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Trialling a simple camera-trap based method to estimate Black-backed jackal population density

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Abstract

Globally damage causing animals, particularly mesopredators, are subjected to lethal control where they occur on small stock farms. This situation prevails in South Africa in relation to Black-backed jackals. However, despite their ubiquity, no attempt has been made to develop a repeatable, practical method to estimate Black-backed jackal population sizes. We estimated the Black-backed jackal population density on Telperion Nature Reserve in Mpumalanga Province using a combination of camera traps and established population estimation models (random encounter model (REM) and generalized random encounter model (gREM)) that do not require the individual identification of animals. Furthermore, we attempted to estimate all metrics for REM and gRem models exclusively from camera trap data and compared the estimates from these models, generated using GPS collar velocity metrics, to those based on home range metrics. We found that density estimates based on camera trap data combined with GPS velocity estimates returned the most plausible estimates of Black-backed jackal population. We suggest that using the method trialled in this study may present a relatively simple and practical way to estimate Black-backed jackal population density. The applicability of this method across a variety of landscapes should be trialled. If proved practicable, it would allow for consistent monitoring of Black-backed jackal populations using a repeatable density estimation method and may provide a basis for future management.

KEYWORDS: Population density estimation, Black-backed jackal, random encounter model (REM), generalised random encounter model (gREM), camera-trap

INTRODUCTION

The continuing growth in the human population is putting wildlife habitats under ever-increasing pressure, leading to an increase in human wildlife interactions. Often these interactions are negative, result in conflict, and could ultimately lead to biodiversity loss (Crist, Mora & Engelman 2017). These conflicts are particularly pronounced in human modified agricultural landscapes where damage causing animals have a direct impact on human livelihoods (Loveridge & Nel 2004). In many cases this conflict is cited as a motivation for the lethal control of damage causing animals (Dolbeer 1998; Inskip and Zimmerman, 2009), such as Black-backed jackals (*Lupulella mesomelas*), which can legally be done in South Africa (Government Gazette, 2016). However, lethal control of damage causing animals is increasingly in conflict with broader societal opinion (Dolbeer 1998; Treves & Naughton-Treves, 2005, Behrens *et al*. 2018), and such management has contributed to the decline of certain species (Treves & Naughton-Treves, 2005).

Irrespective of the species in question, to implement any form of population management, it is imperative that wildlife and land managers base their decisions on a sound understanding of the status and dynamics of the wild animal populations in question (Dolbeer 1998; Gaillard, Loison & Toigo, 2003). Unfortunately, in the case of many damage causing animals land managers / owners have no idea of their abundance at any given point in time. Little is known about either their historic or current population trend or dynamics (Minnie *et al*. 2018). Furthermore, little effort and minimal resources are committed to understanding the population dynamics of mesopredators in South Africa (Minnie *et al.* 2018).

A variety of techniques are available to land managers to monitor wild animal population densities and sizes. These methods span the spectrum from direct counts to spatially explicit capture recapture methods (Jimenez et al. 2017). The identification and implementation of the best population density estimation technique requires an intimate knowledge of the biology of the species in question, especially where management decisions are motivated by these estimates. For example, where Black-backed jackals have been culled in areas where food is not limiting, conspecifics are known to emigrate from areas of relatively high density to areas of low density, i.e., into those areas where individuals have been removed. Furthermore, Black-backed jackals are known to increase their rate of reproduction in areas where they are actively persecuted (Minnie, Gaylard & Kerley 2016).

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Prior to the initiation of a population monitoring programme, it is vital that the nature of the results required be identified. Broadly, there are two approaches to assessing animal abundance, either relative abundance or absolute abundance (Gese 2001; Rowcliffe *et al.* 2008; Rowcliffe *et al.* 2011). Metrics of relative abundance are easily estimable using indices, such as spoor counts (counts of animal tracks either along transects or within a prescribed area) (e.g., Gusset & Burchener, 2005; Tourenq *et al.* 2005), which result in non-specific estimates of whether populations are increasing, decreasing or stable. Absolute abundance estimates result in projections of specific population densities per unit area (Gese 2001). For the purposes of management, regular estimates of absolute abundance are preferable as they provide specific population density estimates rather than simple trends, which may or may not relate to population density (Rowcliffe *et al.* 2008). If one aims to manage a population at a specific density with a predictable level of impact, it is essential to know what the current population density and trend is so that management can specify definite levels of removal. Indices, however, are useful for management purposes only in cases where a correlation between the index value and the population density has been demonstrated (Gese 2001).

