted to the analysis of elephant and buffalo which were the species most commonly observed during aerial censuses (Mackie 1998; Davies 1999). Still, detection rate of elephants was higher in simple ground transect methods (i.e. bicycle and foot counts) than in aerial censuses (Table 3). Results on buffalo observations indicated the same tendency but had a larger variability. Heterogeneous distribution of buffaloes over the study area was mainly responsible for this variability, whereas elephants were observed over the whole area. When we restricted the comparison to the same year of survey (1999), the gap between aerial censuses and foot or bicycle counts remained important ($DEI_E = 0.56$ and $DEI_B = 0.15$ ind./km^2 for aerial census, see (Table 3) for foot and bicycle counts). For car counts, detection efficiency index of elephants and buffaloes were similar to results of aerial censuses.

Discussion

Our study provides information on advantages and limits of a variety of wildlife census methods in terms of cost and effort to search for the information and efficiency to obtain it. The main limits of the comparative efficiency we present in this study is that methods were not tested for their inter-annual precision and their ability to detect changes in wildlife populations (i.e. a relationship of cost and effort to %CV, Plumptre 2000; Walsh et al. 2001; Reilly and Reilly 2003). Since our methods were not replicated over many years, and that some methods collected a limited number of sightings, it was not possible to conduct such analysis.

Sampling efficiency

Little information is available on costs attached to wildlife censuses (Van Hensbergen and White 1995), and the comparison of costs between studies is difficult because these costs depend on the economic situation of the country, and vary from year to year. Nevertheless, some studies at other African sites give some indications on costs: day and night car counts conducted in South African forestry plantations (Van Hensbergen and White 1995) were estimated to cost of 18.6$ and 10.9$ per km^2, respectively (converted from South African Rand); in Burkina Faso, costs of Elephant census related to area covered, were estimated to 3.5$ per km^2 by plane and 7.8$ per km^2 by car using local labour only (costs converted to $ per km^2 from Jachmann 1991). The costs calculated for our surveys (from 4.5$ per km^2 for aerial censuses to 6.3$ per km^2 in night car counts) were therefore in the range of values from other sites.

Aerial censuses are widely used for their capacity to cover large areas, but they are generally expected to be expensive compared to ground counts. However, in our study where costs were related to the area covered, aerial censuses presented similar costs to car counts, thanks to the large area of ground covered. This result is consistent with similar costs found between helicopter and ground (horse and car) counts in South Africa (Reilly and Haskins 1999) and for elephant counts in Burkina Faso (see above: Jachmann 1991).

The low sampling efficiency we found in car counts seemed to be due to a reduced visibility distance, particularly in comparison with foot counts. The protocols, season and staff were similar for both methods, so differences in visibility may be explained by car transects crossing more densely wooded habitats. Visibility in car counts may be also affected by a strip of dense vegetation growing on the edge of dust roads, whereas foot counts mostly followed small paths opened up in the bush. Such vegetation constraints would be a constant cost associated with the use of established roads. However, this does not explain why visibility distance was higher for bicycle counts. The importance of visibility in the evaluation of the sampling cost can be further illustrated by the results from a car day count conducted in Hwange National Park (Zimbabwe), where the SCI was 2.0$ per km^2 compared to 4.5$ per km^2 in our study area, with a visibility distance of 180 m as opposed to 56 m, respectively (Bourgarel M. and Fritz H. unpub. data).

The comparison between the sampling efficiencies of game counting methods in our study gave great advantages to simple ground techniques, such as bicycle and foot counts. With low cost attached to their implementation, they are less susceptible to budget constraints hence more sustainable in the context of community-based wildlife management programmes. Our study also showed that a simple and low cost method such as bicycle counts might require less effort to sample an area (in human-h investment) than a classically used car count. The bicycle option can thus provide more replicates for given labour and funding, hence collect a larger sample size.

