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Spoor density as a measure of true density of a known population of free-ranging wild cheetah in Botswana

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Abstract

Knowledge of the abundance of animal populations is essential for their management and conservation. Determining reliable measures of abundance is, however, difficult, especially with wide-ranging species such as cheetah *Acinonyx jubatus*. This study generated a correction factor to calculate true cheetah density from spoor survey data and subsequently tested its accuracy using the following season's data. Data were collected from October 2005 to December 2006 on a known population of wild, free-ranging cheetah in the Jwana Game Reserve, Botswana. The cheetahs in the area were captured, tagged and photographed. The reserve was divided into twelve 9 km transects covering all vegetation types and prey densities. The total sampling distance was 8226 km, with a spoor density of 2.32 individual cheetah spoor per 100 km^2. To determine a precise and accurate spoor density, it was necessary to sample for a longer period during the dry season (April–September) than during the wet season (October–March). This difference may be due to cheetah behavioural changes with seasonal variations in habitat and prey. The true density was 5.23 cheetahs per 100 km^2 ranging from 3.33 to 7.78 at the low and high points of the population, respectively. A positive linear correlation between spoor and true density was observed. This relationship differed in the wet and dry season and required refinement with the following season's data. Correction factors may be viable, but require further testing taking the behavioural responses to seasonal, habitat and prey variations into consideration.

Introduction

An accurate estimate of population density is essential for the management and protection of endangered species, such as the cheetah *Acinonyx jubatus*, which is listed as vulnerable by IUCN (2007). As in most large carnivores, the cheetah population is declining (Marker *et al*., 2003) and the ability to develop an accurate, repeatable and cost-effective method to assess population trends and density is required. Direct methods such as visual counts and physical mark and recapture are often the method of choice; however, they rely on the visual recognition of individuals and in large carnivores such methods are often expensive, difficult and time consuming (Stander, 1998; Gusset & Burgener, 2005). When direct methods are too expensive or impractical, as is often the case in low-density species such as the cheetah (Mills, 1997; Wilson & Delahay, 2001), the use of indirect measures that rely on the presence and detection of field signs, as an index of true density, is a more favourable option. For example, it is possible to obtain relative estimates of carnivore populations by calculating the number of scat samples, den sites or spoor seen in the study area (Mills, 1997). Spoor surveys, in particular, have been used extensively as a monitoring tool in several species, including leopard *Panthera pardus*, lion *Panthera leo*, brown hyena *Hyaena brunnea* (Stander, 1998; Funston *et al*., 2001), caracal *Caracal caracal* (Melville & Bothma, 2006) and mountain lion *Felis concolor* (Smallwood & Fitzhugh, 1995). They are less invasive and more cost-effective than direct methods (Jewell, Alibhail & Law, 2001), while remaining repeatable, objective, valid and accurate (Stander *et al*., 1997; Gusset & Burgener, 2005). However, they only provide a relative estimate of population size and a quantifying technique must be applied to calculate the population density. One technique is to use spoor measurements to identify and count individuals within a population. This has been applied to mountain lion (Lewinson, Fitzhugh & Galentine, 2001), tiger *Panthera tigris* (Sharma, Jhala & Sawarkar, 2005) and black rhino *Diceros bicornis* (Jewell *et al*., 2001). However, it requires further study before it may be applicable for use in the field with varying substrates (Lewinson *et al*., 2001).

Alternatively, by double sampling the population by a direct technique such as the physical capture and marking of individuals and an indirect technique such as spoor tracking, the relationship between them may be quantified and a correction factor to calibrate the indirect method may be calculated (Eberhardt & Simmons, 1987; Wilson & Delahay, 2001). Stander (1998) showed a significant linear relationship between spoor counts and true density determined by the recognition of marked or collared lion, leopard and wild dog *Lycaon pictus*. Gusset & Burgener (2005) used Stander's regression equation to estimate the leopard population in the Waterberg region of South Africa and showed the result to be similar to that derived from the identification of individuals from spoor measurements. Funston *et al.* (2001) also found a similar regression equation in lions and extrapolated the slope of the line to brown hyena, spotted hyena *Crocuta crocuta*, cheetah and leopard.