The estimation of population densities for cryptic carnivores is particularly challenging. Typically, carnivores are secretive, nocturnal, highly mobile, and occur at relatively low densities (Gese 2001). Where carnivores have distinctive, individually identifiable pelage patterns there are well-established techniques (see for example Karanth & Nichols 1998; Maffei *et al.* 2005; Rowcliffe *et al.* 2008) to overcome many of the challenges associated with estimating population density. In such cases, modified mark-recapture estimators can be employed in association with photographic 'recapture' analyses. However, these approaches are confounded in the case of species, such as Black-backed jackal, that are not individually identifiable (Rowcliffe *et al.* 2008). The urgency to develop a method of accurately estimating Black-backed jackal density is amplified as this species is one of the primary damage-causing animals associated with small stock losses and the consequent reduction in profitability of small stock farms (Carruthers & Nattrass 2018) in southern Africa. Despite lacking population estimates, thousands of Black-backed jackals are killed annually (Thorn 2009) on farmlands to try and reduce the impact that these animals are perceived to have (Du Plessis *et al.* 2018).

Over the past decade, substantial advancements have been made in the arena of population modelling and estimation. Random encounter models (Rowcliffe *et al.* 2008) encompass density estimators that impose Brownian motion assumptions on animal populations to estimate population density. The benefit of these models is that they are not constrained by the requirement to identify individual animals within a population. These models have been used to estimate the population densities of a variety of wild species including lions (*Panthera leo*) (Cusack *et al.* 2015), Grevy's zebras (*Equus grevyi*) (Zero *et al.* 2013) pine martens (*Martes martes*) (Balestrieri *et al.* 2016), and brown hares (*Lepus europaeus*) (Caravaggi *et al.* 2015). Estimating a population density using random encounter models require that several variables relating to both the detection zone of the camera-traps and the behaviour of the animals in question are included into the population estimation equations. Most of the variables (number of detections, time intervals, radius of detection zone, angle of detections zone, and animal velocity) required for the implementation of random encounter models can be directly measured or calculated in the field. However, the variable that has substantial leverage on the calculation of population density, animal velocity, is also a variable that is very challenging to estimate accurately (Rowcliffe *et al.* 2012).

We trialled a field method to estimate all the metrics required to calculate Black-backed jackal population density applying random encounter model (REM) and generalised random encounter model (gREM) estimators, exclusively from data gathered using camera traps. We then compared those estimates to REM and gREM estimates derived using velocity values from GPS collared animals from different areas.

STUDY AREA

The Telperion Nature Reserve (Telperion) is a privately owned protected area in the Elandsfontein municipal district of the Mpumalanga Province, South Africa. While the management of Telperion focuses on wildlife conservation, surrounding properties are managed for the production of cattle (*Bos taurus*) and maize (*Zea mays*). Telperion is *ca.* 7350 ha in extent (Roux 2018) and located on the eastern extremity of the Magaliesberg Mountain Range. The western boundary of Telperion is the perennial Wilge River (Grobler 1999). The study site co-ordinates are 25°41'35.20"S and 29° 0'7.01"E.

Telperion lies on the Wilge River, Ecca and Dwyka formations of the Waterberg and Karoo groups (Grobler 1999). Lithology is dominated by Arenite-Conglomerate, which produces dystrophic or mesotrophic red soils. Rocky areas have miscellaneous soils (Grobler 1999). The mean altitude for the reserve is 1350 m above sea level.

Summer rainfall ranges from 650 mm to 700 mm per annum, peaking in January. The mean minimum and maximum temperatures are 7°C and 27°C respectively. Frost occurs in winter from May to August (Bornman 1995). Telperion is located within the Rand Highveld Grassland in the Mesic Highveld

Grassland Vegetation type (Rutherford, Bredenkamp & Powrie 2006). The extensive grasslands on Telperion are interspersed with rocky outcrops, which increase the biodiversity of the reserve. Remnants of Drakensberg plant communities occur in sheltered areas (Magagula 2018). The vegetation of Telperion comprises five primary plant communities, comprising grasslands, woodlands, shrublands, wetlands and riverine associations. We confined our investigation to the *Eragrostis curvula–Seriphium plumosum* mid plateau grassland community (hereafter grassland) which comprises *ca.* 58% (4267 ha) of the total area of Telperion (Magagula 2018).

Telperion supports a diverse faunal assemblage representative of indigenous animals of the region including Black-backed jackals.