The successful implementation of bicycle counts in this study was however linked to the good local road network, built for tsetse fly targets control (Biodiversity Project 2001). Bicycle counts could only be effective on such large and safe tracks, where the observer can concentrate his attention on animal detection. Conversely, foot transects can be planned anywhere in the bush though they will require additional effort for paths to be opened up and marked out. Both bicycle and foot counts present another limit: the area monitored by a single observer is low. Therefore, for a wide area to be monitored, sampling effort must be shared over a great number of observers, with thus a potential observer bias (Gaidet et al. 2003). Furthermore, in order to avoid counts being spread over a long period and therefore subjected to fluctuation in wildlife abundance, observers have to operate simultaneously. The coordination of such a count would hence be difficult over a large management area. The application of bicycle and foot counts should therefore be restricted to small management areas.

Water point counts presented the highest potential sampling efficiency, when combining effort and costs requirements. However, in order to meet the assumption of an exhaustive count, this method requires knowledge of all water points used by wildlife in the area and a strong field implementation. Simultaneous counts at several points require detailed logistical support and a highly co-ordinated effort of organisation. Therefore, this method could be effectively used only in some well-known areas, and the weight of its implementation has to be closely examined before being selected.

Detection efficiency

When we compared detection efficiency, the easiest and cheapest transect methods we employed (i.e. bicycle and foot counts) appeared to also be the most efficient at collecting wildlife observations. Several characteristics of our study site may explain these results. For instance, the protected status of an area conditions the response of wildlife to the presence of observers. Outside protected areas, wildlife that is hunted shows fear of human approach, whereas in National Parks wildlife should be less susceptible to human disturbance (Caro 1999a). The silent approach of observers during foot and bicycle counts is highly advantageous in communal land such as our study site. The highest detection efficiency we obtained in foot counts may therefore be explained by the fact that observers walking along narrow trails were able to approach wildlife more closely before detection. Such behaviour is likely to have been more frequent in dense habitat, resulting in a higher efficiency rate. Likewise in car counts, we can also assume that animals are more often encountered at night, especially in open habitats, when disturbance from human activities are normally minimal.

Wildlife density determines the potential encounter rate of a count. The high sensitivity of a method to detect wildlife is advantageous in an area of low animal density. At high wildlife density, a high encounter rate may compensate for poor detection, consequently methods offering a high area of coverage (aerial and car counts) should be favoured in order to maximise sample size. Levels of wildlife abundance may thus determine the relative efficiency of methods, and species density is an important factor to consider in the choice of a suitable monitoring method. In Hwange National Park, where animal densities are high and animals habituated to cars, the detection efficiency is about 10 times that measured in our study area (M. Bourgarel & H. Fritz, unpub. data).

Density of vegetation cover will modify the detection ability of methods, through visibility bias (Caro 1999b; Jachmann 2002). Vegetation type may set a threshold in cruising speed during a count for detection to be efficient. At higher speed, observers miss a significant number of animals along the transect. This is illustrated by our results from car counts: in open woodland detection efficiency was higher than in thick shrubland, and it was also similar to efficiency to bicycle counts carried out on the same roads. The heavily bushed or wooded savannah which covers much of our site may require a low speed, and faster methods such as car counts may be less effective in this context. The vegetation constraint is even more problematic in aerial surveys, where the classical undercounting bias of aircraft counts (Caughley 1974; East 1998) is especially pronounced in areas with high vegetation cover (Bayliss and Yeomans 1989; Southwell 1996; Caro 1999b; Jachmann 2002). This is consistent with the low detection efficiency we found with aerial censuses of our study site.

Finally, detection efficiency of methods may differ from one species to another (Reilly and Hoskins 1999). The ability of a method to detect an animal depends on the animal's body size, colour, social organisation and behaviour (Jachmann 2002). The undercounting bias between methods is expected to be less for the more conspicuous species. However, in large dark bodied and social species such as elephant and buffalo, large differences in detection efficiency were still found between methods. This suggests that the vegetation structure in our study area plays a key role, especially in explaining the differences recorded between slow moving ground methods and aerial surveys.

