Livestock guarding dogs enable human-carnivore coexistence: first evidence of equivalent carnivore occupancy on guarded and unguarded farms

Katie Spencer[1], Melissa Sambrook[1], Samantha Bremner-Harrison[1], Deon Cilliers[2], Richard W. Yarnell[1], Rox Brummer[3], Katherine Whitehouse-Tedd[1*]

[1] School of Animal, Rural and Environmental Sciences, Nottingham Trent University, Southwell, NG250QF, United Kingdom

[2] Livestock Guarding Dog Programme, Cheetah Outreach Trust, Paardevlei, Somerset West, South Africa

[3] Green Dogs, P.O.Box 215, Alldays 0909, South Africa

* Corresponding author: Email: katherine.whitehousetedd@ntu.ac.uk Phone: +44 (0)115 8485293.

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Abstract

Livestock guarding dogs (LGDs) are advocated to reduce livestock depredation on agricultural lands. However, LGDs have been proposed as excluding carnivores from guarded farms; this study is the first to test this hypothesis in an African ecosystem. We investigated carnivore occupancy (black-backed jackal, leopard and brown hyaena) from 1029 camera-trap days (126 camera locations) in relation to the presence of LGDs and a range of habitat and land-use covariates across eight South African farms, five of which utilised an LGD. Models containing LGDs had little support in explaining leopard or black-backed jackal occupancy, although LGD presence had a positive relationship with brown hyaena occupancy (β = 1.14, 95% CI = 0.05, 2.23). Leopard detection was positively related to the presence of black-backed jackals (β = 1.47, 95% CI = 0.18, 2.74) and sheep (β = 1.13, 95% CI = 0.14, 2.12), whilst black-backed jackal detection was negatively related to lures (β = -1.33, 95% CI = -2.00, -0.65) and positively related to the presence of brown hyaena (β = 0.90, 95% CI = 0.43, 1.40). Previous research in this LGD population has demonstrated the cessation of livestock depredation in 91% of cases, making dog ineffectiveness unlikely to explain their lack of influence on carnivore occupancy. Our results provide the first empirical evidence based on ecological data of the capacity for LGDs to promote human-carnivore coexistence in an African agricultural context, further validating the use of specialist guarding dogs as a conservation tool of benefit to both human and wildlife populations.

1.0 Introduction

Human-wildlife interactions resulting in negative implications for the other, commonly called "human-wildlife conflict" (HWC), is one of the most widespread issues currently facing conservationists (Dickman, 2010) as the growing human population encroaches on wildlife habitats and resources (Waters et al., 2016) . Interactions between many mammalian carnivores and humans typically involve competition for resources as a result of carnivore species' predisposition for large home ranges and a dietary reliance on animal tissue (Thorn et al., 2012). It follows that the most common cause of human conflict over carnivores is livestock depredation (Krafte Holland et al., 2018; Torres et al., 2018). This leads to the persecution of carnivores in retaliation for livestock losses or as part of lethal control methods, and is the main reason many species are classified as Vulnerable, Endangered, or Critically Endangered (IUCN, 2016), but equally, threatens the sustainability of many agricultural practices around the world (Baker et al., 2008; Van Eeden et al., 2017).

Therefore, the on-going global agricultural expansion and increased livestock production is a major source of conflict between conservationists and agricultural stakeholders

Livestock depredation has important negative economic implications for individual farmers, the farming industry, and local economies as a whole (Mkonyi et al., 2017; Moreira-Arce et al., 2018). Annually, livestock depredation around the world has been reported to equate to losses of between 0.02 – 15% of total herd size (Blackwell et al., 2016; Butler, 2000; Graham et al., 2005; Mkonyi et al., 2017). In financial terms, such losses can represent over USD $600 per household in Tanzania (Mkonyi et al., 2017), or $98.5 million annually for the US farming industry (Blackwell et al., 2016).