METHODS

From 6 April to 15 June 2017, we deployed 10 Bushnell Essential EII camera-traps (hereafter cameras) at random locations throughout the grassland, with a minimum inter-camera distance of 1 km. The camera specifications indicate that their sensors detect movement up to a distance of 20 m (https://www.bushnell.com/on/demandware.static/-/Library-Sites-HuntShootAccessoriesSharedLibrary/default/dw5ffe5d56/productPdfFiles/bushnellPdf/Product%20Manuals/Trail-Cameras/PDF/119736C-trophycam-essential.pdf). The cameras were attached to tree trunks at a height of exactly 1.20 m from ground level to the centre of the lenses; the minimum height that would allow for the capture of photos out to 20 m due to the grass sward. No attempt was made to clear vegetation from the camera detection zones and no attractants or lures were used to induce animals towards the cameras (Rowcliffe *et al.* 2008). Furthermore, Black-backed jackals are thought to avoid novel stimuli (Natrass et al. 2017) and, as such, the removal of grass might have reduced the number of Black-backed jackal detections because of avoidance behaviour. The cameras were not specifically located near to known travel corridors, tracks or game trails (Rowcliffe *et al.* 2008). Each camera was programmed to capture a 20 second video clip when triggered. We programmed the cameras with a 30 second latency between consecutive triggers. We considered any detections of a Black-backed jackal within 30 minutes of an initial detection to be the same individual and did not include these in our analysis (Meek *et al.* 2014). We assumed that the Black-backed jackal on the study site complied to the assumption of closure for the two months of the study (Caravaggi et al. 2016). Although Rowcliffe et al. (2008) recommend a minimum of 20 camera locations, we were limited to 10 locations on the study site. We deployed the cameras for two sessions, session 1 (6 April 2017 to 6 May 2017) and session 2 (15 May to 15 June 2017). We excluded video clips, for an 11 day period, for one of the cameras (camera 5 from 4 June to 15 June) because of the mortality of a blue wildebeest (*Connochaetes taurinus*) within the vicinity of the camera and the associated potential for confounding the assumption of random encounters (Rowcliffe *et al.* 2008) for that camera during that period. Although Black-backed jackals may be active throughout the day (Skinner & Chimimba 2005), they tend to be more active during the crepuscular and nocturnal period (Kaunda 2000, Minnie et al. 2018). Reduced activity during daylight hours and the resultant reduction in the number of detections would substantially reduce our density estimates (Rowcliffe et al. 2008), therefore, we have limited our analysis to the crepuscular and nocturnal period by calculating the mean times of sunrise and sunset during the study period (https://www.sunrise-and-sunset.com/en/sun/south-africa/witbank). We assumed that the crepuscular period began an hour before sunset and ceased an hour after sunrise (Pratas-Santiago et al. 2016). Therefore, for the purposes of this analysis, the Black-backed jackal activity period spanned the 15 hours from 16:30 to 07:30 (the sunrise time in Ekurhuleni at this time of year varies from 06:27 to 06:51 and sunset varies from 17:18 to 17:32) (https://www.sunrise-and-sunset.com/en/sun/south-africa/witbank).

We determined the angle of the camera detection zone by mounting one of the cameras on a vertical pillar, at the centre point of the base of a 20 x 40 m warning tape grid, divided into 16 rectangles of 5 x 10 m, that we pinned to the ground. This allowed us to measure the intersection of the detection zone with known distances and angles from the camera lens. Based on this, we calculated the angle of the detection zone (41 degrees, 0.716 radians). We followed Rowcliffe et al. (2008) and assumed that all cameras complied to the same specifications and there was zero variance between cameras. To calibrate the detection zone to a known spatial reference, we used video clips of a 20 x 40 m grid to create a standardised overlay for the video clips. This spatial reference allowed us to calculate animal velocity from the video clips. We constrained any detections to ≤ 20 m from the front of the camera, i.e., all detections beyond this maximum distance were excluded from our analyses.

Calculation of velocity from video clips: due to the configuration of the overlay, we assumed for each 5 x 10 m rectangle that an animal could be travelling in one of three planes relative to the detection zone, specifically: directly across the detection zone (parallel to the horizontal plane of the camera lens), perpendicular to the detection zone or diagonal relative to the detection zone. Therefore, each movement across a quadrant was 5.0 m, 10.0 m, or 11.2 m (hypotenuse) in length. We calculated the total distance moved for each Black-backed jackal based on the sum of all component distances within the camera detection zone. The total time that the animal spent within the detection zone, i.e., the elapsed time on the video clips was used in each calculation. Consequently, our calculations were in metres per second (ms^{-1}), which we converted to metres per hour (mh^{-1}) to facilitate population estimation and to allow for comparison with GPS collar data.

