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SPECIAL ISSUE: DOGS AND CONSERVATION: CURRENT AND EMERGING CONSIDERATIONS

Reducing livestock-carnivore conflict on rural farms using local livestock guarding dogs

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Abstract. Livestock depredation can be devastating to both farmers and the species considered responsible if they are subsequently persecuted. Many proposed conflict solutions are limited in their uptake because they may be short-term, localised, expensive or species-specific. Livestock guarding dogs have been a successful solution in many parts of the world, however recommended imported breeds are generally expensive or inaccessible to many rural farmers. In this study, we report on a program placing local Tswana dogs with farmers in Botswana as a tool to reduce livestock loss. Seventy-five farmers who experienced high conflict from carnivores in both rangelands and wildlife areas were selected to receive a Tswana puppy. Puppies were monitored regularly to determine their performance, survival and owner attitudes toward wildlife. From initial baseline reports of goat losses before farmers received a puppy, loss declined by at least 85% over the following three years. Farmers were very satisfied with the performance of their livestock guarding dog and attitudes toward protection and tolerance of wildlife improved after one year of receiving a puppy. Our study suggests locally bred Tswana dogs are an effective solution for livestock at risk to depredation, particularly for rural farmers and development of community-led programs can be further used to reduce conflict.

Key words: conservation, depredation, human-wildlife conflict, mitigation, rangelands

Introduction

Finding effective solutions to reducing human-wildlife conflict between livestock and carnivores is an ongoing challenge in conservation around the world. As human populations continue to expand, there is an increasing reduction in available space and habitat for many wildlife species, particularly for wide-ranging carnivores (Ripple et al. 2014). This has led to a reduction in populations of large carnivores as a result of persecution (Treves & Naughton-Treves 2005, Dickman et al. 2018) and the growing abundance of meso-carnivores in many non-protected areas often exacerbates conflict with livestock (Prugh et al. 2009, Du Plessis et al. 2015). While a number of ways to deter carnivores, protect livestock, increase tolerance and draw benefits from the presence of carnivores have been recommended (Shivik et al. 2003, Dickman 2010, McManus et al. 2015, Treves et al. 2016), there is no one solution that will be effective worldwide. It is likely that a range of localised solutions will provide the most relief for reducing depredation and conserving carnivores.

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One recommended solution with increasing use is the deployment of livestock guarding dogs (LGDs) to protect herds of a variety of livestock species (Rigg 2001, Gehring et al. 2010a, McManus et al. 2015). Guarding dogs have been used for millennia in Europe and are currently widely used in the US and parts of Africa and Australasia (Rigg 2001, Gehring et al. 2010a). Dogs have a natural tendency to form protective bonds with their pack or in this case a herd or flock of livestock and instinctively bark at and even attack potential predators (Andelt 2001), which can serve as a useful means of protecting more vulnerable species. Reports have shown that LGD can reduce livestock loss by more than 90% (Andelt 2001, Marker et al. 2005a) and are potentially highly valuable across a wide range of areas, particularly where alternative methods are difficult to implement, costly, or more labour intensive.

While LGDs are recommended as a non-lethal mitigation tool, they still must maintain their effectiveness and be sustainable long-term to be considered as a successful solution. This can be evaluated in many ways. The reduction in livestock losses must exceed the cost of keeping the dog, and the dog should not cause harm to either the livestock themselves or to other wildlife (Potgieter et al. 2015). Some studies have shown that while LGDs can be effective at reducing loss, they can, in turn, cause other detrimental impacts on wildlife through chasing and even killing (Potgieter et al. 2015, Allen et al. 2019, but see Johnson et al. 2019), which counteracts being a wildlife-friendly and non-lethal conservation tool. In addition to reducing livestock losses it is also important to ensure that the farmer is satisfied with their dog. If they are pleased then they are more likely to increase their tolerance of carnivores (Potgieter et al. 2015), which is a fundamental element in reducing carnivore persecution.

While many dogs can be used effectively as guarding animals, several behaviours (e.g. ability to protect a herd, vigilance and absence of non-desirable behaviours like chasing livestock) have been recognised as essential in producing a successful LGD (Coppinger & Coppinger 1980, Lord et al. 2014). Several recognised dog breeds such as Anatolian shepherds, Pyrenees and Komondor are commonly used as LGDs in Europe and the United States due to their size and natural aggressiveness (Green & Woodruff 1988, Andelt 2001). While there may be many breeds that could be useful as LGDs (Green & Woodruff 1988), larger and more specialised breeds are less attainable, more costly to feed and maintain, and can be more aggressive (Green & Woodruff 1988, Gonzalez et al. 2012, Rust et al. 2013), so their applicability may be more limited for rural farmers in Africa. Mixed-breed dogs, on the other hand, have also been reported to be useful as LGDs while also being cheaper and readily available (Black & Green 1984, Gonzalez et al. 2012) and may be more likely to retain playful non-predatory behaviour necessary for a successful LGD (Coppinger et al. 1985). Similarly, breeds that have developed in the local environment, sometimes referred to as "landrace" dogs, are also considered a good option for LGDs due to their long term adaptation to local environmental and cultural conditions (Lord et al. 2014).

In Botswana, there is an abundance of locally bred village dogs that are highly acclimatised to local conditions. These Tswana dogs fit the general landrace dog description by being short-haired, small-medium sized and lightly built (Lord et al. 2014) and are therefore potentially valuable as LGDs. A study comparing the value of local and purebred dogs as LGDs in Botswana, showed the potential for Tswana dogs as a sustainable conflict tool. This study found that Tswana dogs had few health problems, reduced depredation and were affordable (Horgan 2015). Subsequently, a program was initiated by Cheetah Conservation Botswana (CCB) to utilise local Tswana dogs as a conflict-mitigation tool (Van der Weyde et al. 2020). Conflict is an ongoing issue in Botswana: lethal methods like poison and persecution are common threats to the local wildlife (Klein 2007, Gusset et al. 2009, Hemson et al. 2009, Margalida et al. 2019) and consequently there is a need for low-cost and effective mitigation solutions. As there have been recent calls for more evidence-based assessment of techniques used to reduce livestock predation (Gehring et al. 2010a, Treves et al. 2016, Eklund et al. 2017, van Eeden et al. 2018), our goal is to evaluate the current effectiveness of the program by reporting on the 1) health, survival and behavioural attributes of Tswana dogs in the program, 2) changes in livestock loss since having an LGD 3) effectiveness of Tswana LGDs against a range of carnivore species, and 4) attitudes of farmers toward carnivores who received LGDs.