Selecting a census method is always a matter of a trade-off between the positive and negative characteristics of each available technique, with their respective merits varying according to conditions of the study site. Our study illustrates that a simple, low speed and low cost method may be, in some instances, the most suitable way to monitor an area and collect observations of the resident wildlife. With the increasing need for conservation monitoring in various ecological contexts (Caro 1999b; Walsh and White 1999), census techniques must be adapted to site-specific conditions and rely on local facilities rather than being restricted to a standard methodology (Hulme and Taylor 2000), and results from our study may encourage the development of original approaches.

Suitability of the methods in the context of a community based programme

Though seldom mentioned, the costs of conventional methodologies employed during a wildlife survey are generally prohibitive for a conservation project without financial assistance (Hulme and Taylor 2000; Plumptre 2000). For a community-based programme that relies on limited local resources, a counting method has to be cheap enough to be used by the wildlife producer communities, i.e. cost-effective from the local communities point of view (Gaidet et al. 2003). Sophisticated and expensive methods may in some instance provide better estimates of population parameters than simple ones (Peel and Bothma 1995). However, if the aim of the project is an economically viable and sustainable exploitation of natural resources (Child and Child 1991), additional expenditures to improve count estimates should not outweigh benefits derived from a potentially more precise population estimate and hence more productive management of population (Van Hensbergen and White 1995).

In situations where high cost and/or effort of standard methodologies limit their use in wildlife management, alternative methods have been proposed and implemented with success. Simple methods based on hunter activities have been used for several decades in North America and Scandinavia, where the hunter observation index has been proved to be reliable in reflecting changes in population size (Ericsson and Wallin 1999; Solberg and Sæther 1999). Similar simple methods based on foot counts also demonstrated the validity of encounter rate (Hochachka et al. 2000) or kilometric index (Vincent et al. 1991) as monitoring tools. These simple methodologies have been transposed with success to rural African hunters, where some wildlife census techniques were integrated into their common hunting activities (Marks 1994; Noss 1999). Foot counts of wildlife by rural residents were also implemented in some communal areas in Zimbabwe to provide a complementary source of information for quota setting decisions (WWF 1998; SCI Foundation 1999; Hulme and Taylor 2000).

In a communal area with a low density of animals and hunting safari activities, the simplest methods we tested were the more cost effective, i.e. more affordable to obtain a set number of sightings to achieve the goals of profitable and sustainable wildlife management. When we pooled our indexes, the average cost to observe an elephant during a count ranged from around 1$ per individual on bicycle and foot counts up to 8$, 18$, 38$ and 44$ per individual on water point, aerial, car night and car day counts, respectively. It needs to be stressed that the sampling design and effort differed between methods, and the comparison of these crude estimates should be considered with caution. However, differences between costs were large enough to give serious indications on comparative financial requirements of these methods in such a context, and for their use by wildlife producer communities.

Further, for a monitoring method to be effectively used as a management tool in the context of a community-based programme it has to be affordable and efficient, but it also has to rely on the support of local communities (Kiss 1990; IIED 1994). Successful implementation can only be achieved with the active involvement of community members (KWFT and UNEP 1988; Wells and Brandon 1992) through the development of practical and usable participatory methods (Marks 1994; Noss 1999; Hulme and Taylor 2000). In our study, agents involved in ground counts were used to patrol the area either riding a bicycle or walking in the bush, for anti-poaching activities or human–animal conflict surveys. Bicycle and foot transect protocols were hence an additional activity based on a standardisation of their common duties (Gaidet et al. 2003). Although we proposed regular technical support to the local team, it only required a few days of training for observers to be autonomous in the collection of data. After a time, some agents even trained new observers to join the team. This could be considered as a successful step towards autonomous replacement of observers over time and for sustainability in the long term.

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