Calculation of velocity from GPS collars: To compare population estimates using our camera derived velocity to those derived using more traditional velocity metrics, we used hourly linear displacement values based on data from the Central Karoo (Drouilly unpublished) and from Kwa-Zulu-Natal (Humphries *et al.* 2016). These values represent the linear distances between consecutive hourly locations during the nocturnal period (18:00 to 06:00) using ArcGIS (Environmental Systems Research Institute, CA, USA). We only used data for the astronomical autumn in the southern hemisphere (20 March to 20 June) to ensure that the temporal period was the same as that for which our cameras were deployed.

Density calculations: We used the Random Encounter Model (REM) (Rowcliffe *et al.* 2008):

$$D = \frac{y}{t}\frac{\pi}{vr(2+\theta)}$$

In this equation, D = estimated density (Nkm^{-2}) (N = number of individuals), y = number of contacts or detections, t = number of time intervals, v = velocity of the animal, r = radius of the detection zone and θ = estimated angle of the detection zone from the camera in radians.
We also used the generalised Random Encounter Model (gREM) (Lucas *et al.* 2015):

$$D = \frac{z}{2rvt}$$

In this equation, D = estimated density (Nkm^{-2}), z = number of contacts or detections, r = radius of the detection zone, v = velocity of the animal, and t = number of time intervals. We used the bootstrap method (Rowcliffe et al. 2008; Jourdain et al. 2020) to resample camera locations 10 000 times with replacement to calculate the variance of our density and abundance estimates. The bootstrapping was conducted using Program R (R core team 2021).

In our implementation of these models we made the following assumptions: 1) the movements of the Black-backed jackals conformed to the "ideal gas" model (animal movements are independent, equally likely in all directions, at speeds that conform to a "Maxwell-Boltzmann" distribution) (Hutchinson & Waser 2007), 2) each camera detection was an independent event, 3) the Black-backed jackal population at the time of survey was closed, and 4) the area within which the population occurred was homogeneous (Rowcliffe *et al.* 2008). Random encounter models require that where population estimates are calculated for animals that occur in groups, the density estimate should be multiplied by the mean group size (Rowcliffe *et al.* 2008). We, therefore, present estimates for single individuals and mated pairs.

We used our detection data to calculate a detection index (detections per 100 camera nights). We also compared our REM and gREM density estimates to density calculations (Nkm^{-2}) based on the home range estimates (minimum convex polygon method) for Black-backed jackal mated pairs in a similar habitat type on the Suikerbosrand Nature Reserve, Gauteng province (Ferguson, Nel & De Wet 1983).

Ethical clearance for this research was granted by the Unisa College of Agriculture and Environmental Sciences Research Ethics Committee, under the reference number: 2017/CAES/020.

RESULTS

We deployed 10 Bushnell Essential E2 trail cameras for a total of 589 camera nights from 6 April to 15 June 2017. The deployment period varied from 49 to 60 nights (mean = 58.9), for the entire study, 300 camera nights (6 April to 6 May 2017) (mean = 30), and 289 camera nights (16 May to 15 June 2017) (mean = 28.9). We recorded a total of 47 (mean = 4.7) (April / May = 14; May / June 33) discrete Black-backed jackal detections during our study, of which 39 detections fell within the crepuscular and nocturnal period. We omitted 17% (8) of the Black-backed jackal detections as they either fell beyond the detection zone of the cameras or they were recorded outside the crepuscular and nocturnal period. Two Black-backed jackal detections were omitted as they were recorded beyond the 20 m maximum detection zone specified for the cameras. We omitted a further six detections (one in the April / May session and five in the May / June session) as they were recorded outside of the prescribed activity period. The detection rate for the entire period was 0.07 detections per camera night. For the April / May period the detection rate was 0.04 detections per camera night and in the May / June period the detection rate was 0.10 detections per camera night. The mean number of detections per camera for the entire period was 3.9 (± 2.7). In the April / May period the mean number of detections per camera was 1.1 (± 2.9) detections per camera. In the May / June period the mean number of detections per camera was higher at 2.8 (± 1.9) detections per camera. Of the 39 Black-backed jackal video clips, 22 were useable for the purposes of calculating animal velocity. The movement rates of the Black-backed jackals on Telperion, as calculated from our camera grids, varied ~300-fold with the mean velocity calculated as 5544 ±3381.1 mh^{-1} (Table 1).