Material and Methods

Study area

The program was initiated in southern Botswana in 2015 and expanded to areas in western Botswana. This region is part of the larger Kalahari ecosystem of Botswana and receives low annual rainfall (250-400 mm). The vegetation is predominantly comprised of low tree and shrub savanna and bush encroachment is evident in much of the area (Cole & Brown 1976). Farmers who were selected as part of the program where either farming in communal grazing areas (open-range farming), commercial ranches (freehold or leasehold fenced farms) or in wildlife management areas (WMAs; semi-protected areas with livestock farming only allowed around settlements). Farmed livestock in the area is predominantly goats, sheep and cattle. Other domestic species such as donkeys, horses, poultry, and dogs were also present in many of the farms, and across all areas, a large suite of wildlife species utilised these rangelands (Wallgren et al. 2009, Keeping 2014, Van der Weyde et al. 2018). Despite the variability in farming practices across the study area, small livestock such as goats and sheep were able to roam freely, even in most fenced ranches, but in general, returned to the kraal (traditional enclosure) of each homestead every evening. All farmers in the study had a kraal for livestock, although kraal construction and quality varied. The amount of grazing available to livestock varied between farms and likely contributed to variable movement patterns.

Puppy training and placement

Local Tswana puppies, and on occasion Tswana-cross puppies, were sourced and brought to the CCB training facility at ages between four to eight weeks. The program focussed on developing LGDs for the protection of goats. Younger dogs are more effective in training to be LGDs than older dogs (Green & Woodruff 1988) as they bond more successfully with the livestock. Puppies were dewormed and vaccinated and placed in the training kraal that consisted of a goat herd (30-60 mothers and kids) and between two to four existing adult LGDs. Puppies were fed twice daily and had water *ad libitum.* Puppies stayed in the kraal for the first few weeks upon arrival. After approximately four weeks (puppy age approximately two months), they were allowed to join the goat herd under the watch of a herder, who then brought them back to the kraal after a few hours. Poor behaviours exhibited by puppies such as biting goats or not staying with the herd were corrected by the herder during this training period. At approximately three to four months of age, puppies were sterilised (before or soon after placement depending on the availability of a registered veterinarian) and placed with a farmer.

Monitoring of puppies

Farmers selected to receive a puppy were those that had experienced high levels of livestock conflict, primarily by cheetahs (*Acinonyx jubatus*), although due to the time lag in receiving a puppy conflict may have reduced in the immediate months prior to receiving a dog. In most cases, farmers who were placed on the waiting list had attended a CCB workshop and received materials on livestock carnivore conflict, carnivore identification and various mitigation techniques. Farmers who received a puppy were required to complete an initial baseline questionnaire with the assistance of a community officer from CCB. The baseline questionnaire was designed to collect information on the economic and social circumstances of the farmer, conflict levels before receiving the puppy, and attitude towards predators. One month after placement, the community officer visited the farmer to check on the health of the puppy and ensure adequate care was being provided. In rare circumstances where this was not considered to be the case, the puppy was removed and placed with another farmer. Approximately three, six, and nine months after initial placement, farmers were again required to complete a monitoring questionnaire. This questionnaire focussed primarily on the dog's health, behaviour and livestock loss in the preceding months. Lastly, at 12 months and annually thereafter, a questionnaire was completed that covered economic circumstances, livestock loss, and attitudes toward predators, similar to the baseline questionnaire. Each questionnaire included both closed and opened ended questions and was based largely on a previously tested questionnaire undertaken in the region (Klein 2013). Questionnaires were administered by CCB personnel via an interview as not all respondents were literate or familiar with the use of computer tablets. All interviewees provided informed consent to the survey and were assured anonymity for any reproduction or presentation of the findings.

Data analysis

From early 2015 to July 2020, a total of 81 LGD puppies (35 male, 46 female) were placed with 75 farmers across southern and western Botswana

(Fig. 1) and monitored. In a few cases, farmers were given two puppies if they had very large herds or were given a replacement due to rehoming or death of the original puppy. Questionnaire data from each monitoring period was collated from each of the placements; in a few cases, questionnaires represented two dogs from a single farmer. Not all questionnaires were undertaken at each designated monitoring period due to logistical reasons. Therefore, we used days since placement rather than the monitoring period to determine the period of activity categories: three months (1-90 days), six months (91-180 days), nine months (181-270 days), one year (271-365 days), two years (366-730 days) and three years (> 730 days) since placement. Annual questionnaires were also completed for a fourth (n = 5) and fifth (n = 2) year for a few dogs but not included in the analysis due to small sample size. All reports of depredation before (up to six months) and after receiving an LGD were collected at each questionnaire stage to ensure accurate records of loss were recorded. Farmers were asked to report what and how many livestock were lost, what species were responsible, how they knew this, where the loss occurred and whether a herder was present. However, due to logistical reasons or lack of reporting, these losses were unable to be verified by CCB. Herd size changed regularly with births of kids, selling and purchase of adults, and deaths, making relative loss rate difficult to calculate as accurate records were not generally kept by farmers. We, therefore, used a categorical measure similar to that of Marker et al. (2005a) with deaths per herd due to depredation recorded as none, low (1-5), or high (> 5). We used logistic regression models to determine whether various predictor variables influenced the likelihood of our dependent variable of loss level at various monitoring periods. These variables included sex, goat breed (Boer or mixed breeds), herder presence at night, and herder presence during the day.