Stander (1998) found the linear relationship between spoor counts and true density to be species specific and predicted that the slope of the line would vary with habitat use and species behaviour. It is therefore reasonable to assume that differences in lion, leopard and wild dog home range, daily movements and road usage, compared with cheetah, will cause differences in this relationship. However, this correlation has not yet been quantified. This paper's aim is to compare cheetah spoor counts with capture and radio collaring information in an open and free-ranging population of cheetah in Southern Botswana. Thus, the objectives of this study were to calibrate the spoor survey technique to calculate a correction factor for use in future cheetah spoor surveys and to subsequently test the correction factor in a spoor survey in the following wet season.

Materials and methods

Study area

The study was conducted in Jwana Game Reserve, Jwaneng, Botswana (24°33′09.3S, 024°43′38.0E). The cheetah population within the area had been monitored since November 2003 and the spoor survey was conducted from October 2005 to September 2006. The experimental zone had an area of 180.31 km^2 plus an additional 32.62 km^2 covered by the Debswana Diamond Mine. The actual mine area is fenced and although accessible to predators via warthog *Phacochoerus africanus* holes, it was assumed this area was not regularly utilized due to high human disturbance and a lack of prey. Jwaneng city centre is located 5 km south of the mine and cattle posts surround the game park. The reserve is enclosed by game fencing, allowing the free movement of predators through warthog holes and under fences. The main predators are cheetah, leopard, brown hyena and black-backed jackal *Canis mesomelas*.

The area is sandveld, with the major tree species being *Acacia mellifera*, *Acacia luedritzii* and *Boscia albitrunca* (pers. obs.). Vegetation is primarily open semi-wooded savannah mixed with a moderate to thick bush. The topography of the area is flat, in a sandy aerosol environment with no hills or high rises, rivers or lakes. The annual rainfall in 2006 was 581 mm (Jwaneng Airport Metrology Centre, 2007). The dry season is from April to October, and the wet season is from November to March. The temperatures range from below 0 °C to over 40 °C (Greenway, 2001). The soil type is desert sand and the roads in the reserve are primarily sandy soils with two calcrete main roads. As larger predators, including cheetah in thick bush areas, frequently, if available, use roads to travel on (Kutilek *et al.*, 1983), spoor tracking was conducted on these sandy roads.

Spoor survey design

The spoor survey was divided into two seasons: the wet season from October 2005 to March 2006 and the dry season from April 2006 to September 2006. The spoor survey was continued for 3 months in the subsequent wet season from October 2006 to December 2006 in order to test the correction factor.

The game reserve was divided into four sections, with three transects of 9 km each driven in each section, thus yielding 12 transects in total (Fig. 1). Transects were designed to reduce the chance of double sampling by making

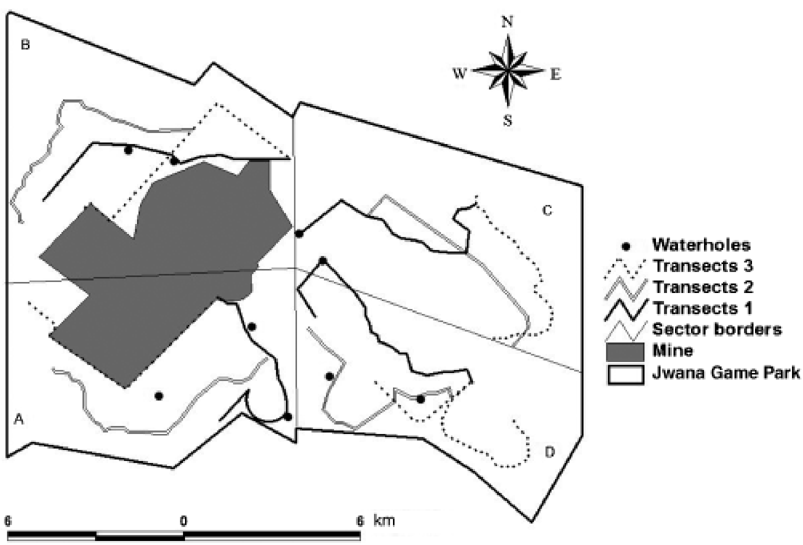

Figure 1 A map of Jwana game park, showing the mine area, sectors, waterholes and the transects driven during the spoor survey.

them as linear as possible, while including all habitat types. One transect per section was driven daily, in a systematic order, to ensure at least 48 h had passed since the transect was last surveyed. The total distance sampled was 108 km; this equates to a ratio of 1 km of road sampled for every 1.67 km^2 study surface area. The sum of the distance surveyed was expressed as a ratio of the sample area, that is 1 km surveyed: x km^2 survey area will be referred to as road penetration (Stander, 1998). Therefore, a high road penetration will actually be reflected by a low number.