Our Black-backed jackal density estimates were highly variable (Table 2) dependent on the velocity metric used. Our estimated density of Black-backed jackals for the entire period varied from 0.02 individuals km^{-2} (using the gREM density estimator and our camera velocity estimate) to 1.20 individuals km^{-2} (using the REM population estimator and GPS collar velocity estimates from Humphries *et al.* (2016)) for mated pairs of Black-backed jackal (Table 2). These density estimates translate to estimated abundances of 1 and 50 Black-backed jackals in the study habitat using the gREM (and camera velocity estimates) and REM (and Humphries *et al.* 2016 GPS collar velocity estimates) procedures, respectively. Our estimated density of Black-backed jackals for the April / May period varied from 0.01 individuals km^{-2} (using the gREM density estimator and our camera velocity estimate) to 0.66 individual km^{-2} (using the REM population estimator and Humphries *et al.* 2016 GPS collar velocity estimates) (Table 2). These density estimates translate to estimated abundances of 1 to 28 Black-backed jackals in the *Eragrostis curvula–Seriphium plumosum* mid plateau grassland community (Table 2). Our estimated density of Black-backed jackals for the May / June period varied from 0.031 individuals km^{-2} (using the gREM density estimator and our camera velocity estimate) to 1.73 individuals km^{-2} (using the REM population estimator and Humphries *et al.* 2016 GPS collar velocity estimates) (Table 2). These density estimates translate to estimated abundances of 1 to 74 Black-backed jackals in the *Eragrostis curvula–Seriphium plumosum* mid plateau grassland community (Table 2). The gREM procedure generated density and population estimates that varied between approximately 32% and 44% of the magnitude of those calculated using REM (Rowcliffe *et al.* 2008). The population estimates varied depending on which estimation technique was employed and in relation to the estimated mean group size (Table 2).

Our population density estimates using gREM and REM are similar to those that we calculated using the smallest home range estimates from the Suikerbosrand Nature Reserve (Ferguson *et al.* 1983) (Table 3). However, our estimates are substantially higher than those estimated using mean or maximum home range estimates from the Suikerbosrand Nature Reserve (Ferguson *et al.* 1983) (Table 3).

DISCUSSION

Accurate and robust estimates of Black-backed jackal population density are lacking in the scientific literature (Minnie *et al.* 2018; Minnie, Gaylard & Kerley 2016). We aimed to determine whether it would be possible to use REM and gREM estimators, in conjunction with commercially available cameras, to develop a repeatable method for monitoring of Black-backed jackal population densities on wildlife reserves, with the intention of possibly using such a method, once validated, on a wide variety of landscapes and land management regimes (potentially including stock farming enterprises).

We found that it was possible, theoretically, to derive all the metrics (animal velocity, radius of the detection zone and angle of detection zone) required for the calculation of population estimates using REM and gREM from commercially available cameras. The velocities that we have estimated using our camera estimation method were an order of magnitude higher than those based on hourly GPS collar locations from the Karoo and Kwa-Zulu/Natal (Table 2), but comparable to the maximum distance (3 000 m) travelled in one hour reported in Botswana (Kaunda 2001a). When movement rates are determined based on hourly GPS locations, the assumption is that the individual animals move in straight lines between consecutive positions. Animal movements are rarely linear for an entire hour, and there is reason to believe that hourly GPS locations underestimate movement rates (Musiani, Okarma & Jedrzejewski 1998). However, Black-backed jackals exhibit an aversion of novel stimuli (Kaunda 2001b; Natrass *et al.* 2017) so it is possible that Black-backed jackal movement rates were over-estimated with our cameras.

Table 1: Velocity of Black-backed jackal (*Lupulella mesomelas*) movements on Telperion Nature Reserve from April to June 2017

	Velocity (mh^{-1})				
Source	Maximum	Minumum	Mean	SD	n
Natal[1]	4192.5	0.2	431.5	286.5	162
Karoo[2]	4747.3	0.9	501.8	309.4	68
Telperion[3]	11988.0	36.0	5545.0	3381.1	22
All velocity values are only for the nocturnal period (18h00 to 06h00)					
[1]Data from Humphries et al. (2016) - these data are based on linear displacement between hourly GPS Locations [2]Drouilly Personal communication (2019) - these data are based on linear displacement between hourly GPS locations [3]These data are from estimates of Black-backed jackals' movements through spatially rectified camera detection zones					

