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Original Research Article

# Cost-benefit analysis of increasing sampling effort in a baited-camera trap survey of an African leopard (*Panthera pardus*) population

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ABSTRACT

The use of baits at camera trap stations has been shown to increase capture rates in population surveys of large carnivores. This study set out to establish the most cost-effective density and duration of sampling for baited-camera trapping (BCT) of leopards in a semi-arid savanna environment. To determine this, we used batches of 30 BCT stations (sampling occasions) to survey a population of leopards (*Panthera pardus*) at Malilangwe Wildlife Reserve in south-eastern Zimbabwe from July to October 2017. We applied combinations of low to high sampling densities (2–7 occasions) and short to long sampling durations (2–14 days) and observed the effects on population estimates and cost of conducting the survey. Sixty-one leopards were identified from 4596 photographs collected over 2940 camera days. At the highest level of sampling (7 occasions and 14 days), 50 out of the 61 recorded individuals were captured more than twice indicating a near-complete survey, so the population estimate at this level (61; 95% CI = 61–67) was used as a benchmark to gauge accuracy of estimates from lower levels of effort. Accuracy and precision of population estimates stabilized over a range of efforts with 4 occasions and 9 days being the most cost-effective and sampling beyond this point incurring increased costs but negligible benefits. A minimum cost of US\$47 $km^{-2}$ was required to obtain a reliable estimate with running costs responding more to changes in sampling density than sampling duration. We concluded that using BCT stations at a density of 0.24 cameras $km^{-2}$ for 9 days is optimal for censusing leopards in semi-arid savannas. Conducting a cost-benefit analysis may help researchers allocate resources and time within budget and technical constraints, ensuring that effort is not expended beyond what is economically or ecologically necessary.


## 1. Introduction

Ecologists use census data to make informed decisions regarding the management of wildlife populations (Bissett et al., 2012; Roy et al., 2016). This is especially important where the target species is of conservation concern, such as leopards

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(*Panthera pardus* Linnaeus, 1758), which are currently listed as vulnerable by the International Union for the Conservation of Nature (IUCN, 2018). Censusing leopard populations has traditionally been done using spoor and scat counts (Stander, 1998). However, due to the species' solitary and elusive nature, estimates from these methods are often unreliable (Gusset and Burgener, 2005; Pirie et al., 2015). Since Karanth (1995) pioneered the use of camera-traps to estimate tiger (*Panthera tigris*) numbers in India, population studies of carnivore species that were previously difficult to survey have increased rapidly (Sollmann et al., 2013; O'Connor et al., 2017). Advances in digital camera technology have also promoted the wide-scale adoption of the methodology by increasing portability and lowering hardware costs (Rovero et al., 2013; Trolliet et al., 2014). Camera-trapping is currently the most successful tool available to survey individually identifiable cats (Royle et al., 2017; Devens et al., 2018).

An understanding of how changes in sampling effort influence the accuracy and precision of population estimates is especially important for species that are difficult to survey (Si et al., 2014). Camera-trap surveys of rare or elusive carnivores usually suffer from low capture rates (Belbachir et al., 2015; Braczkowski et al., 2016; Rocha et al., 2016). This is a concern, because a low sample size precludes in depth population analyses (O'Connell et al., 2010; Tobler et al., 2013). To improve capture rates, researchers have increased sampling intensity (Sun et al., 2014; Brassine and Parker, 2015), extended sampling periods (Tobler et al., 2013; Gerber et al., 2014) and adopted the use of baits at camera stations (Gerber et al., 2012; Grant, 2012; du Preez et al., 2014; Roy et al., 2016).

Baited camera-trapping (BCT) has been shown to improve capture rates of leopards (du Preez et al., 2014). However, optimal density and duration of sampling for BCT has not been determined. Since increasing sampling effort has cost implications, establishing the optimal sampling intensity for different environments is an important step towards improving the cost effectiveness of the BCT method. We hypothesised that increasing sampling effort would initially result in significant improvements to the accuracy and precision of population estimates, but a point would be reached beyond which further gains are negligible. Given that high levels of sampling would also increase the cost of the survey, what then is the optimal sampling effort for BCT for leopards in different savanna environments? This study sought to fill this information gap by testing the effect of varying sampling effort in a semi-arid Zimbabwean savanna. Our objectives were twofold, first we tested the effect of different combinations of sampling density and duration on the accuracy and precision of population estimates and second, we carried out a cost-benefit analysis to determine the optimal sampling density and duration for BCT for leopards in the study environment.