One or two 4 × 4 vehicles were driven along the transects at 8–12 kph. All large predator spoor (cheetah, leopard, brown hyena and domestic dog *Canis lupus familiaris*) were identified and recorded with the date, time, location, number of animals and individual cheetah identity if known. Owing to the social grouping, cub age, known GPS locations from cell collar information and a distinctive round hind foot in females from one specific cheetah family (F6), it was frequently possible to identify spoor to a specific individual. Each individual was only recorded once per day. Spoor identification was made by trained researchers with a minimum of two people per vehicle. The lead researcher had 3 years of experience in spoor tracking and put additional researchers through thorough training and testing on spoor identification. Spoor were recorded as individual spoor, not as a family group, that is five spoor found together were counted as five individual spoor. Spoor tracking began 1 h after sunrise and ended by 11:30 h. Preparing the roads before sampling has not been found to be beneficial (Smallwood & Fitzhugh, 1995), and was therefore not performed in this survey.

Cheetah population

The number of cheetah utilizing the game park, defined as the true cheetah density, was calculated independently of spoor counts. The cheetah population had been monitored daily by radio telemetry, GPS cell collar data and opportunistic visuals since October 2003. Additionally, cheetahs were identified by spot patterns from tourist photographs and were individually recognizable by researchers and game park staff by the presence of ear tag/collar and spot patterns. On average, 89% of cheetahs present in the reserve each month were known individuals. All spoor believed to be from new individuals were followed with the aim to obtain visuals and set traps for their capture. Cheetahs were captured using a double-ended box trap using limited access or live bait held in a separate holding cage. They were tranquilized by the project veterinarian and a medical work-up was performed (Marker, 2002). Ear tags and micro-chip ID transponders were inserted for individual identification and ID photos were taken, enabling spot pattern identification. All cheetahs were released at their capture sites. A cell collar was placed on a lone female (F5, in October 2005), who gave birth to five cubs in February 2006; four of these cubs survived beyond September 2006. GPS locations were recorded one to four times a day for this female and visuals were obtained at least once a month after the cubs had left the lair. A second female (F6) with four 9-month-old cubs was captured during October 2005. This female left her sub-adult cubs in July 2006. The mean number of days between opportunistic visuals of this family was 11.8 ± 2.2 days. F6 returned with a new litter of four cubs in November 2006. In addition to F5 and F6, visuals of unidentified cheetah occurred almost monthly; the known locations of F5 and F6, in conjunction with the lack of ear tags and spot patterns, made it possible to assign these cheetahs as 'unknown'. Attempts to capture these cheetahs were unsuccessful; however, all reports from tourists and game park staff supported the population data.

To take into consideration the varying population, a mean population density for the wet and dry season was calculated, based on the number of cheetah known to be present each month within the 180.31 km^2 reserve, divided by the number of months per season. To examine the relationship between true density and spoor count data, comparisons were drawn between the true density for one specific family (F5) and the spoor density relating to that family, in the wet and dry season. This was then recalculated and graphed with two families (F5 and F6) and with all cheetah (F5, F6 and unknowns).

Validation of the correction factor

The second wet season data between October 2006 and December 2006 were used to validate the relationship between spoor count data and true density. A new wet season correction factor was calculated by plotting the cheetah family data points (i.e. F5, F5 and F6 and all cheetahs) for the first wet season and second wet season, subsequently generating a linear trend line for all the points.

Prey counts

From March 2006 to December 2006, visual prey counts were conducted on the spoor transects concurrently with the spoor counts. One observer in addition to those performing the spoor survey counted species of prey, number of prey and visually estimated the distance from the road. These data were used to calculate prey density during the wet and dry season. Prey was defined as blue wildebeest *Connochaetes taurinus*, zebra *Equus burchelli*, warthog, ostrich *Struthio camelus* and all antelope species (except eland *Tragelaphus oryx*).