Despite evidence to demonstrate that lethal control is more expensive than non-lethal alternatives and often less effective (Lennox et al., 2018; McManus et al., 2015; Moreira-Arce et al., 2018; Treves et al., 2016), lethal carnivore control methods are still employed. These are often part of farming culture, readily available, and perceived to be the cheapest, most practical method (Blackwell et al., 2016; McManus et al., 2015). However, lethal control of apex carnivores is not always directly associated with the damage they are perceived to have incurred, whereby indiscriminate lethal removal occurs even in the absence of perceived damage (Marker et al., 2003). This has caused dramatic declines in large carnivores across unprotected land (Boshoff et al., 2016), which has major implications for the ecosystems as well as human health and well-being (O'Bryan et al., 2018; Ritchie and Johnson, 2009; Thorn et al., 2012; Treves and Karanth, 2003). Furthermore, there is a funding deficit for protected areas in Africa, and carnivore conservation on private and unprotected lands, alongside improved management of protected areas, has become critical to many species' survival (Durant et al., 2017; Lindsey et al., 2018). It is therefore imperative that conservation efforts achieve a state of strong coexistence in these agricultural environments (Clements et al., 2016; Durant et al., 2017). With the negative ecological and economic impacts of lethal control on the unprotected areas in mind, the importance of finding carnivore-safe livestock management practices, of benefit to both human and wildlife land-users and enabling co-existence, has never been more apparent (Van Eeden et al., 2018).

In spite of a relative paucity of empirical evidence regarding HWC mitigation method effectiveness, one of the most successful methods documented is livestock guarding dogs (LGDs) (Eklund et al., 2017; Krafte Holland et al., 2018; Shivik, 2004; Torres et al., 2018; Van Eeden et al., 2018). Generally, LGDs are bred and trained to stay with the livestock herd and prevent carnivores from attacking through protective displays, often without physical conflict (Allen et al., 2017; Gehring et al., 2010). The ability of these dogs to protect livestock from carnivores and subsequently increase farmer tolerance towards carnivores on their farmland (Potgieter et al., 2016; Rust et al., 2013) has supported the promotion of LGDs as a human-carnivore conflict mitigation tool.

However, the potential exists that the reduced depredation of livestock, and subsequent decrease in conflict, occurs at the expense of carnivore utilisation of LGD-guarded farms and can potentially reduce carnivore carrying capacity. Studies from across the world have reported negative consequences of LGD placements, ranging from unwanted LGD behaviours (chasing and killing wildlife species, including carnivores (Marker et al., 2005; Potgieter et al., 2016; Urbigkit and Urbigkit, 2010)), to altered behaviour and reduced habitat utilisation by a range of wildlife species (Gehring et al., 2011; Gingold et al., 2009; Van Bommel and Johnson, 2016). Although these studies indicate that the classification of LGDs as non-lethal is not wholly supported, it is typically argued that the severity of carnivore persecution is markedly reduced following the placement of a LGD, compared to when more traditional, lethal control methods were in place (Binge, 2017; Potgieter et al., 2016).

For LGDs to be considered beneficial to carnivore conservation, it is imperative they do not have negative impacts at the population level, i.e. the utilisation of farmland by carnivores. Yet, ecological and community-level responses to LGDs have only occasionally been reported, and are restricted to certain regions. In Australia, LGDs have been considered a surrogate top-predator as they create a "landscape of fear" whereby the presence of dogs leads to unintended altered behaviour and reduced habitat utilisation by a range of wildlife species, especially for prey species or competitors of large canids (Van Bommel and Johnson, 2016). LGD-associated spatial avoidance by wild canid species has been recorded (Van Bommel and Johnson, 2016), along with reduced carnivore visitation of North American farms (Gehring et al., 2011). Conversely, LGD presence did not disrupt the behaviour and distribution of meso-carnivore species in North America (Bromen et al., 2019), thus indicating LGDs can be utilised without negative consequences for non-target carnivore ecology in some contexts.

It is apparent that there is a current gap in our understanding of the impacts of LGDs at the population level, particularly for carnivores associated with livestock depredation in African countries. To date, no empirical studies have investigated the impact of LGDs on carnivore utilisation of private farmland in Africa. Despite this, the use of LGDs to prevent livestock depredation is increasing globally; in South Africa alone ~ 300 LGDs have been placed on farms to protect livestock from carnivore depredation (Stannard and Cilliers, 2018). To utilise LGDs for the benefit of agricultural stakeholders and wildlife alike, it is imperative LGD impacts on ecosystems are understood. Our study aimed to address this knowledge gap by investigating the impact of LGDs on carnivore occupancy, providing the first empirical comparison between farmlands with and without LGDs in Africa. Based on existing literature in other regions, the hypothesis that LGD presence would negatively influence carnivore occupancy was tested.