## 2. Material and methods

### 2.1. Study area

The study was conducted at Malilangwe Wildlife Reserve (MWR), a medium-sized (490 $km^2$), fenced, protected area in south-eastern Zimbabwe (20°58′ and 21°15′S and 31°47′ and 32°01′E) (Fig. 1). MWR is a non-hunting property whose main objectives are conservation, ecotourism, and community development. Altitude ranges from 290 m to 500 m above sea level (Traill and Bigalke, 2007). Rainfall, which is highly variable (mean = 565 mm per annum, n = 66, CV = 34%), is seasonal, with approximately 84% falling between November and March. Droughts are frequent. The average minimum and maximum monthly temperatures range from 13.4 °C (July) to 23.7 °C (December), and 23.2 °C (June) to 33.9 °C (November), respectively (Clegg, 2010).

Alluvium, forest sandstone, gneiss and basalt are the dominant geological substrates. Vegetation cover is diverse, ranging from grassland to dry, deciduous woodland, with 38 vegetation types occurring on soils ranging from 90% sand to 40% clay (Clegg and O'Connor, 2012). The main prey species (density in parentheses) are impala (*Aepyceros melampus,* 13.6 $km^{-2}$), nyala (*Tragelaphus angasii,* 0.38 $km^{-2}$) and bushbuck (*Tragelaphus sylvaticus,* 0.22 $km^{-2}$). Competing predators include lion (*Panthera leo*, n = 48), spotted hyena (*Crocuta*, n = 60), wild dog (*Lycaon pictus*, n = 27) and cheetah (*Acinonyx jubatus,* n = 11) (Clegg, 2017).

### 2.2. Ethical considerations

To collect home range data, five male and five female leopards were trapped and fitted with Followit Global Positioning System (GPS) collars (Followit, Lindesberg, Sweden) from May 07 to June 20, 2017. Immobilization procedures were carried out by a certified para-veterinarian (license number: 2017/25) following professional guidelines stipulated by the American Society of Mammalogists (Sikes and Animal Care and Use Committee of the American Society of Mammalogists, 2016). Impala meat was used as bait and culling was done by licensed hunters in accordance with Zimbabwean regulations (Government of Zimbabwe, 1975). MWR has a healthy impala population (±6658 over 490 $km^2$) (Clegg, 2017) and the number taken off as baits did not exceed the annual management quota of 300. All animal handling operations in this study were cleared by the Chinhoyi University of Technology Ethics Committee (clearance certificate number: 01/17).

