

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

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14 **Abstract**

15 Livestock guarding dogs (LGDs) are advocated to reduce livestock depredation on
16 agricultural lands. However, LGDs have been proposed as excluding carnivores from
17 guarded farms; this study is the first to test this hypothesis in an African ecosystem. We
18 investigated carnivore occupancy (black-backed jackal, leopard and brown hyaena) from
19 1029 camera-trap days (126 camera locations) in relation to the presence of LGDs and a
20 range of habitat and land-use covariates across eight South African farms, five of which
21 utilised an LGD. Models containing LGDs had little support in explaining leopard or black-
22 backed jackal occupancy, although LGD presence had a positive relationship with brown

23 hyaena occupancy ($\beta = 1.14$, 95% CI = 0.05, 2.23). Leopard detection was positively related
24 to the presence of black-backed jackals ($\beta = 1.47$, 95% CI = 0.18, 2.74) and sheep ($\beta = 1.13$,
25 95% CI = 0.14, 2.12), whilst black-backed jackal detection was negatively related to lures (β
26 = -1.33, 95% CI = -2.00, -0.65) and positively related to the presence of brown hyaena ($\beta =$
27 0.90, 95% CI = 0.43, 1.40). Previous research in this LGD population has demonstrated the
28 cessation of livestock depredation in 91% of cases, making dog ineffectiveness unlikely to
29 explain their lack of influence on carnivore occupancy. Our results provide the first empirical
30 evidence based on ecological data of the capacity for LGDs to promote human-carnivore
31 coexistence in an African agricultural context, further validating the use of specialist
32 guarding dogs as a conservation tool of benefit to both human and wildlife populations.

33 **1.0 Introduction**

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

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

48 Livestock depredation has important negative economic implications for individual farmers,
49 the farming industry, and local economies as a whole (Mkonyi et al., 2017; Moreira-Arce et
50 al., 2018). Annually, livestock depredation around the world has been reported to equate to
51 losses of between 0.02 – 15% of total herd size (Blackwell et al., 2016; Butler, 2000; Graham
52 et al., 2005; Mkonyi et al., 2017). In financial terms, such losses can represent over USD
53 \$600 per household in Tanzania (Mkonyi et al., 2017), or \$98.5 million annually for the US
54 farming industry (Blackwell et al., 2016).

55 Despite evidence to demonstrate that lethal control is more expensive than non-lethal
56 alternatives and often less effective (Lennox et al., 2018; McManus et al., 2015; Moreira-
57 Arce et al., 2018; Treves et al., 2016), lethal carnivore control methods are still employed.
58 These are often part of farming culture, readily available, and perceived to be the cheapest,
59 most practical method (Blackwell et al., 2016; McManus et al., 2015). However, lethal
60 control of apex carnivores is not always directly associated with the damage they are
61 perceived to have incurred, whereby indiscriminate lethal removal occurs even in the absence
62 of perceived damage (Marker et al., 2003). This has caused dramatic declines in large
63 carnivores across unprotected land (Boshoff et al., 2016), which has major implications for
64 the ecosystems as well as human health and well-being (O’Bryan et al., 2018; Ritchie and
65 Johnson, 2009; Thorn et al., 2012; Treves and Karanth, 2003). Furthermore, there is a
66 funding deficit for protected areas in Africa, and carnivore conservation on private and
67 unprotected lands, alongside improved management of protected areas, has become critical to
68 many species’ survival (Durant et al., 2017; Lindsey et al., 2018). It is therefore imperative
69 that conservation efforts achieve a state of strong coexistence in these agricultural
70 environments (Clements et al., 2016; Durant et al., 2017). With the negative ecological and

71 economic impacts of lethal control on the unprotected areas in mind, the importance of
72 finding carnivore-safe livestock management practices, of benefit to both human and wildlife
73 land-users and enabling co-existence, has never been more apparent (Van Eeden et al., 2018).
74 In spite of a relative paucity of empirical evidence regarding HWC mitigation method
75 effectiveness, one of the most successful methods documented is livestock guarding dogs
76 (LGDs) (Eklund et al., 2017; Krafte Holland et al., 2018; Shivik, 2004; Torres et al., 2018;
77 Van Eeden et al., 2018). Generally, LGDs are bred and trained to stay with the livestock herd
78 and prevent carnivores from attacking through protective displays, often without physical
79 conflict (Allen et al., 2017; Gehring et al., 2010). The ability of these dogs to protect
80 livestock from carnivores and subsequently increase farmer tolerance towards carnivores on
81 their farmland (Potgieter et al., 2016; Rust et al., 2013) has supported the promotion of LGDs
82 as a human-carnivore conflict mitigation tool.