Farmers were asked a variety of questions related to their LGDs behaviour toward humans, threatening wildlife (carnivores) and non-threatening wildlife (livestock, ungulates and small mammals), however, no specific details on species for either category were provided by the farmer. We compared the percentage of dog responses (ignore, herd livestock, bark, chase, or attack) toward wildlife at six

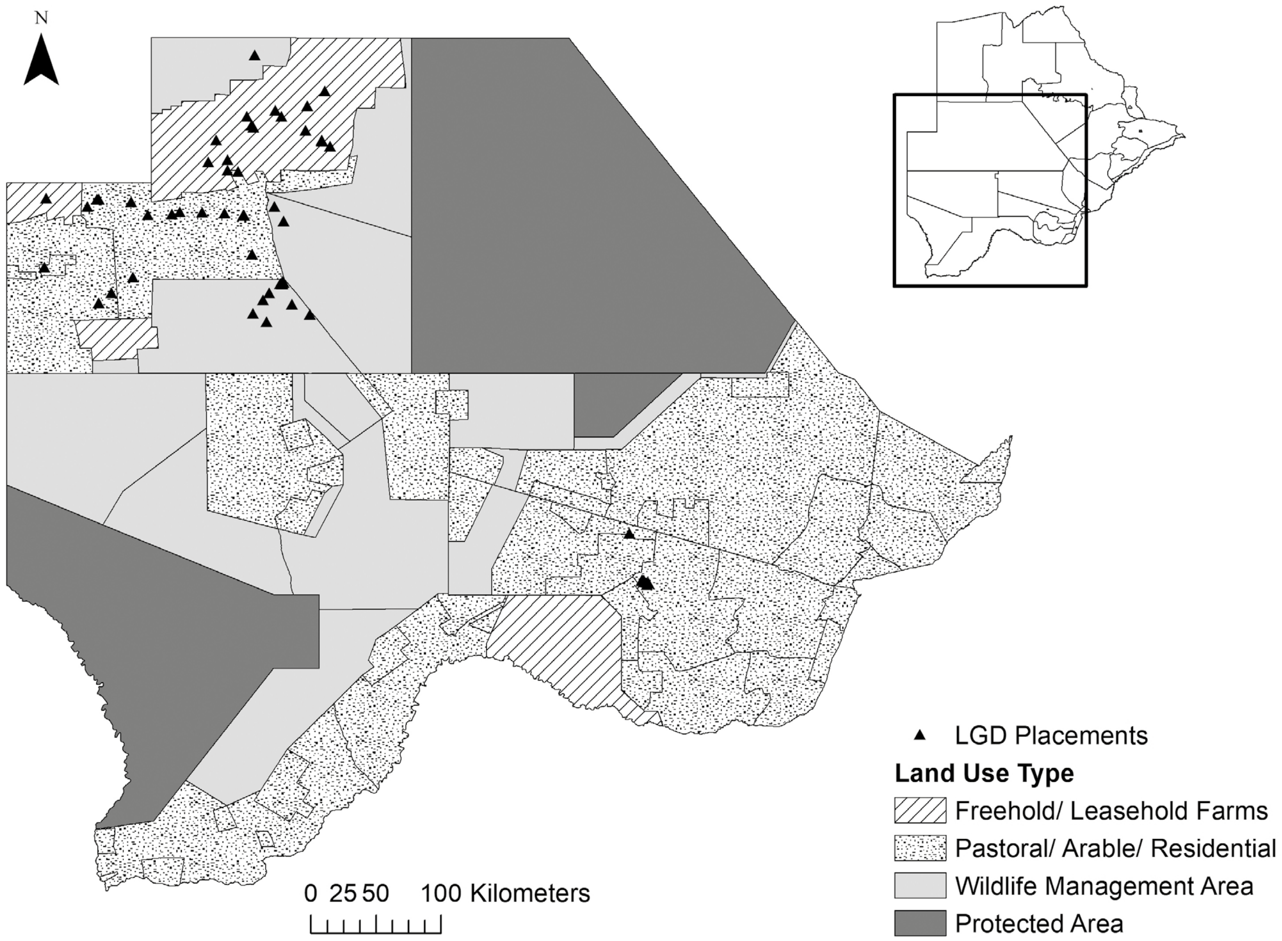

Fig. 1. Map of locations of livestock guarding dog placements in southwest Botswana.

months after placement (LGD age approximately nine months), as younger juvenile dogs were still considered to be in the training phase. Logistic regression was also used to look at the probability that LGD sex or location (ranch, communal, or WMA) affected the response type to both groups of wildlife. We checked the model fit of all our logistic models by plotting residuals and compared several competing models using Akaike Information Criterion for small sample sizes (AICc).

Depredation events specifically affecting goats were used to assess whether LGDs were more effective against particular carnivore species, although farmers were able to report on any livestock loss in the questionnaire. A two-sample test for equality of proportions (two-sample proportion Z test) was used to determine if there was a change in the proportion of carnivores involved in depredation before and after receiving an LGD. To assess change in attitudes towards wildlife and primarily carnivores, farmers were asked to rate a series of statements on a scale from strongly agree to strongly disagree (five levels) at both initial baseline and annual questionnaires. We used Wilcoxon signed-rank paired tests to compare the change in response and report effect sizes (r) to determine the strength of change between questionnaires. Across all analyses, where sample sizes were restricted we collapsed categorical categories. All analyses were conducted in R software (R Core Team 2016) and statistical significance was set at $P < 0.05$.