Statistical methods

Spoor frequency and spoor density were calculated in accordance to Stander (1998). Spoor frequency may be defined as the mean number of km per individual spoor (Stander, 1998), or as the mean number of km travelled to locate one spoor. Spoor density is defined as the number of individual cheetah spoor per 100 km (Stander, 1998) and is derived from the spoor frequency, that is after 100 km of spoor tracking one would expect to see x number of spoor. The desired sample intensity and sample effort were also determined. Sample intensity was measured by road penetration defined as the distance that must be sampled (km) as a ratio of the study area (km^2). Two roads were randomly selected, and the predicted spoor frequencies for 1000 replicates were simulated using Monte Carlo analysis, a form of bootstrap analysis (Efron & Tibshirani, 1993). This analysis was performed using PopTools 2.7.5 (Hood, 2006) with the Microsoft Excel (Microsoft Corporation 1985–2003) computer program. The road penetration, spoor frequency and confidence limits (5 and 95%) were calculated, and the process was repeated by increasing the sample progressively to 2, 3, 4,. . . 12 transects with replacement. New mean spoor frequencies and confidence limits were calculated after every increase. The desired sample intensity was deemed as the point where the spoor frequency had reached an asymptote and increasing the road penetration failed to considerably alter the confidence limits. The desired sample effort was determined as the point where further sampling failed to significantly alter the spoor frequency, that is it was accurate and precise. Precision was defined as a $<5\%$ change in the coefficient of variation (CV) between the full sample and this defined point, while accuracy was assigned as the point the spoor frequency reached an asymptote. Sample effort was examined in the wet season (October 2005 to March 2006) and the dry season (April 2006 to September 2006), separately.

All statistical tests were performed with SPSS version 11.0.1 (SPSS Inc. Chicago, IL, USA). Data were tested for normality using the Komogorov–Smornov two-sample test, and the appropriate parametric or non-parametric test was chosen accordingly. Pearson's correlation coefficient was used to examine the relationship between interdependent variables, and one-way ANOVA with *post hoc* testing was used to examine the differences between transects. All means are quoted with standard error ($x \pm$ SE) and significance was measured at $P<0.05$, two tailed.

Results

Eight transects (transects 1 and 2) were sampled 89–93 times (mean $= 91.38 \pm 0.50$), while the remaining four transects (transects 3) were sampled 44–47 times (mean $= 45.75 \pm 0.63$) during the first wet and dry season (Fig. 1). There was no significant difference between the spoor frequency for transects 1, 2 and 3; therefore, the differences in sampling frequency are unlikely to have influenced the final results ($f = 0.179$, $P = 0.836$). A total distance of 8226 km was sampled. The total number of spoor detected was 191; this equated to a spoor frequency of 43.07 ± 9.74 km (i.e. one individual cheetah spoor per 43.07 km sampled) and a spoor density of 2.32 cheetah spoor per 100 km.

Sample intensity

At low road penetration, spoor frequency had large confidence limits, indicating that the result was unreliable (Fig. 2). When road penetration reached 1 km: 3.34 km^2, the spoor frequency was 51.31 ± 0.29 km with lower and upper confidence limits of 36.94–67.27 km. Increases in road penetration beyond this point led to only minor decreases in the confidence interval (Fig. 2), therefore, a road penetration of 1 km: 3.34 km^2 or above would be recommended for spoor surveying and was deemed the desired sample intensity.

Sample effort

In the wet season (October 2005 to March 2006), the spoor frequency was accurate and precise when *c*. 38 individual cheetah spoor were counted; this occurred after sampling 1296 km (Fig. 3). Owing to an unexplained absence of cheetah spoor for 2 months, the CV increased at the end of the season, as such precision was defined as less than a 5% change in the CV value before this absence occurred. In the dry season, spoor frequency was precise and accurate after *c*. 90 individual cheetah spoor were counted, equivalent to sampling 3636 km (Fig. 4).