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

94 For LGDs to be considered beneficial to carnivore conservation, it is imperative they do not
95 have negative impacts at the population level, i.e. the utilisation of farmland by carnivores.
96 Yet, ecological and community-level responses to LGDs have only occasionally been
97 reported, and are restricted to certain regions. In Australia, LGDs have been considered a
98 surrogate top-predator as they create a “landscape of fear” whereby the presence of dogs
99 leads to unintended altered behaviour and reduced habitat utilisation by a range of wildlife
100 species, especially for prey species or competitors of large canids (Van Bommel and
101 Johnson, 2016). LGD-associated spatial avoidance by wild canid species has been recorded
102 (Van Bommel and Johnson, 2016), along with reduced carnivore visitation of North
103 American farms (Gehring et al., 2011). Conversely, LGD presence did not disrupt the
104 behaviour and distribution of meso-carnivore species in North America (Bromen et al.,
105 2019), thus indicating LGDs can be utilised without negative consequences for non-target
106 carnivore ecology in some contexts.

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

119 **2.0 Methodology**

120 *2.1 Study site*

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

134 <Insert Figure 1 here>

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

143 satisfied) (Wilkes et al., 2018). This programme is therefore considered a valid case study of
144 LGD operation.

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

155 Table 1 here.

156 All guarded farms had a single LGD present on farmland at the time of the study; dogs
157 differed by their sex and length of time on the farm prior to the study period (ranging from 6
158 weeks to > 3.5 years) but all were adult Anatolian Shepherds which had been raised and
159 trained using standard techniques by Cheetah Outreach Trust (Cheetah Outreach Trust n.d.).
160 Moreover, all guarded farms had a history of consecutive LGD presence for at least 12
161 months prior to the study (mean 4.4 ±2.6 years, one dog in this study was a replacement for a
162 previously placed dog), such that the LGDs were considered to be established (not novel)
163 components of these farming environments. Sex of dog has previously been determined to
164 have no influence over the effectiveness of the dog in its guarding ability (Leijenaar et al.,
165 2015; Marker et al., 2005).

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

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

185 *2.2 Camera trap survey design*

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

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

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

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

210 *2.3 Occupancy Modelling*

211 Single-species, single-season occupancy modelling was used to examine the occupancy of
212 carnivores across all sites (black-backed jackals, leopards and brown hyaena) in relation to
213 LGDs and other site covariates, using PRESENCE v10.5 (Hines, 2006). A species was

214 recorded as present within each trapping day if an animal of that species was detected at least
215 once during a 24-hour period. For carnivore occupancy estimates, each camera-trap location
216 was treated as an individual sampling unit and each camera-trap day as a sampling occasion.
217 Since each camera location was considered an independent site, sampling occasion reflects a
218 sequential repeat of the survey (Linkie et al., 2007; Thorn et al., 2009).

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

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

238 **3.0 Results**

239 *3.1 Trapping intensity and species detected*

240 A total of 1029 camera-trap days (sampling occasions) from 126 camera locations across 8
241 farms were recorded in this study. In 2015, 21 locations were surveyed and 105 in 2016.
242 LGDs were present at 77 locations and absent from 49. Bushnell cameras were deployed at
243 71 locations and Acorn cameras at 55, while lures were placed at 13 locations and were
244 absent from 113. Cameras were placed at 59 water sources, 34 roads, 18 fence lines and 15
245 other locations. Cattle were present at 98 locations, sheep at 28, goats at 84, and horses at 28.
246 Five carnivore species of relevance to human-carnivore conflict in this region (Potgieter et
247 al., 2016; Rust et al., 2013; Weise et al., 2015) were detected more than once on camera-traps
248 on at least one farm: black-backed jackal at 68, brown hyaena at 50 sites, leopard at 16,
249 caracal at 5, and cheetah at 2 locations. Caracal were only detected on guarded farms, and the
250 four remaining carnivore species were detected on at least one guarded and unguarded farm.
251 Vegetation type (Figure 1) varied for one guarded farm (mixed bushveld type) compared to
252 the others which were either mopani veld or arid sweet bushveld. However, this farm was not
253 determined to be an outlier when presence data were investigated. Sightings of brown hyaena
254 occurred on this mixed bushveld farm on 15% of camera trapping days, compared to 3 – 14%
255 on other farms; sightings of leopards occurred on 0% of days, compared to 0 – 3% on other
256 farms, and sightings of black-backed jackal occurred on 11% of days on this farm, compared
257 to 2 – 22% on other farms. This, along with its classification as “mixed”, meant that the
258 vegetation type on this farm was not considered further.