2.0 Methodology

2.1 Study site

This study was conducted over two consecutive years, between 7th June and 8th July 2015, and 18th May to 5th August 2016, across eight private farms in the north of Limpopo Province, South Africa (Figure 1). In both years, the study was conducted in the dry/winter season which has an average daily rainfall of 0mm (+/- 2.6 mm) and mean daily temperature ranging between 8°C and 27°C (Meteo Blue, n.d.). Vegetation consisted of a mixture of bushveld types across all farms (Figure 1), with sparse coverage in or adjacent to the study site. All farms in this study farmed domestic livestock and kept game species for hunting (game species were left to breed and forage naturally, but farms were fenced to prevent dispersal beyond property boundaries). Fencing was not considered likely to restrict movement of the carnivore species of interest. Game species populations were artificially controlled via re-stocking and removals by farmers. Ethical review was conducted and approved according to the Nottingham Trent University School of Animal, Rural and Environmental Sciences ethical review procedures.

<Insert Figure 1 here>

The study utilised guarded farms that were part of the Cheetah Outreach Trust LGD programme. In this programme, farmers enter into an agreement with Cheetah Outreach Trust, in which the farmer agrees to cease all forms of lethal carnivore control on the property at the point when the LGD is deployed. Cheetah Outreach Trust provides veterinary and feed supplies for the dogs during the first year of placement, as well as monthly monitoring and training, to ensure the dog is working as efficiently as possible for the farmer. This programme has successfully reduced farmer-reported livestock depredation by up to 100% (Rust et al., 2013) and farmer satisfaction with the dogs is high (90% 'very' or 'completely' satisfied) (Wilkes et al., 2018). This programme is therefore considered a valid case study of LGD operation.

This study surveyed eight livestock farms with a total combined area of 12800 ha; five farms were protected by an LGD (“guarded”) and had a combined area of 8900 ha, whilst three farms were not protected by an LGD (“unguarded”) and had a combined area of 3900 ha (Table 1). Fewer unguarded farms were surveyed than guarded farms due to the difficulty of finding willing participants that weren’t already associated with Cheetah Outreach Trust’sLGD programme. All farms had livestock combinations of sheep, goats and/or cattle (Table 1), and had similar farming and husbandry practices; during the day the livestock and LGDs had free-range over the farmland (unaccompanied by human shepherds), but the LGDs and livestock were kept in kraals overnight as an additional precaution against carnivores. All game species were free to roam the farmland at all times.

Table 1 here.

All guarded farms had a single LGD present on farmland at the time of the study; dogs differed by their sex and length of time on the farm prior to the study period (ranging from 6 weeks to > 3.5 years) but all were adult Anatolian Shepherds which had been raised and trained using standard techniques by Cheetah Outreach Trust (Cheetah Outreach Trust n.d.). Moreover, all guarded farms had a history of consecutive LGD presence for at least 12 months prior to the study (mean 4.4 ±2.6 years, one dog in this study was a replacement for a previously placed dog), such that the LGDs were considered to be established (not novel) components of these farming environments. Sex of dog has previously been determined to have no influence over the effectiveness of the dog in its guarding ability (Leijenaar et al., 2015; Marker et al., 2005).

Guarded farms were assumed to have met the condition of only utilising non-lethal methods of carnivore control on their properties. Unguarded farms used a range of carnivore control methods, some of which included lethal measures such as poisoned carcasses and shooting, as well as live trapping. At least one unguarded farm used only non-lethal control methods. Due to the high degree of uncertainty in self-reporting on the use of controversial (and in some cases illegal) control techniques (St John et al., 2012) non-LGD control method data was not included as a covariate in occupancy models.

Effectiveness of the LGDs on guarded farms in preventing depredation was not investigated here but had previously been determined in the wider LGD programme that these farms were participating in (see Rust et al., 2013) and shown to be highly effective (up to 100% reductions in depredation). Due to recent criticism of farmer perceived evidence for LGD effectiveness (Eklund et al., 2017; van Eeden et al., 2018) we did not undertake formal interviews with farmers and empirical determination of dog-wildlife interactions was beyond the scope of this study. However, informal discussions with farmers held in the process of completing camera-trapping surveys determined that all guarded farms were considered by farmers to be depredation-free for the duration of our study and all reported having experienced noteworthy reductions in depredation rates since the LGDs were placed. In contrast, one unguarded farm reported the depredation of calves during the study period; the farmer assumed this event to have been due to a leopard.

2.2 Camera trap survey design

Seven camera traps comprising two models of camera (Ltl Acorn (Pakatak Ltd, Essex, UK), Covert Extreme and Bushnell Trophy Cameras (Aggressor; Bushnell Outdoor Products, KS, USA)) were placed on each farm at any one time. A total of 126 camera locations were sampled between 7 and 14 days each.