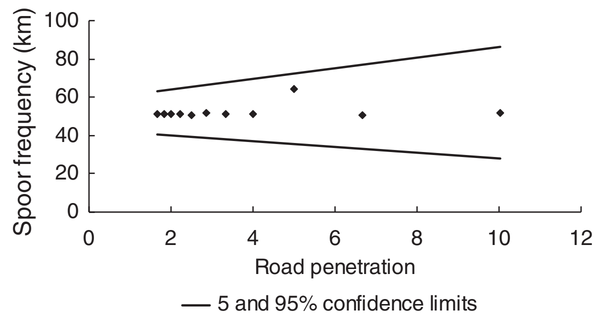

Figure 2 Relationship between road penetration as a measure of sample intensity and cheetah *Acinonyx jubatus* spoor frequency.

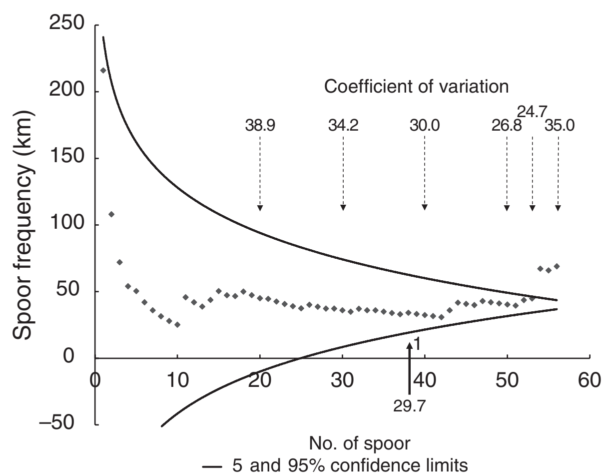

Figure 3 Effect of increased sample effort (measured by the number of individual cheetah *Acinonyx jubatus* spoor sampled) on spoor frequency during the wet season. [1]The point defined as accurate and precise.

True density

A true density of 5.23 cheetah per 100 km^2, ranging from 3.33 to 7.78 at the low and high points of the population, respectively, was recorded (Table 1). The results showed a linear relationship between spoor and true density in the wet and dry seasons, with trend line equations of $y = 0.403x-0.071$ ($r = 0.973$, $P = 0.147$) and $y = 0.569x-0.406$ ($r = 0.982$, $P = 0.121$), respectively.

During the first wet season, 1.45 cheetah spoor were detected per 100 km; this contrasts with 3.10 cheetah spoor per 100 km in the dry season. This increase in spoor density corresponded with the observed increase in cheetah population from 3.80 cheetah per 100 km^2 in the wet season to 6.67 cheetah per 100 km^2 in the dry season.

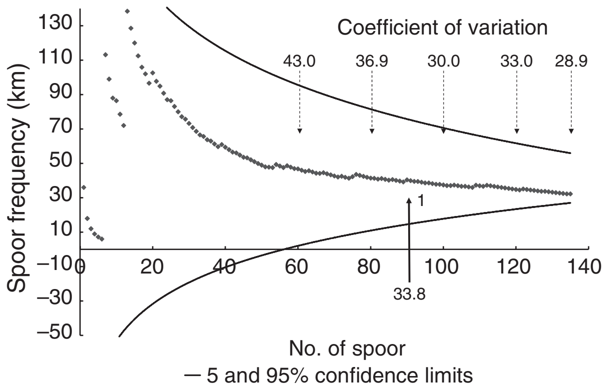

Figure 4 Effect of increased sample effort (measured by the number of individual cheetah *Acinonyx jubatus* spoor sampled) on spoor frequency during the dry season. [1]The point defined as accurate and precise.

Table 1 The true number of cheetah in the study area per month

Month	F5[a]	F6[b]	Unidentified[c]	Total in study area	True density per 100 km^2
Oct-05	**1**	**5**	**2**	**8**	**4.44**
Nov-05	**1**	**5**	**2**	**8**	**4.44**
Dec-05	**1**	**5**	**0**	**6**	**3.33**
Jan-06	**1**	**5**	**0**	**6**	**3.33**
Feb-06	**1**	**5**	**0**	**6**	**3.33**
Mar-06	**1**	**5**	**1**	**7**	**3.89**
Apr-06	6	5	1	12	6.67
May-06	6	5	1	12	6.67
Jun-06	6	5	3	14	7.78
Jul-06	6	5	1	12	6.67
Aug-06	6	4	1	11	6.11
Sep-06	6	4	1	11	6.11
Oct-06[d]	**5**	**4**	**0**	**9**	**5.00**
Nov-06[d]	**5**	**9**	**0**	**14**	**7.78**
Dec-06[d]	**5**	**9**	**2**	**16**	**8.89**