259 *3.2 Carnivore occupancy*

260 The presence of cheetah and caracal were not modelled due to a low number of detections
261 across the study. Naïve occupancy was highest for black-backed jackal (0.5397), followed by
262 brown hyaena (0.3968), and leopard (0.1270). The models containing LGD covariates had

263 little support in explaining leopard (Table 2) or black-backed jackal occupancy (Table 3).
264 However, LGD presence had a positive relationship with brown hyaena occupancy (Table 4).
265 The best fitting models for leopard occupancy included the presence of black-backed jackals
266 and sheep. These covariates were present in the top 6 ranked models, with a combined AIC
267 weight of 0.833. The highest ranked model was a constant occupancy across sites. Leopard
268 detection was significantly and positively related to the presence of black-backed jackals ($\beta =$
269 1.47, 95% CI = 0.18, 2.74) and sheep ($\beta = 1.13$, 95% CI = 0.14, 2.12).

270 Table 2 here.

271 The best fitting model for black-backed jackal occupancy included the presence of leopards
272 and detection covariates of lures and brown hyaena. The presence of leopards as a covariate
273 of black-backed jackal occupancy was non-significant ($\beta = 1.33$, 95% CI = -0.42, 3.07).

274 However, black-backed jackal detection was significantly negatively related to lures ($\beta = -$
275 1.33, 95% CI = -2.00, -0.65) and significantly positively related to the presence of brown
276 hyaena ($\beta = 0.90$, 95% CI = 0.43, 1.40).

277 Table 3 here.

278 The best fitting brown hyaena occupancy model was explained by the occupancy covariate of
279 LGD presence showing a significant positive relationship ($\beta = 1.14$, 95% CI = 0.05, 2.23) and
280 hyaena detection was significantly negatively related to the presence of sheep ($\beta = -1.45$,
281 95% CI = -0.65, -2.25). This model alone had an AIC weight of 0.48, and the presence of
282 sheep was a key detection covariate in the top ranked models for brown hyaena.

283 Table 4 here.

284 **4.0 Discussion**

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

296 Although based on a small sample size, our findings provide a better understanding of the
297 role that the dogs may be having in the environment in terms of carnivore populations. Given
298 the well-established presence of the LGDs on our guarded farms, the ecological systems were
299 not likely in an acute phase of adapting to the introduction of LGDs. As such, our findings
300 suggest that carnivores are not prevented from occupying South African farms with LGDs. It
301 therefore appears that LGDs facilitate a strong state of coexistence, defined as one where
302 humans and carnivores share an environment without risk of exclusion to either (Chapron and
303 López-Bao, 2016). Under this state, niche differentiation between humans and carnivores
304 must be highly realised (Chapron and López-Bao, 2016), such that the LGD presence could
305 act as an effective driver for this differentiation, so long as suitable alternative prey and space
306 is available to the carnivores. Human-carnivore coexistence is likely enabled, at least to some
307 extent, by the removal of competition for food resources. Studies of free-ranging leopard and
308 cheetah diets have revealed a preference for wild prey over livestock when biomass of wild

309 medium-large ungulates is above a certain threshold (Drouilly et al., 2018; Khorozyan et al.,
310 2015; Ott et al., 2007; Winterbach et al., 2015). Likewise, brown hyaenas are less of a threat
311 to livestock as long as sufficient carrion is available (Van Der Merwe et al., 2009; Yarnell et
312 al., 2013). These prey preferences would therefore support the equal occupancy of both
313 guarded and unguarded farms by these carnivores, regardless of the availability of livestock,
314 as was also found for meso-carnivores in the USA (Bromen et al., 2019). Specifically, in the
315 case of brown hyaena being positively associated with LGD, ample wild prey in conjunction
316 with lower levels of human persecution on LGD-protected farmland (Rust et al., 2013) may
317 support a higher density of this social species on guarded farms (Yarnell et al., 2013), but this
318 remains to be tested.