Results

Health, survival, and behaviour of Tswana dogs

From the 81 puppies placed by CCB, 45 LGDs remained active and monitored, four remained active but not monitored due to a change in location, two became pets, five were removed and 25 had died or disappeared by mid-2020. Where data were available the mean length of activity of an LGD up until death or removal was 532 days (SD 309, n = 25). Removal was attributed to poor care by the farmer (n = 1), lack of bonding with livestock (n = 2), or poor behaviour by the dog (n = 3). Death was attributed to several causes, with some due to poison used in the area (n = 6), rabies (n = 1), surgery complications (n = 1), and several unknown causes. Of the remaining dogs being monitored, more than half had been active for at least two years and several five years from initial placement. Health checks undertaken by community officers after one month and in subsequent visits found that the dogs were in good or excellent health in most cases, despite the variability in diet and care provided by each farmer. Diet was highly variable for most of the LGDs and in many cases a range of food options was provided. Interviews conducted at three months from placement (n = 45) found that farmers fed their LGD local maize (80%), leftovers (76%), milk (60%), raw or cooked meat (56%), commercial dog food (42%) and bone dust (20%).

Several questions were directed towards the behaviour of the LGD. At approximately six months of age, all farmers reported that the LGD remained with the livestock at all times (n = 50), however as many did not use herders (68%) this could not be verified. When asked if they still needed to correct the LGDs behaviour 88% replied "never" but 12% reported, "yes this was still required". Farmers were asked to report on the response of their LGD toward wildlife. All farmers stated that their LGD had never injured or killed any game, livestock, or predator. However, in a separate question, some

Table 1. Binary logistic model results on the effects of sex and farmtype on the behavioural responses by LGDs toward threatening (bark *vs.* defensive reactions) and non-threatening species (ignore *vs.* defensive reactions).

Model	Model parameters	df	AICc	Delta AICc	Weight	logLik	Deviance	Dispersion
Response to threatening species	Sex	3	40.27	0	0.50	–17.90	35.79	1.38
	Intercept	2	40.83	0.55	0.38	–19.34	38.67	1.43
	Farmtype	4	44.47	4.20	0.06	–18.74	37.47	1.50
	Sex + Farmtype	5	44.64	4.37	0.06	–17.45	34.90	1.45
Response to non-threatening species	Farmtype	4	31.19	0	0.46	–12.02	24.05	1.09
	Intercept	2	31.82	0.63	0.33	–14.82	29.65	1.24
	Sex + Farmtype	5	34.04	2.85	0.11	–12.02	24.04	1.14
	Sex	3	34.19	3.00	0.10	–14.82	29.65	1.29

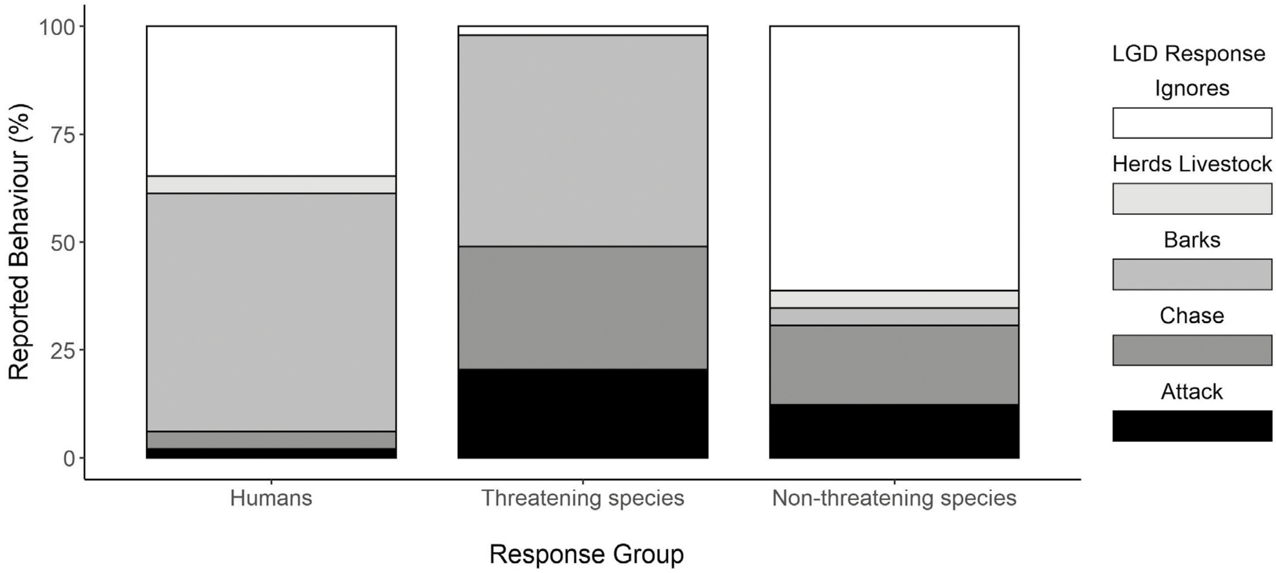

Fig. 2. Percentage of each behavioural response of LGDs towards humans, threatening and non-threatening wildlife species as reported by the farmer.

farmers reported that threatening (48%) and non-threatening (30%) species were sometimes chased or attacked by the LGD. The majority of farmers, however, reported that the LGD barked in response to threatening species (50%) and humans (54%), and ignored non-threatening (62%) species (Fig. 2).

We tested whether the sex or location of the dog (ranches, communal grazing or WMAs) affected their response to threatening and non-threatening species. Because of limited sample size for response to threatening species, we grouped chase and attack responses as a "defensive" response and compared this with barking using a binary logistic regression model (bark = 0, defensive = 1). While barking may also be involved during defensive responses, we assumed the farmer in his answer to the question reported on the most active response by the LGD (e.g. attack, then chase, then bark). We assumed that a bark would be the first level of deterrence by an LGD and it would only engage in more active defensive responses when necessary. We did not include an ignore response due to low sample size (n = 1) and there were no herd livestock responses. Model selection showed that our top performing model (~ sex) was not different to the null model (Table 1), and in the top model, sex was not a significant factor. For non-threatening species we again combined attack and chase responses and compared with this with an ignore response using a binary logistic model (ignore = 0, defensive = 1). The bark response (n = 1) and herds livestock response (n = 1) were too low for inclusion. Similarly to responses to threatening species, our top model (~ farmtype) was only slightly better than the null model (Table 1) and there were no significant effects of any farmtype on response type. From the available questionnaires undertaken at the first annual survey (n = 39), all farmers reported they were either satisfied (46%) or very satisfied (54%) with the performance of their LGD.