Due to the low population density and elusiveness of carnivore species, camera-trap placement was targeted to increase the likelihood of capturing images of carnivore species (Cusack et al., 2015). Therefore, the camera locations were determined by farmers' knowledge and areas indicating signs of mammal activity, such as tracks and signs. The camera locations were set along fence lines, roads, game trails and at water points (Cusack et al., 2015). To further increase detection rate of predators, camera-trap locations were increased during the second year of the study by moving cameras after 7 days, instead of 14 days in the first year.

The cameras were set between 0.5m and 1.0m in height and set to take only static images, operational over the entire 24 hours period each day with no visible flash (nocturnal images captured using infrared flash). Cameras were set to capture 3 burst images and had a 5-10 second interval between being triggered. Additionally, to reduce false triggering of the cameras, vegetation was removed from the immediate vicinity of the camera.

On the farms studied in 2015, a scent lure was used at 13 camera trap locations (in the form of two teaspoons of liquefied tinned tuna (Long et al., 2008)) to encourage carnivore species to stop near the camera, in order to improve species identification purposes. A scent lure was considered preferable to bait as the lack of food reward would be less likely to attract individuals repeatedly due to the lack of reinforcement following initial introduction. Luring was discontinued once it became apparent that picture quality was sufficient to identify species without it.

2.3 Occupancy Modelling

Single-species, single-season occupancy modelling was used to examine the occupancy of carnivores across all sites (black-backed jackals, leopards and brown hyaena) in relation to LGDs and other site covariates, using PRESENCE v10.5 (Hines, 2006). A species was recorded as present within each trapping day if an animal of that species was detected at least once during a 24-hour period. For carnivore occupancy estimates, each camera-trap location was treated as an individual sampling unit and each camera-trap day as a sampling occasion. Since each camera location was considered an independent site, sampling occasion reflects a sequential repeat of the survey (Linkie et al., 2007; Thorn et al., 2009).

Fifteen site level covariates to estimate both occupancy (ψ - probability that a species occurred at a site) and detectability (p - probability that the species was detected if present) were modelled. Covariates included in the models were: guarding type (LGD presence/absence), livestock presence (goats, cattle, sheep and horses), camera location (water, road, fence line or other), camera type (Bushnell or other), the use of scent lures, year of study, and the presence of other carnivores (black-backed jackal, leopard and brown hyaena). All farms had game species (i.e. wild prey) present, permitted game hunting, but the use of offal dumps was unknown. Although data was collected over two years, no farms were surveyed in both years and each sampling unit (camera trap location) and sampling occasion (one camera trap day) only spanned a maximum of two weeks, so carnivore populations were assumed to be closed in this study.

Models were ranked in order of parsimony via the Aikake's Information Criterion (AIC) value (with the smallest value representing the best fitting model), and we considered models with ΔAIC > 2 to have little or no support (Burnham and Anderson, 2002). Goodness of fit for the best fitting model was assessed using 100 bootstrap iterations. The variance inflation factors ($\hat{c}$) were below 1 for brown hyaena and leopard occupancy models. For black-backed jackals the data was over-dispersed $\hat{c} = 1.4312$ and the standard errors were inflated by the square root of $\hat{c} = 1.19$, whilst models were ranked using quasi-AIC (QAIC). Models that failed to converge were excluded from the candidate set of models.

3.0 Results

3.1 Trapping intensity and species detected

A total of 1029 camera-trap days (sampling occasions) from 126 camera locations across 8 farms were recorded in this study. In 2015, 21 locations were surveyed and 105 in 2016. LGDs were present at 77 locations and absent from 49. Bushnell cameras were deployed at 71 locations and Acorn cameras at 55, while lures were placed at 13 locations and were absent from 113. Cameras were placed at 59 water sources, 34 roads, 18 fence lines and 15 other locations. Cattle were present at 98 locations, sheep at 28, goats at 84, and horses at 28.

Five carnivore species of relevance to human-carnivore conflict in this region (Potgieter et al., 2016; Rust et al., 2013; Weise et al., 2015) were detected more than once on camera-traps on at least one farm: black-backed jackal at 68, brown hyaena at 50 sites, leopard at 16, caracal at 5, and cheetah at 2 locations. Caracal were only detected on guarded farms, and the four remaining carnivore species were detected on at least one guarded and unguarded farm. Vegetation type (Figure 1) varied for one guarded farm (mixed bushveld type) compared to the others which were either mopani veld or arid sweet bushveld. However, this farm was not determined to be an outlier when presence data were investigated. Sightings of brown hyaena occurred on this mixed bushveld farm on 15% of camera trapping days, compared to 3 – 14% on other farms; sightings of leopards occurred on 0% of days, compared to 0 – 3% on other farms, and sightings of black-backed jackal occurred on 11% of days on this farm, compared to 2 – 22% on other farms. This, along with its classification as “mixed”, meant that the vegetation type on this farm was not considered further.