319 Our findings contrast with those from other countries, which determined mainly negative
320 impacts on wildlife. We did not measure dog-wildlife interactions here, but reports of LGD
321 chasing or killing wildlife exist (Marker et al., 2005; Potgieter et al., 2016; Urbigit and
322 Urbigit, 2010) and similar interactions may have occurred in our study site. Other studies
323 have shown wildlife to avoid or move further away from areas with LGDs (Van Bommel and
324 Johnson, 2016). In a similar study to ours, Gehring *et al.* (2011) directly compared cattle
325 farms with and without LGDs in Michigan, North America, and found cattle pastures
326 protected by LGDs to be devoid of wolf (*Canis lupus*) and coyote (*C. latrans*) visitation to
327 pastures. Despite the clear deterrence of carnivore species from LGD-guarded pastures, the
328 pastures were only 10-40ha (Gehring et al., 2011), which is notably smaller than most
329 commercial livestock farms in South Africa. Farms in our study ranged between 500-3000ha
330 which allows for greater spatial separation between wildlife and dogs. This is supported by
331 Gingold *et al.* (2011) who found that LGDs only had a significant impact on gazelle
332 reproduction in smaller pastures (100-180ha), where mountain gazelles (*Gazella gazella*)
333 were less able to avoid dogs, compared to larger pastures (240ha). Equally, the “landscape of

334 fear” suggested in Australia (Van Bommel 2016) occurred on farms which, although similar
335 in size to ours, maintained up to four LGDs per farm. Moreover, the farming practices in our
336 study facilitated temporal separation between LGDs and carnivores since the dogs were
337 kraaled overnight with the herds, when the three species of carnivores investigated here
338 would be most active. Further research is needed to understand dog-wildlife interactions,
339 breed-specific differences in LGD behaviours, spatio-temporal overlap and separation
340 between LGDs and wildlife species, and the impact that farming environment and
341 management system has on the utilisation of guarded farmland by free-ranging carnivores.

342 Predator and prey avoidance behaviour towards LGDs has previously been attributed to dogs
343 actively chasing wildlife (Marker et al., 2005), especially in such cases where dogs are
344 specifically trained to seek and attack certain species (Linhart et al., 1979), or dogs fatally
345 interact with wildlife (Potgieter et al., 2016). Recently, large carnivores and LGDs have
346 been postulated as having the potential to levy considerable harm on wildlife in South Africa
347 (Allen et al., 2019). These authors suggest that leopards may act to negatively influence
348 populations of smaller carnivores, such as jackals, and that the presence of an LGD could
349 indirectly increase leopard-induced reductions in jackal populations. Moreover, Allen et al.
350 (2019) suggest that the dogs themselves may directly alter wildlife population abundance or
351 distribution. As acknowledged by the authors, this hypothesis requires testing and our
352 findings therefore offer timely and relevant insights into the LGD-wildlife interactions that
353 may be occurring on South African farmlands. In contrast to the hypothesised negative
354 influence of LGDs, data from our study demonstrates a more neutral impact of LGDs on
355 carnivore occurrence on farms. Specifically, the presence of LGDs was not a significant
356 factor predicting either leopard or black-backed jackal occupancy, and the presence of
357 leopards actually had a positive (but non-significant) relationship with black-backed jackal
358 occupancy.

359 Within the Cheetah Outreach Trust LGD programme, unwanted behaviours including chasing
360 game and straying from the herd are quickly corrected through behavioural training, or the
361 dog replaced. For example, in a previous study of this programme (Rust et al., 2013), only
362 17% were reported with behavioural problems (not exclusively including chasing wildlife);
363 the majority of these were removed from the programme, although a quarter of them were
364 corrected following training intervention. Therefore, LGDs provided by Cheetah Outreach
365 Trust and similar organisations that discourage behavioural problems in LGDs should
366 facilitate co-existence between LGDs and carnivores (Dawydiak and Sims, 2004; Potgieter et
367 al., 2016). In these cases, dogs directly protect livestock if approached by a carnivore but do
368 not exclude predators from guarded farmland (Allen et al., 2017; our study) and do not chase
369 wildlife beyond a few hundred metres from the herd because they are behaviourally
370 compelled to remain with the livestock they are guarding (Chestley and Whiting, 2015).
371 Anecdotal evidence from farmers (this study), and historical data from the same programme
372 (Rust et al., 2013) suggested dogs and carnivores rarely came into direct contact. Moreover,
373 there were no known carnivore or livestock fatalities on the guarded farms during this study,
374 suggesting coexistence.