Perceived livestock loss

At the time of placement, farmers had a mean goat herd size of 51 (±32 SD), therefore our high loss level represented a loss of 10% or more of the mean herd size. The percentage of goat deaths due to predation as reported by the farmer is shown in Fig. 3. Within the first three months of receiving an LGD, there were no reported losses due to depredation, while at six months 14.6% of farmers reported a loss and no losses were reported at nine months. After one year 87.5% of farmers reported no depredation events, and this was similar at two years (84.8%) and three years (90%). As there were so few reports for the three levels of loss at different monitoring periods, we compared factors that may influence the loss level only at the six-month and two-year monitoring stage. We only compared low and no loss levels using binary logistic regression models (no = 0, low = 1) as there were no reports of high loss levels at these monitoring stages. There was no effect of sex, goat breed or the presence of a herder at night on loss levels at either monitoring stage (Table 2).

Effectiveness against carnivores

Perceived livestock loss due to carnivores was attributed primarily to jackal (*Canis mesomelas*),

Table 2. Binary logistic model results showing the effect of sex, goat breed and herder presence at night on no and low loss levels of livestock at six month and two year stages of the LGD monitoring program.

Model	Model parameters	df	AICc	Delta AICc	Weight	logLik	Deviance	Dispersion
Loss level 6 months	Intercept	2	36.24	0	0.38	–17.07	34.14	0.85
	Goat breed	3	36.98	0.74	0.26	–16.33	32.66	0.84
	Sex	3	37.86	1.62	0.17	–16.77	33.55	0.86
	Sex + Goat breed	4	38.75	2.51	0.11	–16.05	32.10	0.84
	Sex + Goat breed + Herder night	5	39.16	2.92	0.09	–15.03	30.05	0.81
Loss level 2 years	Intercept	2	41.33	0	0.59	–19.62	39.23	0.87
	Goat breed	3	43.49	2.16	0.20	–19.60	39.21	0.89
	Sex	3	44.37	3.04	0.13	–18.90	37.80	0.88
	Sex + Goat breed + Herder night	5	46.26	4.94	0.05	–17.38	34.76	0.85
	Sex + Goat breed	4	46.74	5.42	0.04	–18.88	37.77	0.90

cheetah, caracal (*Caracal caracal*) and leopard (*Panthera pardus*) both before and after receiving an LGD (Fig. 4). There was no significant difference across species responsible for livestock loss before and after the placement of LGDs (Fisher exact test, $P = 0.68$). The species reported by the farmer as causing the death of the livestock was not verified by the CCB team, however farmers were asked how they knew which species was responsible and, in all cases, it was stated that it was by either observing the species, identification of spoor or finding the carcass. While we recognise these reports may be biased, verification through official reporting to government departments is also challenging (LeFlore et al. 2019).

Farmers were asked how regularly they saw particular carnivore species and how regularly each caused problems for them. The rates at which they were reported were combined into categories for comparison: never, rarely, sometimes, and often. In terms of how often they were a problem, these were rated as never, sometimes, and often. We compared the proportion of responses in the "often" categories for both sighting and problem causing species (Fig. 5). As with actual reported

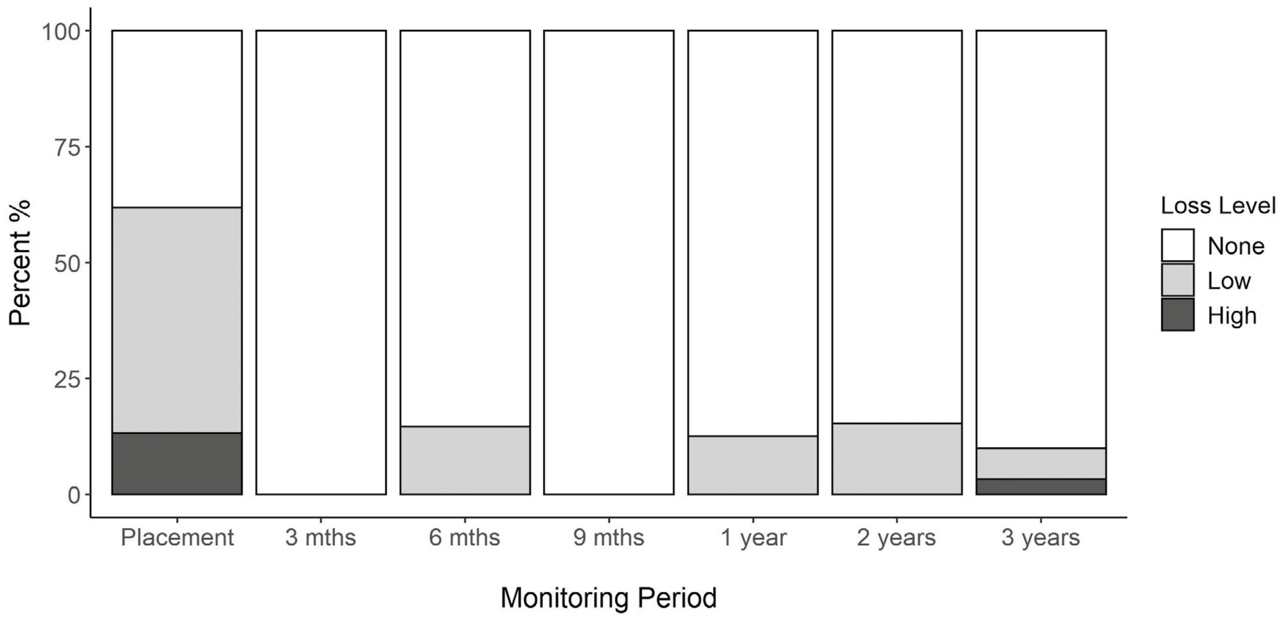

Fig. 3. Percentage of perceived loss of livestock attributed to predation at various monitoring periods after receiving an LGD. Loss level was either: None (no loss), Low (1-5 goats/herd), or High (> 5 goats/herd).