3.2 Carnivore occupancy

The presence of cheetah and caracal were not modelled due to a low number of detections across the study. Naïve occupancy was highest for black-backed jackal (0.5397), followed by brown hyaena (0.3968), and leopard (0.1270). The models containing LGD covariates had little support in explaining leopard (Table 2) or black-backed jackal occupancy (Table 3). However, LGD presence had a positive relationship with brown hyaena occupancy (Table 4).

The best fitting models for leopard occupancy included the presence of black-backed jackals and sheep. These covariates were present in the top 6 ranked models, with a combined AIC weight of 0.833. The highest ranked model was a constant occupancy across sites. Leopard detection was significantly and positively related to the presence of black-backed jackals (β = 1.47, 95% CI = 0.18, 2.74) and sheep (β = 1.13, 95% CI = 0.14, 2.12).

Table 2 here.

The best fitting model for black-backed jackal occupancy included the presence of leopards and detection covariates of lures and brown hyaena. The presence of leopards as a covariate of black-backed jackal occupancy was non-significant (β = 1.33, 95% CI = -0.42, 3.07). However, black-backed jackal detection was significantly negatively related to lures (β = -1.33, 95% CI = -2.00, -0.65) and significantly positively related to the presence of brown hyaena (β = 0.90, 95% CI = 0.43, 1.40).

Table 3 here.

The best fitting brown hyaena occupancy model was explained by the occupancy covariate of LGD presence showing a significant positive relationship (β = 1.14, 95% CI = 0.05, 2.23) and hyaena detection was significantly negatively related to the presence of sheep (β = -1.45, 95% CI = -0.65, -2.25). This model alone had an AIC weight of 0.48, and the presence of sheep was a key detection covariate in the top ranked models for brown hyaena.

Table 4 here.

4.0 Discussion

This study represents the first empirical investigation into the ecological impact of LGD placement in Africa. Our findings support the classification of LGDs as a conservation tool in mitigating HWC, whereby no overall influence on carnivore occupancy was detectable on guarded farms, compared to farms without LGDs. Moreover, in the case of brown hyaena, LGD presence was found to be positively related to their occupancy. It is important to note that occupancy is a measure of the probability that a species occupies or utilises an area during the period of investigation (during which occupancy is assumed to be static) (Bailey et al., 2014). Therefore, our study does not purport to determine carnivore abundance or density and does not attempt to define carnivore populations on these farms in comparison to any baseline or "ideal" measure. We encourage future studies to incorporate more comprehensive assessments of carnivore ecology.

Although based on a small sample size, our findings provide a better understanding of the role that the dogs may be having in the environment in terms of carnivore populations. Given the well-established presence of the LGDs on our guarded farms, the ecological systems were not likely in an acute phase of adapting to the introduction of LGDs. As such, our findings suggest that carnivores are not prevented from occupying South African farms with LGDs. It therefore appears that LGDs facilitate a strong state of coexistence, defined as one where humans and carnivores share an environment without risk of exclusion to either (Chapron and López-Bao, 2016). Under this state, niche differentiation between humans and carnivores must be highly realised (Chapron and López-Bao, 2016), such that the LGD presence could act as an effective driver for this differentiation, so long as suitable alternative prey and space is available to the carnivores. Human-carnivore coexistence is likely enabled, at least to some extent, by the removal of competition for food resources. Studies of free-ranging leopard and cheetah diets have revealed a preference for wild prey over livestock when biomass of wild medium-large ungulates is above a certain threshold (Drouilly et al., 2018; Khorozyan et al., 2015; Ott et al., 2007; Winterbach et al., 2015). Likewise, brown hyaenas are less of a threat to livestock as long as sufficient carrion is available (Van Der Merwe et al., 2009; Yarnell et al., 2013). These prey preferences would therefore support the equal occupancy of both guarded and unguarded farms by these carnivores, regardless of the availability of livestock, as was also found for meso-carnivores in the USA (Bromen et al., 2019). Specifically, in the case of brown hyaena being positively associated with LGD, ample wild prey in conjunction with lower levels of human persecution on LGD-protected farmland (Rust et al., 2013) may support a higher density of this social species on guarded farms (Yarnell et al., 2013), but this remains to be tested.