375 Unguarded farms utilised in this study did not share a boundary with a guarded farm. Since
376 carnivores are not confined by property boundaries as many of the larger wild prey species
377 are, it is currently unknown what, if any, impact LGD placement may have on wildlife in
378 their immediate neighbours' unguarded properties. When lethal control of wolves was
379 modelled previously, a detrimental effect (increased predation risk) was demonstrated for
380 neighbouring farms in the USA (Santiago-Avila et al., 2018), aligning with increased
381 carnivore visitation to unguarded farms adjacent to LGD-guarded farms also observed in that
382 country (Gehring et al., 2011). As such, a similar spill-over effect may be seen with LGD-
383 associated changes in carnivore habitat utilisation in African contexts. However, in situations

384 where a carnivore includes both guarded and unguarded farms within its territory, it is
385 unlikely that the foraging strategies of individual carnivores will change within this space
386 because of LGD placement, as long as sufficient wild prey is available. Moreover, the
387 continued occupancy of this territory by large carnivores (as apparent in our study) should
388 prevent increased depredation of livestock that may arise from the vacuum effect (associated
389 with lethal control) causing increased immigration of large carnivores into vacant territories
390 (Loveridge et al., 2007; Van Der Meer et al., 2014). However, further investigation is
391 required to determine the impact of LGDs on unguarded neighbouring farms in South Africa.

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

406 It is acknowledged that only eight farms were assessed in this study and small sample sizes
407 can lead to differences not being detected between groups during statistical analysis (Type II
408 error) and outliers greatly affecting results (Nayak, 2010). However, we minimised the risk of

409 this by treating each camera-trap location as an individual sampling unit, regardless of farm
410 or year, resulting in 77 locations with an LGD present and 49 locations without. Furthermore,
411 this study utilises a similar number of farms and/or LGDs as used in other ecological studies
412 on the impact of LGDs on wildlife outside of Africa (Allen et al., 2017; Gehring et al., 2010;
413 van Bommel & Johnson, 2016), and spanned a larger area than some studies (Gehring et al.,
414 2011; Gingold et al., 2009). Another important limitation to our study relates to the other
415 predator control methods that were being utilised at the time across both types of farms.
416 Whilst we had no reason to suspect guarded farms were not abiding by the prohibition of
417 lethal control methods which is a prerequisite of their dog placements, it is possible that other
418 non-lethal methods varied between farms, and likely that lethal control methods were
419 employed on some unguarded farms. Such variation in husbandry practices could be expected
420 to influence carnivore occupancy and it will be important for future studies to incorporate this
421 variable in their analyses. To fully understand the impact of LGDs on predator occupancy, we
422 encourage the replication and expansion of this study in South Africa and internationally.
423 Likewise, it will be important to monitor population dynamics and prey utilisation across
424 seasons and over a longer time period, including comparisons between neighbouring guarded
425 and unguarded farms.

426 Targeted placement of camera traps was necessary for increasing the probability of detection
427 for elusive carnivores; this strategy has previously been shown to provide more reliable
428 population estimates than a random trap design (Brassine and Parker, 2015) and has been
429 used in occupancy studies on low-density species such as jaguar (Solmann et al., 2012).
430 However, it is understood that targeted placement of cameras can introduce an irregular
431 sampling effort across the landscape as habitat heterogeneity is not accounted for (Brassine
432 and Parker, 2015); this was avoided as far as possible by placing cameras in similar locations
433 across farms. However, despite this biased camera-trapping design, detection rate was still

434 quite low for elusive species that naturally occur in low densities, such as caracal and cheetah
435 (Cusack et al., 2015), therefore we encourage future studies to maximise trapping effort by
436 increasing the number of farms and length of study.

437 **5.0 Conclusion**

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

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463 **8.0 References**

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677

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 ($\Delta\text{QAIC} < 2.0$) 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 ($\Delta\text{QAIC} < 2.0$) 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 ($\Delta\text{QAIC} < 2.0$) are in bold and only the top 5 models (and any Livestock Guarding Dog model(s)) are shown.

Model	AIC	deltaAIC	AIC wgt	Model	no.Par.	-2*LogLike
Likelihood						
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

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684 **Figure Legend**

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