Table 2: Density estimates for Black-backed jackals (*Lupulella mesomelas*) in the grassland habitat on Telperion Nature Reserve from April to June 2017

Period		Variables							REM				gREM			
	Source of velocity data	**Y**	**T**	**Pi**	**V (kmh^{-1})**	**R**	**2 + theta**	**Group size**	**Density (nkm^{-2})**	**Density 95% CI**	**n**	**n 95% CI**	**Density (nkm^{-2})**	**Density 95% CI**	n	n 95% CI
Full duration	Telperion[1]	39	8835	3.14	5.04	0.04	2.71	1	0.05	[0.01 to 0.13]	2.16	[0.28 to 5.38]	0.02	[0.00 to 0.05]	0.93	[0.12 to 2.32]
	Karoo[2]	39	8835	3.14	0.50	0.04	2.71	1	0.51	[0.07 to 1.27]	21.71	[2.78 to 53.99]	0.22	[0.03 to 0.55]	9.38	[1.20 to 23.33]
	Natal[3]	39	8835	3.14	0.43	0.04	2.71	1	0.59	[0.08 to 1.47]	25.23	[3.23 to 62.74]	0.26	[0.03 to 0.64]	10.9	[1.39 to 27.11]
	Telperion[1]	39	8835	3.14	5.04	0.04	2.71	2	0.10	[0.01 to 0.25]	4.33	[0.54 to 10.76]	0.04	[0.01 to 0.11]	1.87	[0.24 to 4.65]
	Karoo[2]	39	8835	3.14	0.50	0.04	2.71	2	1.02	[0.13 to 2.53]	43.42	[5.657 to 107.99]	0.44	[0.06 to 1.09]	18.76	[2.41 to 46.66]
	Natal[3]	39	8835	3.14	0.43	0.04	2.71	2	1.20	[0.15 to 2.94]	50.45	[6.47 to 125.59]	0.51	[0.07 to 1.27]	21.80	[2.80 to 54.22]
April / May	Telperion[1]	11	4500	3.14	5.04	0.04	2.71	1	0.03	[0 to 0.07]	1.2	[0 to 3.16]	0.01	[0.00 to 0.03]	0.52	[0.00 to 1.36]
	Karoo[2]	11	4500	3.14	0.50	0.04	2.71	1	0.29	[0 to 0.74]	12.02	[0 to 31.69]	0.12	[0.00 to 0.32]	5.19	[0.00 to 13.69]
	Natal[3]	11	4500	3.14	0.43	0.04	2.71	1	0.33	[0 to 0.86]	13.97	[0 to 36.83]	0.14	[0.00 to 0.37]	6.04	[0.00 to 15.91]
	Telperion[1]	11	4500	3.14	5.04	0.04	2.71	2	0.06	[0 to 0.15]	2.40	[0 to 6.31]	0.02	[0.00 to 0.06]	1.04	[0.00 to 2.73]
	Karoo[2]	11	4500	3.14	0.50	0.04	2.71	2	0.56	[0 to 1.49]	24.04	[0 to 63.39]	0.24	[0.00 to 0.64]	10.39	[0.00 to 27.39]
	Natal	11	4500	3.14	0.43	0.04	2.71	2	0.66	[0 to 1.73]	27.94	[0 to 73.66]	0.28	[0.00 to 0.75]	12.07	[0.00 to 31.83]
May / June	Telperion[1]	28	4335	3.14	5.04	0.04	2.71	1	0.07	[0.01 to 0.18]	3.16	[0.34 to 7.56]	0.03	[0.00 to 0.08]	1.37	[0.15 to 3.22]
	Karoo[2]	28	4335	3.14	0.50	0.04	2.71	1	0.74	[0.08 to 1.78]	31.77	[3.45 to 75.93]	0.32	[0.03 to 0.76]	13.73	[1.47 to 32.35]
	Natal[3]	28	4335	3.14	0.43	0.04	2.71	1	0.87	[0.10 to 2.07]	36.91	[4.01 to 88.23]	0.37	[0.04 to 0.88]	15.95	[1.71 to 37.60]
	Telperion[1]	28	4335	3.14	5.04	0.04	2.71	2	0.15	[0.02 to 0.35]	6.33	[0.69 to 15.13]	0.06	[0.01 to 0.15]	2.73	[0.29 to 6.45]
	Karoo[2]	28	4335	3.14	0.50	0.04	2.71	2	1.49	[0.16 to 3.56]	63.53	[6.90 to 151.85]	0.64	[0.07 to 1.51]	27.45	[2.94 to 64.71]
	Natal[3]	28	4335	3.14	0.43	0.04	2.71	2	1.73	[0.19 to 4.14]	73.83	[8.02 to 176.46]	0.75	[0.08 to 1.76]	31.90	[3.42 to 75.19]