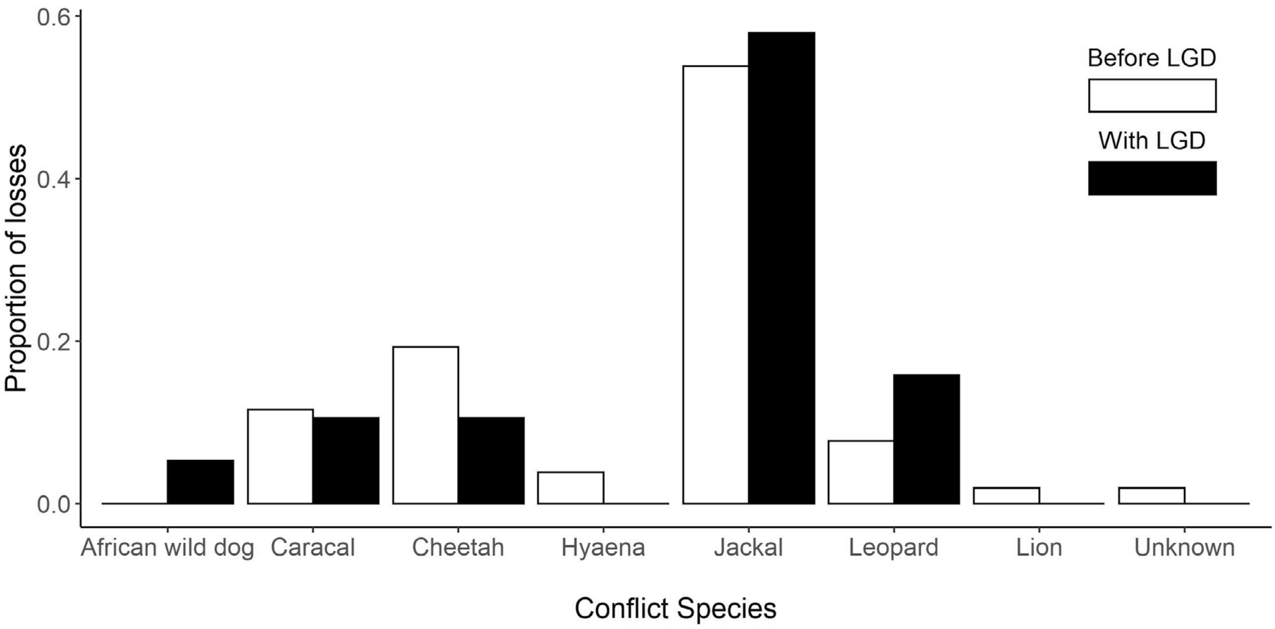

Fig. 4. Proportion of each species reported by farmers as responsible for livestock loss before and after receiving an LGD.

livestock loss, jackals were reported as often sighted and often causing problems at similar proportions. While at much lower rates, similar proportions were reported for caracal and cheetah. Interestingly, African wild dogs (*Lycaon pictus*) were considered to cause problems more often than they were reported to be seen, whereas the reverse was true for brown hyaenas (*Parahyaena brunnea*) and leopards.

Farmer attitudes

All farmers agreed on the first annual questionnaire that "I or my herder need to feed and care for the guarding dog", and most (92%, n = 39) disagreed with the statement that "the guard dog that has been placed with my herd is CCB's responsibility", with one neither agreeing nor disagreeing, and two agreeing with the statement. Farmers were asked to state their level of agreement to a series of statements regarding wildlife in both initial baseline and annual questionnaires. Farmers agreed that "there is value in protecting wildlife and predators" in both baseline and the first annual survey, however, there was a significant shift from agree to strongly agree in the annual survey ($W = 78$, $Z = 2.96$, $P < 0.01$, $r = 0.45$, $n = 43$). When asked the statement "if predators are