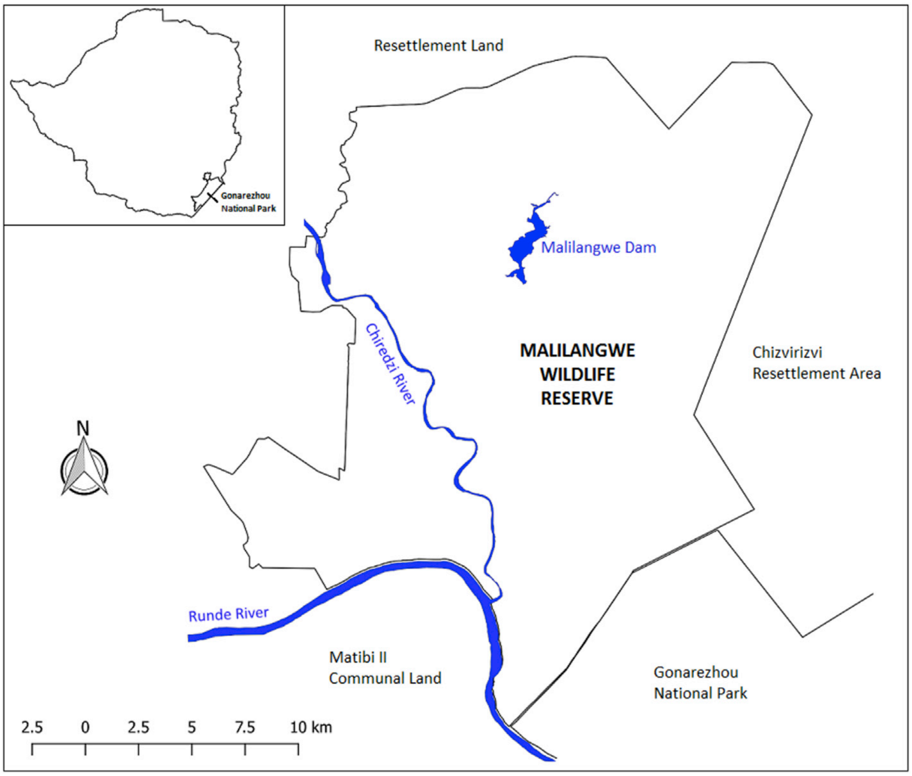


**Fig. 1.** Map showing the location of study area, Malilangwe Wildlife Reserve, south-east Zimbabwe.

### *2.3. Study design for investigating effect of survey effort on population estimates*

#### *2.3.1. Density and positioning of baited-camera traps*

Data were collected over seven sampling occasions. Each occasion comprised a 14-day period during which 30 baited-camera traps were setup across the study area. To avoid bias, each set of 30 baits was evenly distributed across the reserve in a stratified-random pattern. This was done by overlaying a grid of 210 squares (each representing 1.53 × 1.53 km) onto the study area map in Quantum GIS v2.18 (QGIS Development Team, 2016) and then subsampling the grid, without replacement, to obtain 7 sets of 30 evenly distributed squares. In each square, a sample point was placed at random. A baited camera trap was then setup at the closest road intersection to this point. This was done to increase the probability of the bait being found because leopards frequently move along roads (Funston et al., 2010; Mills et al., 2013). In squares without road intersections, the baited-camera trap was placed next to the closest road. In cases where there were no roads, placement was as close as possible to the nearest road in one of the adjoining grid cells. Since trap sites were visited using a vehicle, placing them near roads facilitated access and also complied with MWR's policy of no off-road driving. Sampling intensity was incrementally increased by 0.06 cameras km$^{-2}$ every 14 days, starting at an initial camera density of 0.06 cameras km$^{-2}$ (30 stations) and ending at a maximum of 0.43 cameras km$^{-2}$ (210 stations).

Collared individuals were tracked in the field using VHF telemetry and GPS data downloaded with a UHF receiver (August 08, 2017 to January 29, 2018). These data were used to calculate home range sizes using 95% kernel density estimation in QGIS. Knowledge of home range sizes of leopards is important as it is informative on detection rates at different camera spacings (Wegge et al., 2004; Maffei et al., 2011).

#### *2.3.2. Camera-trap setup*

Bait sites were located in the field using a GPS device. Impala intestines soaked in blood and stomach contents were dragged along the road for the last 300 m of the route to the site in anticipation that leopards would pick up the scent and follow the trail. At the site, two trees spaced 2–4 m apart were selected; one for the bait and the other for the camera. A skinned impala carcass was secured to the bait tree with wire. Skinning prolonged bait life by delaying decomposition. A forked leading pole was placed against the bait-tree to provide easy access for leopards (Fig. 2). To prevent feeding by spotted hyena, baits were hung such that the back legs of the carcass were at least 2 m above the ground. Baits were also covered with leafy branches to camouflage them from vultures. A Cuddeback C2 infra-red camera (Cuddeback, WI, USA), housed in a metal box for protection, was secured to the camera tree to the right of each bait, with its line of sight at 90° to the leading pole.

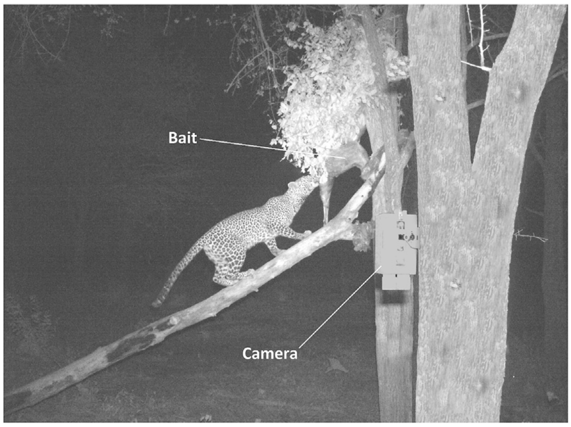


**Fig. 2.** Arrangement of bait, leading pole and camera for the BCT method.

When a leopard climbed up the pole to feed, the sensor triggered the camera and a photograph was taken. Due to its position to the right of the leading pole, the camera consistently took a photograph of the animal's right profile (Grant, 2012). The minimum interval between photographs was set to 1 min and the picture quality to 5 megapixels. Camera-trapping began with sampling occasion 1 and then progressed to occasions 2, 3, 4 up to 7. Logistical constraints prevented all 30 baited-cameras being setup in a single day, so this was done in batches of 15 over two consecutive days. Baits that were removed by lions before leopards encountered them were replaced. Trapping stations were visited every third day and photographs downloaded from the cameras. On the 15th day, baits were taken down, memory cards erased and the cameras moved to the sites for the next sampling occasion. Camera trapping was done in 98 days, from the 1st of July to the 22nd of October 2017.