Our findings contrast with those from other countries, which determined mainly negative impacts on wildlife. We did not measure dog-wildlife interactions here, but reports of LGD chasing or killing wildlife exist (Marker et al., 2005; Potgieter et al., 2016; Urbigkit and Urbigkit, 2010) and similar interactions may have occurred in our study site. Other studies have shown wildlife to avoid or move further away from areas with LGDs (Van Bommel and Johnson, 2016). In a similar study to ours, Gehring *et al.* (2011) directly compared cattle farms with and without LGDs in Michigan, North America, and found cattle pastures protected by LGDs to be devoid of wolf (*Canis lupus*) and coyote (*C. latrans*) visitation to pastures. Despite the clear deterrence of carnivore species from LGD-guarded pastures, the pastures were only 10-40ha (Gehring et al., 2011), which is notably smaller than most commercial livestock farms in South Africa. Farms in our study ranged between 500-3000ha which allows for greater spatial separation between wildlife and dogs. This is supported by Gingold *et al.* (2011) who found that LGDs only had a significant impact on gazelle reproduction in smaller pastures (100-180ha), where mountain gazelles (*Gazella gazella*) were less able to avoid dogs, compared to larger pastures (240ha). Equally, the “landscape of fear” suggested in Australia (Van Bommel 2016) occurred on farms which, although similar in size to ours, maintained up to four LGDs per farm. Moreover, the farming practices in our study facilitated temporal separation between LGDs and carnivores since the dogs were kraaled overnight with the herds, when the three species of carnivores investigated here would be most active. Further research is needed to understand dog-wildlife interactions, breed-specific differences in LGD behaviours, spatio-temporal overlap and separation between LGDs and wildlife species, and the impact that farming environment and management system has on the utilisation of guarded farmland by free-ranging carnivores.

Predator and prey avoidance behaviour towards LGDs has previously been attributed to dogs actively chasing wildlife (Marker et al., 2005), especially in such cases where dogs are specifically trained to seek and attack certain species (Linhart et al., 1979), or dogs fatally interact with wildlife (Potgieter et al., 2016). Recently, large carnivores and LGDs have been postulated as having the potential to levy considerable harm on wildlife in South Africa (Allen et al., 2019). These authors suggest that leopards may act to negatively influence populations of smaller carnivores, such as jackals, and that the presence of an LGD could indirectly increase leopard-induced reductions in jackal populations. Moreover, Allen et al. (2019) suggest that the dogs themselves may directly alter wildlife population abundance or distribution. As acknowledged by the authors, this hypothesis requires testing and our findings therefore offer timely and relevant insights into the LGD-wildlife interactions that may be occurring on South African farmlands. In contrast to the hypothesised negative influence of LGDs, data from our study demonstrates a more neutral impact of LGDs on carnivore occurrence on farms. Specifically, the presence of LGDs was not a significant factor predicting either leopard or black-backed jackal occupancy, and the presence of leopards actually had a positive (but non-significant) relationship with black-backed jackal occupancy.

Within the Cheetah Outreach Trust LGD programme, unwanted behaviours including chasing game and straying from the herd are quickly corrected through behavioural training, or the dog replaced. For example, in a previous study of this programme (Rust et al., 2013), only 17% were reported with behavioural problems (not exclusively including chasing wildlife); the majority of these were removed from the programme, although a quarter of them were corrected following training intervention. Therefore, LGDs provided by Cheetah Outreach Trust and similar organisations that discourage behavioural problems in LGDs should facilitate co-existence between LGDs and carnivores (Dawydiak and Sims, 2004; Potgieter et al., 2016). In these cases, dogs directly protect livestock if approached by a carnivore but do not exclude predators from guarded farmland (Allen et al., 2017; our study) and do not chase wildlife beyond a few hundred metres from the herd because they are behaviourally compelled to remain with the livestock they are guarding (Chestley and Whiting, 2015). Anecdotal evidence from farmers (this study), and historical data from the same programme (Rust et al., 2013) suggested dogs and carnivores rarely came into direct contact. Moreover, there were no known carnivore or livestock fatalities on the guarded farms during this study, suggesting coexistence.