[a]Determined by cell collar data and monthly visuals.
[b]Determined by visuals every 11.8 ± 2.2 days.
[c]Determined by researcher visuals, supported by game park officers and tourists photographs.
[d]Data used to test the spoor correction factor.
The wet season is in bold.

Validation of the spoor correction factor

The second wet season (October 2006 to December 2006) was sampled for 3 months; during this time, the spoor frequency was deemed accurate and precise (at 864 km, 50 spoor). The spoor density in the second wet season was 4.44 cheetah spoor per 100 km; using the specified correction factor for the wet season the true density should equal 10.84 cheetah per 100 km^2. However, by direct observation, the true density was 7.22 cheetah per 100 km^2. Therefore, the correction factor overestimated the true cheetah density. Modification of the spoor/true density trend line to incorporate both wet seasons' data resulted in a significant linear relationship between spoor and true density ($r = 0.968$, $P = 0.002$) and a trend line of $y = 1.450x + 0.676$ (Fig. 5).

Prey density

The prey density in the dry season was 21 prey items per km^2 and 52 prey items per km^2 in the wet season.

Discussion

The use of spoor surveys as a tool to determine the true density of a species is of considerable interest in the field of conservation. However, the relationship between species density derived from a spoor survey and the true density of a species is only beginning to be understood (Stander, 1998; Funston *et al*., 2001; Gusset & Burgener, 2005). This study intended to examine and test this relationship in a known population of free-moving cheetah in southern Botswana.

The spoor survey resulted in a spoor density of 2.32 cheetah spoor per 100 km. These results contrast with those of Funston *et al*. (2001), who calculated a spoor density of 1.7 cheetah spoor per 100 km^2 in the dune/savannah habitat in the Kgalagadi Transfrontier Park, southern Botswana. The higher density reported within this study may be due to a combination of factors, including habitat type, prey availability, season and the absence of large carnivores such as lion and spotted hyena. Cheetahs are known to survive better outside of protected areas, where there is reduced competition from these large predators (Winterbach, 2001; Marker *et al*., 2003).

The sample effort required in the dry season (90 spoor, 3636 km) was higher than that required in the wet season (38 spoor, 1296 km) for spoor frequency to be deemed accurate and precise. It was observed that the spoor density increased between the wet and the dry season, which corresponded to the addition of five cubs to the study area. These seasonal differences may be explained by the relationship between spoor frequency and road usage as a function of cheetah range utilization (Stander, 1998).

During the wet season, cheetah may not have to travel as far for prey and habitat requirements; therefore, they may stay in smaller areas for longer periods of time. The

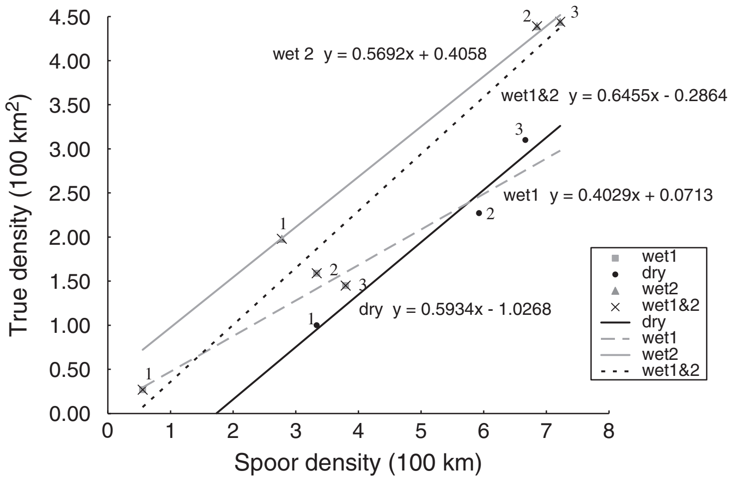

Figure 5 Relationship between true density and spoor density. The data points represent the true and spoor density relevant to one cheetah *Acinonyx jubatus* family[1], two cheetah families[2] and all cheetahs[3] present in the study area during the first and second wet season and during the dry season.