### 2.4. Determining survey cost

For each day of fieldwork, the time spent (in hours), distance travelled (kilometres) and personnel involved were recorded. This information was used to calculate the fuel and labour costs of site preparation, culling of impala, hanging, monitoring and removal of baits and vehicle services. Fixed (hardware) and variable (running) costs were calculated separately. Following du Preez et al. (2014), a 10% contingency was added to fixed costs to cater for failure and destruction of equipment. For each sampling occasion, 40 impala baits were required, 30 for hanging and 10 for replacements. In this study, baits were not a cost as they were provided free by MWR. However, such may not be the case for other studies as bait of other forms may need to be procured. To cater for this, we assigned the value (US$30) of a goat (*Capra hircus*) (most affordable and accessible alternative to impala) to each bait in our cost calculations, following Balme et al. (2014). BCT requires a minimum of two people to carry out the work and labour cost was calculated using the hourly rate for the lowest paid employee at MWR.

### 2.5. Data analyses

Photographs were scrutinised, and individual leopards identified from their unique spot patterns. The resulting identikit was used to construct capture histories for each combination of sampling density (2–7 occasions) and duration (2–14 days). The histories were then fed into CAPTURE software (White and Burnham, 1999) and population estimates, with 95% confidence intervals, generated for each density-duration combination using maximum likelihood capture-recapture analyses. A constant capture probability model was used to ensure comparability between population estimates. The probability ($P$) of detecting a leopard present at the time of the survey was calculated as;

$$P = M_{t+1} \Big/ \widehat{N},$$

Where $M_{t+1}$ = total number of leopards identified by the survey, and $\widehat{N}$ is the population estimate (Anwar et al., 2010; Sharma and Jhala, 2011).

Trap stations were visited at 3-day intervals so costs (US$) were calculated for each level of sampling density at durations of 3, 6, 9, 12 and 14 days. The relative influence of sampling density and duration on total cost was investigated by comparing standardized coefficients derived using the multiple linear regression routine of SPSSv16 (SPSS Inc, 2007). The relationship between cost and the accuracy and precision of the reliable population estimates was then explored by overlaying the population estimates onto a contoured cost surface.

## 3. Results

Two hundred and ten baited-camera trap sites collected data over seven, 14-day, sampling occasions, over a period of 98 days. The cumulative survey effort was 2940 camera-days and of these, 17 were lost to camera failure. All cases of camera failure were due to elephant (*Loxodonta africana*) damage. Lions and vultures (*Gyps spp.*) often robbed baits, while hyenas sometimes knocked off the leading pole. A total of 7070 photographs of leopards were recorded, with 65% being usable for individual identification. Each leopard's spot patterns were unique and as such the right flank of each individual leopard was different to any other animal. If the right-side profile was photographed, individuals could be unambiguously distinguished from each other. This applied even where the photographs contained partial shots of a leopard or when posture varied. The leading pole ensured that feeding leopards were consistently aligned broadside in photographs, thereby revealing the presence or absence of male external genitalia (du Preez et al., 2014). In this way, the sex of each adult individual was easily determined. A total of 61 individual leopards ($M_{t+1}$), (33 females, 23 males and 5 sub-adults), were photographed over the study period (Table 1) and of these, 50 were captured 2 or more times. The adult sex ratio was 1 male to 1.4 females. Because the scrotum is less distinct in males <2 years old we could not distinguish sexes in the sub-adult class (Balme et al., 2012). Sub-adults (≥1 year) were counted, while small cubs (<3 months) were not recorded. This was because cubs did not have identifiable spots and have a low chance of survival, due to infanticide and killing by competing predators. CAPTURE estimated the overall population ($\widehat{N}$) at 61 (95% CI = 61–67) leopards. Home range sizes (mean = 46.4 $km^2$, range = 9.0–112.1 $km^2$) were calculated for 8 (four males and four females) out of the 10 collared leopards. A male leopard shrugged off its collar and one female left the property early in the study.

### 3.1. Effect of sampling density and duration on population estimates

Increasing sampling density and duration increased the accuracy and precision of population estimates. Accuracy and precision stabilized at a sampling density of 4–7 occasions and durations of 7–14 days (Fig. 3). This stabilization was achieved by a minimum of 2 cameras per smallest home range (9 $km^2$ for MWR). However, we observed that sampling efforts beyond 9 days resulted in negligible gains in accuracy or precision of estimates. At the highest level of effort (7 occasions and 14 days), the probability of detecting any of the individual leopards present at the time of sampling ($P$) was 1. This represents a near-complete survey and therefore we considered $\widehat{N}$ for this level of effort (61; 95% CI = 61–67) to be very close to the true population and used it to gauge the accuracy and precision of lower levels of effort. Within the region of stabilized population estimates (4–7 occasions and 7–14 days), the probability of detecting leopards was high ($P \geq 0.93$).

### 3.2. Appraisal of survey costs

The costs for running the BCT survey were split into fixed (equipment) and variable (running) categories (Tables 2 and 3). The overall cost for the study was $28 924 with fixed costs being 56.1% (Fig. 4(a)). Running costs that accumulated with increasing sampling density (site visitation, bait acquisition and hanging) were recorded separately from those incurred from increased sampling duration (visiting sampling sites) and the proportion of each activity is given in Fig. 4(b).