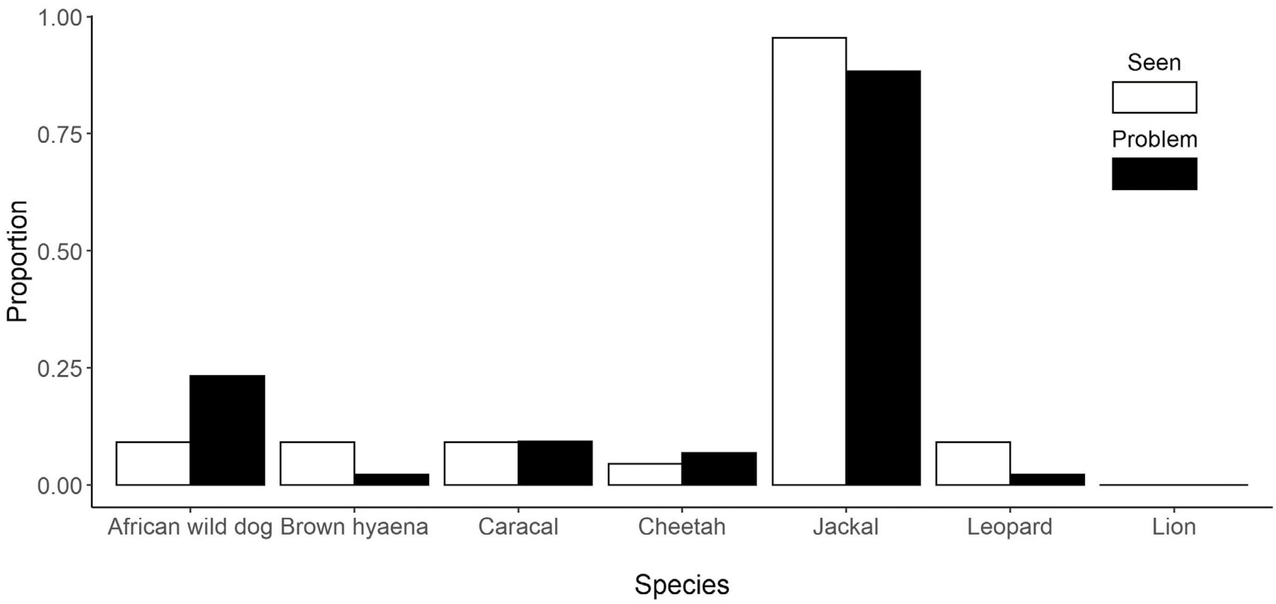

Fig. 5. Proportion of responses reported by farmers as "often" seeing and "often" causing a problem for different carnivore species in the region.

not causing problems I am happy to have them on my farm", there was the same level of agreement in baseline and annual surveys (W = 95, Z = –0.41, P = 0.71, r = 0.06, n = 43). Farmers were also asked to provide a level of agreement with the statement "hunting predators is good entertainment", while there was strong disagreement with this in the initial survey, this shifted to just disagree after one year (W = 56, Z = –4.27, P < 0.01, r = 0.64, n = 44).

Discussion

The goal of this study was to report on the effectiveness of using locally bred Tswana dogs as a conflict mitigation tool as part of an LGD program aiming to protect both livestock and carnivores. LGDs have been reported to be highly effective at reducing loss (Marker et al. 2005a, Gehring et al. 2010a), and the results of this study confirm that non-purebred LGDs are also effective. Livestock loss due to predation was completely eradicated in the immediate months following the presence of an LGD and continued to remain low, with at least an 85% reduction in perceived livestock loss after several years. These results are similar to other studies reporting on LGD effectiveness utilising both mixed and purebred dogs (Gonzalez et al. 2012, van Bommel & Johnson 2012, Rust et al. 2013). We found that young dogs can be very effective at protecting livestock, which has been suspected elsewhere (Rust et al. 2013). Effectiveness varied slightly during annual monitoring, and effectiveness should increase as dogs physically and behaviourally mature (Green et al. 1994). In previous studies, some farmers reported a decrease in effectiveness over time, however, they attributed this largely to increasing carnivore numbers in that area (Green et al. 1994). Both sexes performed equally well which agrees with findings elsewhere (Marker et al. 2005a, Leijenaar et al. 2015) and were effective in protecting all breeds of goats. While this study relies on the farmer perceptions of causes of livestock loss (including non-predator incidents), the results are still largely anecdotal and not experiment-based (Gehring et al. 2010a), but as most farmers had previously attended a CCB workshop discussing these issues, and intervals between successive monitoring were relatively short, it is likely that errors in famer reports was minimised (McManus et al. 2015, Treves et al. 2016, Whitehouse-Tedd et al. 2020).

Local Tswana dogs were considered a valuable asset by most farmers but were still susceptible to a range of issues. Healthwise, Tswana dogs fared very well as they have successfully adapted to a relatively low protein diet (Horgan 2015), but still suffered from mortality at a range of ages. Mortality was primarily attributed to indiscriminate poisoning that occurred in one region in communal farms and was not something that targeted Tswana dogs. Similar reports of LGD deaths due to poisoning in communal farms have also been reported in Namibia (Marker et al. 2005b). In several cases, however, the cause of death was unknown to the farmer. Mortality of LGDs in rural farming areas has previously been attributed to snake bites (Rust et al. 2013) and accidents (Marker et al. 2005b). While snake bites may also have occurred in this study, they may not have been detected as a cause by farmers. Diseases such as tick bite fever and biliary are common in the rainy season when parasite loads become hard to manage and may also be responsible. There were no suspected cases of mortality due to any carnivore. Most LGDs required very little behavioural correction and only in a few cases did not satisfactorily perform as an effective LGD and were removed or placed with another farmer.

Farmers in Botswana who participated in the LGD program were living alongside a wide range of carnivore species. Perceptions of carnivore impact can often be higher than actual reported livestock loss (Marker et al. 2003, Thorn et al. 2013, Boast et al. 2016). Farmers in this program reported for most carnivores a similar rate of observation as causing problems with their livestock, although there was a bias toward African wild dogs as causing problems more often than the relative rate of being observed. In contrast, leopards were reported to be often seen more than they were considered to be major problems for livestock. Jackals, however, were reported by farmers to be the most prevalent and problematic for their livestock, which agreed with actual reported depredation events of goats. While there was a reduction in the numbers of livestock lost to carnivores, even after receiving and utilising an LGD, jackals were still reported as the highest conflict causing species. Jackals are the most abundant carnivore in the study region (L.K. Van der Weyde et al., unpublished data) and are recognised as problematic for many farmers in southern Africa (Du Plessis et al. 2015, Humphries et al. 2016). The reduction in the number of livestock losses confirms that LGDs can be a useful non-lethal tool, although further evidence is needed to assess how many dogs per size of livestock herd is most effective as well as the variability in carnivore density in an area. Using LGDs in combination with other mitigation measures such as herders, well-built kraals and deterrent devices is also likely to further improve the protection of livestock (Woodroffe et al. 2007, McManus et al. 2015).