Unguarded farms utilised in this study did not share a boundary with a guarded farm. Since carnivores are not confined by property boundaries as many of the larger wild prey species are, it is currently unknown what, if any, impact LGD placement may have on wildlife in their immediate neighbours' unguarded properties. When lethal control of wolves was modelled previously, a detrimental effect (increased predation risk) was demonstrated for neighbouring farms in the USA (Santiago-Avila et al., 2018), aligning with increased carnivore visitation to unguarded farms adjacent to LGD-guarded farms also observed in that country (Gehring et al., 2011). As such, a similar spill-over effect may be seen with LGD-associated changes in carnivore habitat utilisation in African contexts. However, in situations where a carnivore includes both guarded and unguarded farms within its territory, it is unlikely that the foraging strategies of individual carnivores will change within this space because of LGD placement, as long as sufficient wild prey is available. Moreover, the continued occupancy of this territory by large carnivores (as apparent in our study) should prevent increased depredation of livestock that may arise from the vacuum effect (associated with lethal control) causing increased immigration of large carnivores into vacant territories (Loveridge et al., 2007; Van Der Meer et al., 2014). However, further investigation is required to determine the impact of LGDs on unguarded neighbouring farms in South Africa.

Whilst our modelling found no significant negative association between LGDs and predator occupancy, we did find other covariates to be significant predictors. This mirrors findings from similar studies, where species have been more influenced by environmental variables such as habitat preference over presence of LGDs (Bromen et al., 2019; Van Bommel and Johnson, 2016). Black-backed jackals were significantly positively correlated to brown hyaena, which can be explained by their dietary overlap as scavengers and generalist feeders (Van der Merwe et al.2009). Brown hyaena directly interact with black-backed jackal more than any other carnivore because of interspecific competition for carcasses and kleptoparasitism (Owens and Owens, 1978). Additionally, leopards were significantly positively correlated to the presence of black-backed jackal and sheep. Despite the small dietary overlap between these two species (Drouilly et al., 2018), both species have been associated with higher levels of livestock depredation compared to other carnivores in South Africa (Somers et al., 2018; Thorn et al., 2012) which may explain the relationship found in this study.

It is acknowledged that only eight farms were assessed in this study and small sample sizes can lead to differences not being detected between groups during statistical analysis (Type II error) and outliers greatly affecting results (Nayak, 2010). However, we minimised the risk of this by treating each camera-trap location as an individual sampling unit, regardless of farm or year, resulting in 77 locations with an LGD present and 49 locations without. Furthermore, this study utilises a similar number of farms and/or LGDs as used in other ecological studies on the impact of LGDs on wildlife outside of Africa (Allen et al., 2017; Gehring et al., 2010; van Bommel & Johnson, 2016), and spanned a larger area than some studies (Gehring et al., 2011; Gingold et al., 2009). Another important limitation to our study relates to the other predator control methods that were being utilised at the time across both types of farms. Whilst we had no reason to suspect guarded farms were not abiding by the prohibition of lethal control methods which is a prerequisite of their dog placements, it is possible that other non-lethal methods varied between farms, and likely that lethal control methods were employed on some unguarded farms. Such variation in husbandry practices could be expected to influence carnivore occupancy and it will be important for future studies to incorporate this variable in their analyses. To fully understand the impact of LGDs on predator occupancy, we encourage the replication and expansion of this study in South Africa and internationally. Likewise, it will be important to monitor population dynamics and prey utilisation across seasons and over a longer time period, including comparisons between neighbouring guarded and unguarded farms.

Targeted placement of camera traps was necessary for increasing the probability of detection for elusive carnivores; this strategy has previously been shown to provide more reliable population estimates than a random trap design (Brassine and Parker, 2015) and has been used in occupancy studies on low-density species such as jaguar (Solmann et al., 2012). However, it is understood that targeted placement of cameras can introduce an irregular sampling effort across the landscape as habitat heterogeneity is not accounted for (Brassine and Parker, 2015); this was avoided as far as possible by placing cameras in similar locations across farms. However, despite this biased camera-trapping design, detection rate was still quite low for elusive species that naturally occur in low densities, such as caracal and cheetah (Cusack et al., 2015), therefore we encourage future studies to maximise trapping effort by increasing the number of farms and length of study.

5.0 Conclusion

Livestock guarding dogs in this study were placed on farms to encourage human-carnivore coexistence and contribute to the conservation of carnivores by reducing livestock depredation thereby decreasing the use of lethal predator control. To be considered a successful conservation tool, the presence of LGDs on farmland must not negatively impact wildlife. Results from this study provide the first empirical evidence that carnivores associated with human-carnivore conflict in an African context are still inhabiting farmland guarded by LGDs, with no significant difference in occupancy between guarded and unguarded farms. Further work exploring the conditions that enable LGDs to coexist with predators should be undertaken to fully understand how LGDs can be utilised to benefit both farmers and wildlife alike. Nonetheless, our findings are encouragingly supportive of the role that LGDs play in carnivore conservation, indicating their capacity to contribute towards a sustainable state of human-carnivore coexistence on agricultural lands.