Multiple linear regression, with total cost as the dependent variable and standardized sampling density and sampling duration as predictor variables (adj $R^2 = 0.997$, $P < 0.001$), showed that a unit increase in sampling density increased cost nine times more than a unit increase in sampling duration (standardized regression coefficient for density = 0.993 compared to 0.109 for duration).

### 3.3. Relationship between cost and accuracy and precision of estimates

Cost increased with increasing sampling density and duration (Fig. 5). The minimum cost of achieving a stable estimate (4 occasions and 9 days - Fig. 3) was US$22 953, which is equivalent to US$47 $km^{-2}$. Sampling beyond this level of effort increased costs but resulted in negligible improvement in accuracy and precision.

**Table 1**
Cumulative capture results for sampling occasions of the baited camera trap survey conducted at Malilangwe Wildlife Reserve.

| Occasion | 1 | 2 | 3 | 4 | 5 | 6 | 7 | $M_{t+1}$ |
|---|---|---|---|---|---|---|---|---|
| Animals caught | 26 | 23 | 34 | 35 | 29 | 25 | 22 | |
| Total marked | 0 | 26 | 36 | 49 | 55 | 57 | 59 | 61 |
| Newly caught | 26 | 10 | 13 | 6 | 2 | 2 | 2 | |

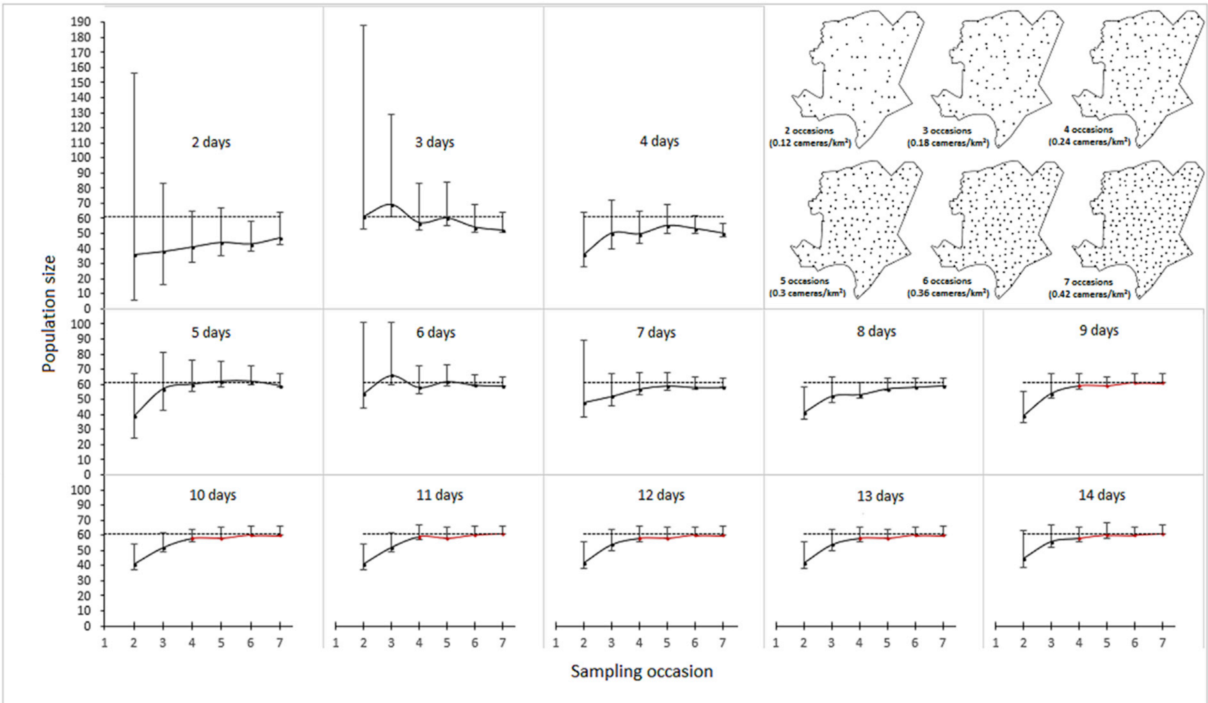


**Fig. 3.** Response of population estimates to increasing sampling density (sampling occasions) and duration (days). Maps depict positions of the baited-camera traps for the different levels of sampling density. Error bars represent 95% confidence intervals calculated by CAPTURE. The region of stabilized estimates is shown in red. The dashed horizontal line represents the assumed true population. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 2**
Fixed costs for the study.