[1] Using camera trap estimated velocity on Telperion
[2] Drouilly unpublished GPS collar data - pers. Comm.
[3] Humphries et al. 2016 GPS collar data
Y = number of detections or speed estimates
T = Number of hours total
Pi = constant
V= estimated velocity in kmh^{-1}
R = radius of detection zone (40m)
theta = base angle of detection zone in radians
REM - Random encounter model as formulated by Rowcliffe et al. (2008)
gREM - generalised Randon encounter model as formulated by Lucas et al. (2015)
95% CI estimated using bootstrap method (Rowcliffe et al. 2008)

Table 3: Population estimates for Black-backed jackals (*Lupulella mesomelas*) in the grassland habitat on Telperion Nature Reserve, from April to June 2017, based on home range estimates, using the minimum convex polygon method, from a previous study in asimilar habitat

Home range estimate	Home range km^2	Density nkm^{-2}	Population estimate for Telperion (individual)	Population estimate for Telperion (mated pair)
Minimum	1.9	0.50	21.34	42.67
Mean	24.8	0.04	1.71	3.42
Maximum	91.5	0.01	0.43	0.86

The study habitat is approximately 42.67 km^2

Based on home range sizes estimated by Ferguson et al. 1983 for Suikerbosrand Nature Reserve in the Transvaal with all home ranges being exclusive.

The REM and gREM techniques were developed using linear displacement values rather than instantaneous velocity values (Rowcliffe *et al.* 2008; Lucas *et al.* 2015). Our camera-based velocity estimates were derived from 20 second video clips and we used simple multiplication of these 'instantaneous' velocity values to derive hourly velocities. Our camera velocity estimates assumed that the Black-backed jackals moved at a constant rate and did not account for periods when the Black-backed jackals might have been stationary or at rest. Our velocity values were distinct from those that were used to develop the density estimators. Linear displacement values determined from consecutive hourly locations from GPS collars more closely replicate the scale of movement used to derive the population estimators (Rowcliffe *et al.* 2008). Hourly GPS collar locations define a start and end point of an animal's movements within an hour (inclusive of rest periods) and are indicative of the minimum distance moved by an individual within that period. A consequence of the variation in velocity values was that population estimates derived using the GPS collar velocities from the Karoo and Kwa-Zulu/Natal were an order of magnitude higher than those derived using our camera-based instantaneous velocities (Table 2).

We confined our investigation to the predominant grassland vegetation type on Telperion, i.e., the *Eragrostis curvula–Seriphium plumosum* mid plateau grassland community (Magagula 2018). The REM (Rowcliffe *et al.* 2008) and gREM (Lucas *et al.* 2015) estimators require that each homogeneous habitat type be assessed individually and that separate component population density estimates be calculated for each habitat. The practical implication of this is that more cameras would be required to assess each vegetation type individually. This requirement would increase not only the cost, but also the time and effort required to deploy and maintain the camera arrays, and to accumulate data from which to derive population density estimates. In addition, certain vegetation types might require longer deployment of the cameras to record the minimum number of 10 (preferably 20) detections (Rowcliffe *et al.* 2008) from which to derive population density estimates. In extreme cases, Black-backed jackals might avoid certain vegetation types completely and one might never achieve the minimum number of detections from which to derive a population density estimate for that component. Given that the aim of this study was to determine whether it would be possible to develop a method to estimate the population density of Black-backed jackals on a broad spectrum, we suggest that it may be reasonable to consider a single property / wildlife ranch (that is limited to a single broad vegetation type) as a homogeneous unit. However, it would be necessary to confirm this by implementing a more comprehensive investigation in which estimates for all component habitats / vegetation types are included.