higher grasses provide concealment for predators to stalk utilizing open areas for hunting while using the thicker bush areas for resting (Caro, 1994; Purchase, 1998; Broomhall et al., 2003). This may concentrate the cheetahs movements in a more confined area in the wet season, which would enable a spoor study to reach the true population number in fewer kilometres, and result in a different relationship between spoor and true density in the dry season. This is supported by Marker (2002) noting that cheetah annual home-range size decreased with increased rainfall.

Conversely, during the dry season, increased prey movements to locate water (reflected by the observed lower prey density) mean that cheetah must travel further to satisfy their dietary requirements. In combination with difficulties in locating thick bush for cover or to conceal cubs, cheetah may occupy a larger area during this time. This is supported by GPS cell collar data collected during this study, which showed that F5 occupied a larger area and spent more time outside of the study area in the dry season, compared with during the wet season. Hence, it is reasonable to assume that in the wet season, a spoor study can be conducted in a shorter period of time to obtain an accurate estimate of spoor density than is possible during the dry season.

Unlike previous studies on leopard and lion where spoor density overestimated true density (Stander, 1998; Funston *et al*., 2001), this study showed cheetah spoor density to be an underestimate of true density in both the wet and the dry seasons. Although there may have been some errors in spoor detection and identification, it is believed that the spoor sampling was no more erroneous than these aforementioned studies; therefore, the differences may be species related. It was observed that in coalitions and families, cheetah do not move in a straight line together down a road or a path and they are often spread out sometimes up to 50–100 m apart. Therefore, the chances of all members being on the roadway at one time is rare; this may have resulted in the underestimation.

The quantifiable relationship between spoor and true density obtained in the first wet season could not be accurately applied to the second wet season when tested. Even with the study area, survey technique, trackers and cheetah families remaining constant, the observed cheetah spoor increased by 306% in the second wet season, despite only a 190% increase in true cheetah density, therefore altering the relationship between spoor and true density. The first wet season had 364 mm more rain than the second wet season; this affected the habitat, resulting in increased vegetation and watering points. These factors may have affected prey movements and density, causing changes in cheetah behaviour and their use of roads. It was necessary to modify the wet season correction factor to incorporate the second season's data due to this variation in rainfall. By consolidating a below-average wet season with a very high wet season, the accuracy of the spoor and true density relationship was increased. This was tested using full and partial wet season datasets.

A limitation of this research was the small study area and the low number of study animals sampled. However, this allowed the population to be closely monitored and for individual family travel patterns to become well known. During this study, we noticed a very cyclic and predictable movement pattern of the two main families. Within a month, the two families would overlap in an area for up to 1 week and then move to different areas within the park for the remaining period. This pattern of movement was consistently repeated. Another limiting factor was the use of an open population containing breeding females over a long period of time. The addition of cubs and the removal of sub-adults and females when they left to breed or were lair bound may have altered the spoor density and increased the required sample effort. This interruption in study animal presence should be considered in populations with breeding females, to ensure that the study is carried out long enough to avoid underestimating the population. This study was unable to validate the dry season trend line with a second dry season; as the correlation remained insignificant, it may be necessary to do this in the future to refine accuracy.

In conclusion, a quantifiable relationship between spoor and true density was established for the wet and the dry season separately, with populations being underestimated by spoor. However, this relationship required modification to incorporate the second wet season data to avoid overestimating true density.

Future research on known cheetah populations, to repeat, test and refine this work, should be conducted. Behavioural patterns vary with season, habitat and prey and may cause an animal to react differently than what a mathematical calculation predicts. Calibration studies need to be performed numerous times in order to incorporate natural environmental fluctuations, atypical or singular events and trends over time within the correction factor. This study was unique in that it was able to not only develop a correction factor, but test and refine it in the same area, keeping most variables constant. The study demonstrated the suitability of spoor surveys and correction factors as a tool in the long-term monitoring of populations, but emphasized that they should be used with caution, ensuring thorough testing of the relationship to accommodate changes in habitat and behaviour.

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