| Equipment | number | US$ | | | |
|---|---|---|---|---|---|
| | | unit price | Sub-total | Contingency (10%) | Total |
| Camera traps | 30 | 339 | 10 170 | 1017 | 11 187 |
| Metal housing | 30 | 69 | 2070 | 207 | 2277 |
| 3-pack mount | 30 | 60 | 1800 | 180 | 1980 |
| Image viewer | 1 | 143 | 143 | 14.3 | 157.3 |
| 8G SD cards | 30 | 8 | 240 | 24 | 264 |
| Batteries (AA) | 480 | 0.66 | 317 | 31.7 | 348.7 |
| | | | | | **16 214** |

**Table 3**
Variable costs (US$) for the study. To get total cost, at each combination of sampling density and duration, add the value of fixed costs.

| | | Sampling duration (days) | | | | |
|---|---|---|---|---|---|---|
| | | 3 | 6 | 9 | 12 | 14 |
| Sampling occasion | **1** | 1554 | 1619 | 1685 | 1750 | 1816 |
| | **2** | 3108 | 3239 | 3370 | 3501 | 3631 |
| | **3** | 4662 | 4858 | 5055 | 5251 | 5447 |
| | **4** | 6216 | 6478 | 6739 | 7001 | 7263 |
| | **5** | 7770 | 8097 | 8424 | 8751 | 9078 |
| | **6** | 9324 | 9717 | 10 109 | 10 502 | 10 894 |
| | **7** | 10 878 | 11 336 | 11 794 | 12 252 | 12 710 |

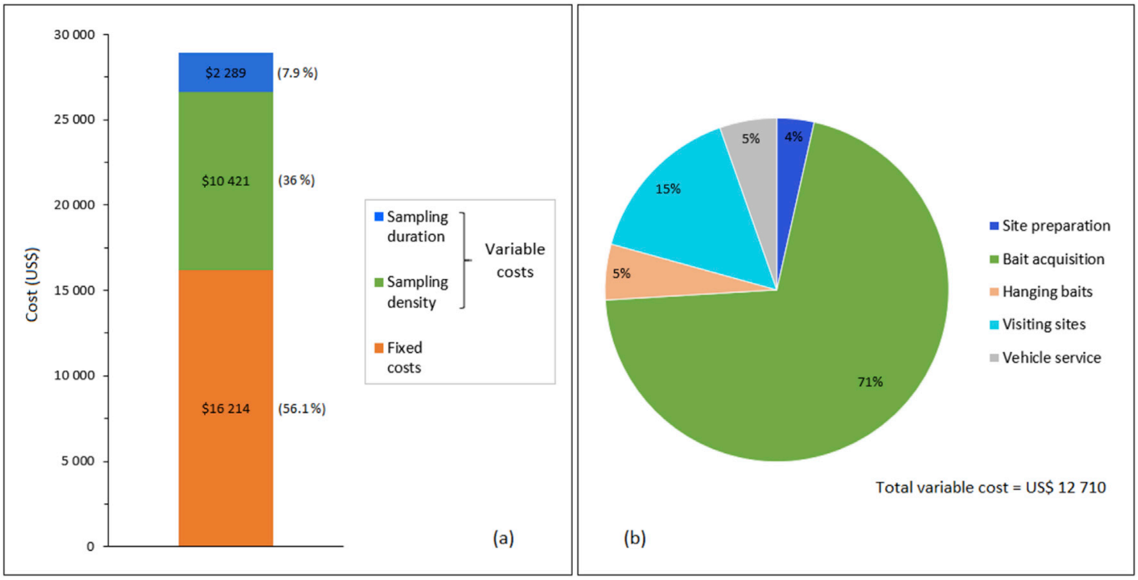


**Fig. 4.** Summary of survey costs. Proportion of fixed versus variable costs (a). Categorization of variable costs by activity (b).