The estimation of population density for wild canids remains one of the challenges in wildlife management because many of these species are cryptic, nocturnal, occur in low densities, have relatively large home ranges, and, in many cases, avoid contact with humans (Roffler et al. 2019). The use of spatially explicit capture-recapture models in conjunction with genetic identification of individuals (using genetic material gathered by any one of several methods) (Roffler et al. 2019), allows for accurate estimation of wild canid populations. However, this approach is most likely unfeasible for most land managers, in terms of practicality, time and cost. Nevertheless, there may be value in conducting this type of investigation in parallel with a comprehensive implementation of the REM and gREM approaches with the intention of comparing the results. Irrespective of approach used, it remains challenging to validate Black-backed jackal population density estimates or indices because that requires methods to be applied in areas where the Black-backed jackal population could be accurately enumerated (Balme, Hunter & Slotow 2009).

While our density estimates using home range data (Ferguson, Nel & De Wet 1983) from a similar area seemed to generate realistic estimates of the possible Black-backed jackal population density for the grassland on Telperion (21 or 43 individuals) (Table 3) using the minimum home-range size, this estimate was based on old data and simplistic (minimum area method) home range analysis. Our estimated density index of 0.07 detections per camera night, within the grassland on Telperion, might give an indication of population trend if the same method were to be repeated iteratively, however it does not give an intuitive feel for the actual population density, especially when the crude value is considered in isolation. Furthermore, such indices are influenced substantially by variability in detection probabilities relative to the local species density, behaviour patterns of individuals, sampling efficiency and vegetation structure (Gu & Swihart 2004). To develop meaningful management goals, using such an index, would require that the index be demonstrated to correlate directly to the density of Black-backed jackals in the study site (Balme, Hunter & Slotow 2009).

The gREM estimates of Black-backed jackal population density returned values approximately 43% of our REM estimates. Our REM estimates of 43 to 50 individuals (based on all individuals being members of mated pairs) (Table 2), using GPS collar movement rates, seemed to be a realistic estimate of the likely Black-backed jackal population based on our experience of the study site. We suspect that the true population of Black-backed jackals on Telperion lies between the gREM (~ 10) and the REM (~50) estimates, although this might be an underestimate of the population because vegetation within the cameras' detection zones may have obscured some Black-backed jackals and consequently lead to missed detections of them. We acknowledge that our results are highly variable, this is probably a consequence of the low number of camera locations that we used. Therefore, we emphasise the necessity to make provision for at least 20 camera locations, as recommended by Rowcliffe et al (2008), to estimate population density using random encounter approaches. Future attempts to validate this approach for the estimation of Black-backed jackal population density will need to take this, and the assumption of population closure, into account.

A contingency that we did not build into our population estimates was that mated pairs of jackals may cohabit in their territories with up to six offspring (Jenner, Goombridge & Funk 2011). Our estimates assume that mated pairs of jackals occupy exclusive territories. As the REM model estimates scale with group size (Rowcliffe et al. 2008), a population of Black-backed jackal in which young of the previous year consistently remained resident within their natal territory would be underestimated should the local group size simply be assumed as two (mated pairs).

The motivation behind this study was to determine whether it would be viable to use commercially available cameras to estimate Black-backed jackal population density. Despite the limitations of our study, which we acknowledge, we suggest that it is possible to use the method that we have outlined here to derive, repeatable estimates of Black-backed jackal population densities, within the grassland on Telperion Nature Reserve and probably in conservation areas that comprise similar, relatively open grassland habitats, provided that the same camera locations and settings are maintained during each deployment. For management purposes, the ability to derive population density estimates, using repeatable methods such as the one that we have trialled here, may be an important step towards gaining an insight into Black-backed jackal population density variability.

The method described herein could possibly be applied relatively cheaply (*ca*. R 40 000.00 / US$ 3 000.00 to capitalise 10 camera traps and batteries), to estimate Black-backed jackal population densities across a wide variety of land types and management zones (after being validated for each habitat type). It is not necessary to use 10 cameras to apply these population estimation techniques, it is valid to move the cameras to different locations (the recommended minimum number of locations is 20) (Rowcliffe *et al.* 2008). A further criterion is that there needs to be a minimum of 10 detections of Black-backed jackals for the estimators to generate reliable results (Rowcliffe *et al.* 2008). The process of validating such Black-backed jackal population density estimation techniques for a variety of habitat types and land uses would be an important next step in developing a mechanism to monitor Black-backed jackal population dynamics. Should such methods be proven reliable, robust and repeatable, it would enable land managers to develop property-specific estimates of Black-backed jackal populations and to track the trajectories thereof over several years. This practice would either corroborate or refute the contention that Black-backed jackal populations are increasing. Furthermore, it would improve our knowledge of the populations of Black-backed jackals in South Africa and would put us in a better position to implement suitable management strategies.

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