Recently, there has been concern about the use of LGDs as a mitigation tool in regards to their impact on other species (Potgieter et al. 2015, Allen et al. 2019). There was some discrepancy in reports by farmers who stated that LGDs did not cause any lethal activity toward livestock or wildlife, but that the behaviour of LGDs in some cases, such as attacking wildlife, was reported to occur. There is the potential bias that farmers were less inclined to report lethal behaviours to CCB personnel as they may fear removal of their LGD. However, many farmers did report on poor behaviours and were given an option to not respond, therefore it is unlikely the results would be largely biased in this regard. Additionally, it is hoped that utilising staff who are familiar with local languages and customs is likely to increase accurate responses. Defensive responses by LGDs have been found in other long-term LGD studies (Whitehouse-Tedd et al. 2020). This study found that farmers reported defensive behaviours by LGDs toward both threatening and non-threatening wildlife species, but it was not confirmed whether this was a single incident or a common response by each dog. While we recognise highly defensive behaviours toward wildlife as a potential issue in recommending LGDs as a non-lethal conflict tool, it is difficult to accurately assess if aggressive attacks did occur in the current program as our results were based entirely on farmer's perceptions and observations. While the impact is not negligible, improved training and corrective measures can reduce negative behaviours by LGDs (Potgieter et al. 2015). Many mitigation methods may potentially impact on spatial and temporal use by various wildlife species, such as fencing, deterrents, or direct loss through lethal methods like poison or shooting (Dubois et al. 2017, Allen et al. 2019). While some level of ecological impact is also likely by LGDs as their role is to deter potential threats, recent evidence shows that in some areas LGDs do not influence carnivore distribution and occupancy on farms (Bromen et al. 2019, Spencer et al. 2020). As a smaller dog breed, Tswana dogs are also unlikely to cause any lethal damage to larger carnivores, but the impact on other wildlife species deserves attention. As farmers reported that LGDs were sometimes prone to chasing wildlife, additional monitoring as part of the program may include spatial monitoring of LGDs movements and predation risk to wildlife, which has been employed to monitor their effectiveness and impact elsewhere (Bromen et al. 2019, Young et al. 2019, Drouilly et al. 2020).

Locally bred Tswana dogs are a valuable tool that can protect livestock from depredation. While we recognise that other breeds such as Anatolians which are also used in Botswana and southern Africa (Marker et al. 2005a, Rust et al. 2013) can be just as effective, the use of local dogs can serve a larger purpose by being more readily available and more cost-effective to use (Gonzalez et al. 2012, Horgan 2015). This is particularly relevant for rural farmers, for whom limited resources and low income often preclude the use of many conflict mitigation tools. A low cost and long-term tool is vital for most farmers and the sustainability of using LGDs is cost-effective, with farmers generally recovering the cost of the dog within a few years through the reduction in livestock loss (Andelt 2001). While this program focussed specifically on the value of LGDs for small livestock, other studies have shown they can also be effectively used for the protection of cattle and other large livestock species (Rigg 2001, Gehring et al. 2010b, Leijenaar et al. 2015), which would also prove highly valuable for farmers in the region.

Scientific evidence is needed to determine the effectiveness of various techniques in reducing depredation events (Treves et al. 2016, Eklund et al. 2017, van Eeden et al. 2018). However, perception by farmers utilising a method can be just as important as actual reductions in livestock loss, as attitudes motivate the actions a farmer will take in response to coexisting with wildlife (Dickman 2010). The effectiveness of an LGD may vary between different farmers depending on whether success is considered to be the prevention of any loss or just a reduction in loss (Green et al. 1994). As there was an immediate reduction in livestock loss in the first few months for all farmers, it is not surprising that farmer satisfaction was very high regarding the value of their LGD in this program. Even though some farmers still experienced some livestock loss over time, farmers showed an increasingly positive attitude toward wildlife and predators one year after receiving an LGD. However, this may only be in circumstances where carnivores did not cause damage, or was quite minimal. As nearly all farmers saw a reduction in livestock loss, we were unable to discriminate between attitudes in cases where farmers continued to maintain high losses even when using LGDs. While attitudes are a commonly used metric to determine success, attitudes are often uncorrelated with behaviour (Romañach et al. 2007, Dickman 2010, Liu et al. 2011); there is a need to promote behavioural changes to improve conservation efforts (Nilsson et al. 2019). By providing a successful method of using locally available and cost-effective LGDs, it is hoped that a change in behaviour such as reducing persecution of carnivores would occur as has been reported elsewhere (Potgieter et al. 2015). While all farmers disagreed that persecuting carnivores was considered to be good entertainment, the slight change in attitude to be weaker after one year was surprising. Although this may simply be a lack of discrimination between the terms "strongly disagree" and "disagree" by farmers, and responses may be biased as CCB staff may not be viewed as neutral observers, it is worth noting that a change in policies towards wildlife, fluctuations in livestock prices, and access to markets, for example, can affect people's attitudes in the short-term. This, in turn, can affect perceptions when dealing with human-wildlife conflict and the uptake of various tools and practices.

The current LGD program implemented by CCB has thus far been shown to be a viable and sustainable option as a non-lethal tool to reduce depredation, which may lead to a reduction in carnivore persecution (Ogada et al. 2003). While the LGD program discussed here still has several areas that can be improved, the implementation of localised and effective programs should be encouraged both nationally and internationally. CCB still provides the main resources for covering costs associated with LGD vaccinations and sterilisations and long-term international funding would be less relied upon by the provision of local government grants or subsidies to farmers. Currently, the program is expanding to be undertaken and run by local communities, with selected model farmers becoming hosts in raising puppies with their goat herd, before placement with other farmers. In this way, ownership of independent community-led programs will facilitate the uptake of the LGD program on a wider scale with lower tangible and intangible costs such as time invested in the procuring and raising of puppies. This will assist with meeting the demands of farmers and potentially provide local employment for community members to monitor dogs. Improving coexistence and successful uptake of conflict solutions will be best achieved where community participation and involvement is a key part of developing interventions (Treves et al. 2009, Dickman 2010). Additionally, encouraging farmers to take the raising of puppies upon themselves, rather than relying on non-profit or government programs, can further increase and expand the use of LGDs as a mitigation tool. Numerous materials are already available to support this and only minor incentives or training opportunities are necessary to maximise the benefits of using local LGDs.

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