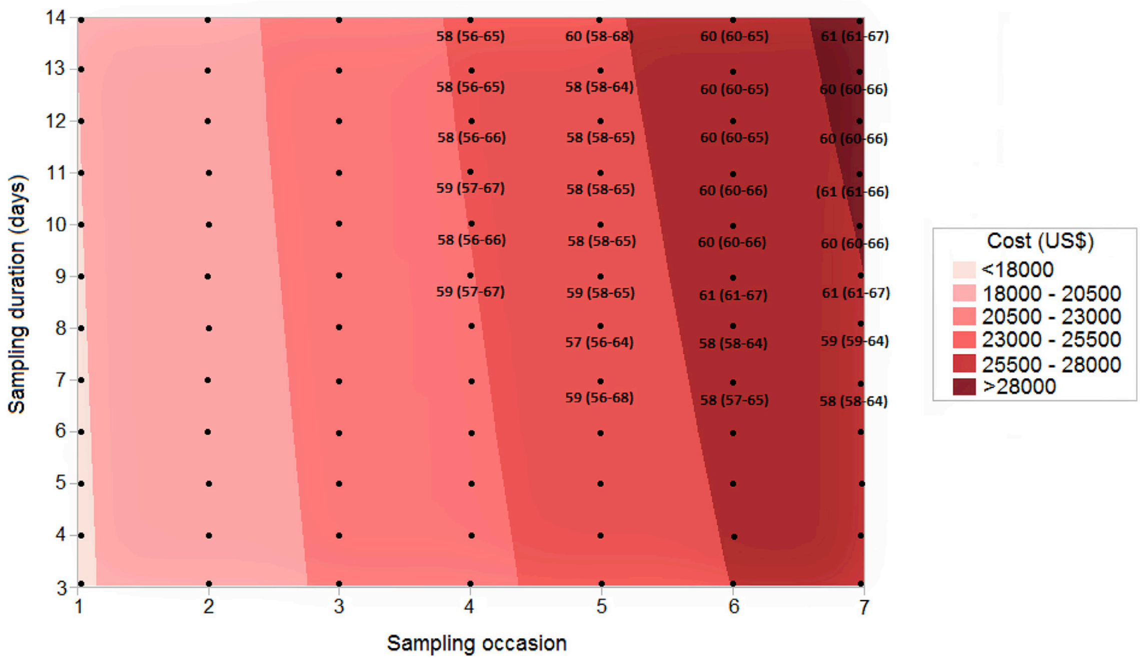


**Fig. 5.** Contour plot showing the total cost of achieving stabilized population estimates (95% confidence intervals in parentheses) in relation to varying sampling density (sampling occasions) and duration (days).

## 4. Discussion

This study investigated the effect of varying sampling density and duration on the accuracy and precision of population estimates and explored the cost-effective level of sampling for surveying leopards using the BCT method in MWR. Accuracy and precision of population estimates stabilized over a range of efforts, with 4 occasions and 9 days being the most cost-effective. Sampling beyond this point resulted in increased costs but negligible benefits. This outcome was expected.

### 4.1. Effect of sampling effort on population estimates

Gerber et al. (2014) have shown that when a large proportion of individuals are captured two or more times, the estimate is likely to be close to the true population. In this study, 50 out of the 61 individuals were captured 2 or more times, indicating a near-complete survey. It has already been established that high camera densities (Sun et al., 2014; Brassine and Parker, 2015), long sampling durations (Wegge et al., 2004; Si et al., 2014; O'Connor et al., 2017) and use of baits (Grant, 2012; du Preez et al., 2014; Roy et al., 2016) can increase the probability that most individuals in the population are captured. Even where detection rates are low, all individuals will eventually be recorded if sampling duration is long enough (Gerber et al., 2014). In this study, we showed that the required sampling period to achieve a near-complete survey can be significantly reduced by using a high sampling density of baited-cameras (0.24 $km^{-2}$). With this sampling strategy a near-complete survey was achieved over an area of 490 $km^2$ in just over a month, which is considerably shorter than most camera surveys for leopards. A near-complete survey is desirable because there is less reliance on statistical extrapolation, and a short survey period reduces the risk of violating closure. Baits helped in this regard as leopards were attracted to them, positioned ideally in front of cameras and stayed at sites for longer, allowing the collection of a large number of identifiable photographs over a short period of time. Where surveys are near-complete, the true population size, sex ratio and age structure can be confidently estimated. Studies that do not have a reference for the true population often assume that software will correctly extrapolate results. This study, however, shows that at low samples sizes CAPTURE software may not reliably estimate population size.

### 4.2. Relationship between sampling effort and cost

We observed a subtle tradeoff between sampling density and duration that was less intuitive, and when related to cost, this relationship had implications for the most cost-effective sampling strategy. Accuracy and precision stabilized over a range of sampling densities and durations but cost over this range varied because the magnitudes of the effects of density and duration on expense were different. For example, a strategy of 7 days and 5 sampling occasions resulted in a reliable estimate. If, however, sampling duration was increased to 9 days, then only 4 sampling occasions were required. Given that a unit increase in sampling density was nine times more expensive than a unit increase in duration, the 9 days and 4 occasions strategy was the more cost-effective option. It is possible that the two-day increase in duration was long enough to allow events that may have precluded detection of individuals, such as mating or feeding on a kill, to be completed. In addition, leopards cover great distances (up to 17 km per night, and 33 km over 24 h) during their search efforts or territorial patrols (Seidensticker and Lumpkin, 2004). Therefore with 2 baited cameras per smallest leopard home range (9 $km^2$ at MWR) at the 4 sampling occasions level of effort, it is likely that actively roaming leopards that were previously not captured be detected over two additional days of sampling. Increases in duration beyond 9 days provided no further reduction in cost, because 4 sampling occasions were still required to derive a reliable estimate. For this reason, increasing sampling duration beyond 9 days was not recommended for the study environment.