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Tables

Table 1. Characteristics and survey effort at farms surveyed for carnivore occupancy, including guarded status, size (ha), livestock present, habitat type. Number of individual camera trap locations and year of survey.

Farm	**Status**	**Size (ha)**	**Livestock**	**Year**
1	Guarded	500	Cattle, sheep and horses	2016
2	Guarded	1600	Goats	2016
3	Guarded	3000	Cattle and goats	2016
4	Guarded	1600	Cattle, sheep and goats	2015
5	Guarded	2200	Goats and horses	2015
6	Unguarded	1200	Cattle and goats	2016
7	Unguarded	1500	Cattle	2016
8	Unguarded	1200	Cattle and goats	2015

Table 2. Summary of single-species, single-season occupancy models run on the complete data set for leopards (*Panthera pardus pardus*). Top ranked models (ΔQAIC < 2.0) are in bold and only the top 6 models (and any Livestock Guarding Dog model(s)) are shown.

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2*LogLike
psi(.),p(BBJackal+Sheep)	**185.02**	**0.00**	**0.40**	**1.00**	**4**	**177.02**
psi(BBJackal),p(Sheep)	**186.70**	**1.68**	**0.17**	**0.43**	**4**	**178.70**
psi(.),p(BBJackal)	187.61	2.59	0.11	0.27	3	181.61
psi(BBJackal),p(.)	188.68	3.66	0.06	0.16	3	182.68
psi(.),p(Sheep)	189.45	4.43	0.04	0.11	3	183.45
psi(Sheep),p(.)	189.66	4.64	0.04	0.10	3	183.66
psi(LGD),p(.)	193.16	8.14	0.01	0.02	3	187.16
psi(.),p(LGD)	193.36	8.34	0.01	0.02	3	187.36

AIC = Aikake's Information Criterion

Psi = occupancy

P = detectability

Table 3. Summary of single-species, single-season occupancy models run on the complete data set for black-backed jackals (*Canis mesomelas*). Top ranked models (ΔQAIC < 2.0) are in bold and only the top 5 models (and any Livestock Guarding Dog model(s)) are shown.

Model	**QAIC**	**deltaQAIC**	**AIC wgt**	**Model Likelihood**	**no.Par.**	**-2*LogLike**
psi(Leopard),p(Lure+Brown_Hyaena)	**581.81**	**0.00**	**0.60**	**1.00**	**5**	**817.69**
psi(.),p(Lure+Brown_Hyaena)	**582.61**	**0.80**	**0.40**	**0.67**	**4**	**821.69**
psi(.),p(Lure)	594.95	13.14	0.00	0.00	3	842.20
psi(.),p(Brown_Hyaena)	597.98	16.17	0.00	0.00	3	846.53
psi(.),p(Location)	600.06	18.25	0.00	0.00	5	843.79
psi(.),p(LGD)	607.77	25.96	0.00	0.00	3	860.53
psi(LGD),p(.)	608.36	26.55	0.00	0.00	3	861.37

AIC = Aikake's Information Criterion

Psi = occupancy

P = detectability

Table 4. Summary of single-species, single-season occupancy models run on the complete data set for brown hyaena (*Parahyaena brunnea*). Top ranked models (ΔQAIC < 2.0) are in bold and only the top 5 models (and any Livestock Guarding Dog model(s)) are shown.

Model	**AIC**	**deltaAIC**	**AIC wgt**	**Model Likelihood**	**no.Par.**	**-2*LogLike**
psi(LGD),p(Sheep)	**551.79**	**0.00**	**0.48**	**1.00**	**4**	**543.79**
psi(BBJackal),p(Sheep)	553.90	2.11	0.17	0.35	4	545.90
psi(.),p(Sheep)	554.28	2.49	0.14	0.29	3	548.28
psi(.),p(Sheep+Horse)	554.63	2.84	0.12	0.24	4	546.63
psi(.),p(Horse)	556.17	4.38	0.05	0.11	3	550.17
psi(.),p(Location)	559.59	7.80	0.01	0.02	5	549.59
psi(LGD),p(.)	562.96	11.17	0.00	0.00	3	556.96
psi(.),p(LGD)	564.13	12.34	0.00	0.00	3	558.13

AIC = Aikake's Information Criterion

Psi = occupancy

P = detectability

Figure Legend

Figure 1. Map of the study area in Limpopo, South Africa (southern Africa shown in insert), with study farms indicated (red points = guarded farms, green points = unguarded farms) and vegetation types (ArcGIS, ESRI, v2.12, March 2019, Redlands, USA).