### 4.3. Challenges

A potential source of bias was introduced when lions and vultures consumed baits before leopards had an adequate chance of finding them. Lions could ably climb trees and all attempts to prevent them from accessing baits failed. Continual replenishment of baits would appear to be the only solution to this problem. Hyenas often visited camera stations and sometimes knocked over the leading pole in their attempts to feed at the bait. Since the pole facilitated the correct positioning of a leopard in a photograph, this reduced the number of usable pictures. Poles that had been knocked over were repositioned during routine monitoring of camera stations. It is possible that activity of competing predators at camera stations may have prevented some age or sex classes from being recorded. Infra-red cameras traps produce black and white night-time images and are prone to motion blur. In this study, rosette patterns from both day and night images were sufficiently clear such that individual leopards were easily identified. Due to the use of baits at camera stations, few images were blurred as leopards were often stationary when photographed. Over the 14 days of sampling, each camera station therefore provided numerous photographs of the same leopard from which identification could be made.

Where hunting is practiced, baits are often used to attract leopards and this can lead to baits being associated with risk. A limitation of the BCT method, therefore, is the possible exclusion of bait-shy leopards from being recorded. However, in a comparison between baited and unbaited surveys on two sites sampled in a hunting area, du Preez et al. (2014) recorded more leopards at baited than at unbaited camera stations, suggesting that leopards were not bait-shy. Based on this, we concluded that the proportion of bait-shy leopards in our non-hunted study population was very low and that our total estimate of 61 represented a near-complete survey. A survey of this nature is labor and time intensive and logistically difficult to carry out. Proper preparation and organization are key to effectively carrying out such a survey.

### 4.4. Implications

Absence of reference cost-structures can limit the adoption or funding of some methodologies. While baited-camera trapping is costly, its fixed costs are lower than the conventional unbaited approach because, for the same level of sampling, only half the number of cameras are required (du Preez et al., 2014). Additionally, running costs of unbaited camera surveys can be higher as sampling periods must be extended to collect sufficient data because of the low detection rates. Baits, which are a key component of the BCT technique, constituted a significant proportion of cost (31% of total and 71% of running costs). If baits can be acquired for free or at a cheaper price, this can significantly lower costs. Nevertheless, it is our position that the benefits realized from using baits in this study outweigh the cost of their procurement. We believe that the large number of identifiable pictures collected and high capture rates would not have been possible without baits. Where applicable, we therefore recommend using baits to improve capture rates.

The study was conducted in a semi-arid tropical savanna and the findings may have relevance for leopard surveys in similar environments. Although we cannot extensively comment on the generalizability of BCT, we believe that the methodology presented here may be applicable for similarly marked, individually identifiable carnivores such as jaguar (*Panthera onca*), ocelot (*Leopardalis pardus*) and clouded leopards (*Neofelis nebulosa*). The BCT method may be limited when surveying tigers and snow leopards (*Panthera uncia*). Although tigers may readily take baits, it is likely that they do not balance well on a leading pole because they are heavy. In this study, it was noted that where lions visited camera sites they could not balance on the leading pole and therefore tigers being larger, may have the same challenge. In the case of snow leopards, BCT may not be suitable due to the lack of adequate trees in the environment in which they exist.

The potential of the BCT method to provide novel data on leopards requires further investigation. Because the method ensures that individuals are consistently positioned at right angles to a camera's field of view, there may be scope for measuring morphometric dimensions of leopards from photographs collected by BCT. In addition, feeding at baits may simulate natural kills and by coupling camera data with GPS collar telemetry gender differences in leopard behavior and interspecific carnivore interactions around baits could be explored.

## 5. Conclusions

Baited-camera trapping can improve the amount and quality of data collectable from leopard surveys. We concluded that using baited-camera stations at a density of 0.24 $km^{-2}$ for 9 days is optimal and cost effective for BCT surveys of leopards in semi-arid environments. This study confirmed our hypothesis that increasing sampling effort initially improves the accuracy and precision of population estimates, but a point will be reached beyond which further gains are negligible. Conducting a cost-benefit analysis may help researchers allocate resources and time within budget and technical constraints, ensuring that effort is not expended beyond what is economically or ecologically necessary. This study is the first to robustly investigate the interplay between sampling effort, accuracy and precision of estimates, and cost in BCT surveys of large carnivores.

## Conflicts of interest

The authors declare no conflict of interest.

## Acknowledgements

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