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SPECIAL ISSUE: DOGS AND CONSERVATION: CURRENT AND EMERGING CONSIDERATIONS

Twenty-five years of livestock guarding dog use across Namibian farmlands

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Abstract. Preventing human-wildlife conflict is key to maintaining viable predator populations. In Namibia, over 90% of cheetahs are found outside of protected areas, therefore risk of conflict with farmers is high. Since 1994, the Cheetah Conservation Fund has implemented a programme to prevent livestock depredation using livestock guarding dogs (LGDs). Long-term (25-year period) monitoring efforts in Namibia have provided insights on the efficiency and performance of LGDs and farmers' perceptions. LGDs reduced livestock losses for 91% of respondents and farmers were highly satisfied with their LGD. Poor performance from behavioural issues, such as "staying at home" and "chasing game", was linked to the LGDs receiving less care and being found in poorer body condition. Unwanted ecological impacts of wildlife killings by LGDs merit further investigation, but occurrence of behavioural issues reduced over time, suggesting a targeted and adaptive management approach to increase performance. Addressing behavioural issues, increasing LGD lifespans and understanding LGD performance under different conditions will be crucial for optimising LGD management leading to better performance. Our long-term study provides unique insights into a highly successful programme and is recommended to be replicated and adapted where imminent human-predator conflicts threaten coexistence.

Key words: Anatolian shepherd, Kangal dog, cheetah, conservation, human-wildlife conflict, livestock farming

Introduction

Predator populations worldwide have declined dramatically as a result of habitat loss, prey depletion and human disturbance (Ripple et al. 2014). Human-wildlife conflict is one of the most prevalent threats to predators, largely due to farmers´ negative attitudes resulting from perceived or actual livestock depredation (Treves & Karanth 2003, Inskip & Zimmerman 2009). Left unaddressed, preventive and retaliatory killings by farmers may ultimately lead to local extinction of predators, causing destabilization of ecosystems (Prugh et al. 2009, Ritchie & Johnson 2009).

Reducing livestock losses through the implementation of non-lethal protection techniques is instrumental to facilitate coexistence (Breitenmoser et al. 2005, Ogutu et al. 2005). Farmers have endeavoured to protect their livestock through various methods, such as the use of guarding animals (Marker et al. 2005, Potgieter et al. 2016), shepherding (Ogada et al. 2003), controlled calving/lambing (Palmeira et al. 2008), health checking (Breitenmoser et al. 2005), the use of predator deterrents (Lesilau et al. 2018, Ohrens et al. 2019, Naha et al. 2020), and night time confinement of livestock in traditional or fortified enclosures (Ogada et al. 2003, Weise et al. 2018).

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Livestock guarding dogs are selected dog breeds that are highly enthusiastic in stock protection and work by marking territories and barking loudly to deter predators (Coppinger et al. 1983, Dickman et al. 2018). The use of livestock guarding dogs (LGDs) is considered as one of the most effective preventive tools against small stock (goats and sheep) depredation (Smith et al. 2000, Gehring et al. 2009, van Eeden et al. 2018). This ancient technique is thought to have originated in Mesopotamia, with archaeological records that date back from 3,585 BC (Olsen 1985, Rigg 2001). The use of LGDs became gradually adopted over different continents, with several studies demonstrating high effectiveness of LGDs (Andelt 1985, 1992, Coppinger et al. 1988, Marker et al. 2005, van Bommel & Johnson 2012, Leijenaar et al. 2015, van Der Weyde et al. 2020). Livestock guarding dogs are often not only efficient in reducing livestock losses, but provide the additional benefit of improving farmer attitudes towards predators and by reducing preventive and retaliatory predator killings (Otstavel et al. 2009, Rigg et al. 2011, Rust et al. 2013, Horgan 2015). However, unwanted behaviours of LGDs, such as predation of wildlife and livestock, have also been identified and may undermine ecological and protective benefits (Potgieter et al. 2016, Drouilly et al. 2020, Smith et al. 2020). Understanding how to reduce problematic behaviours is, therefore, key to LGD management and may be needed to promote harmonious human-wildlife coexistence. Moreover, dog performance likely determines farmer satisfaction and may influence the level of care provided by farmers, which in turn may determine their working ability (Marker et al. 2005, Potgieter et al. 2013, Horgan 2015). Livestock guarding dogs are able to live up to 12-15 years and can be effective in reducing livestock losses after their first year (Rigg 2001). However, their activity and effectiveness may decrease with increasing age (van Bommel & Johnson 2014). Identifying causes of (early) deaths remains important to improve cost-efficiency of LGDs (Marker et al. 2005).

Since 1994, the Cheetah Conservation Fund (CCF) has implemented an LGD programme in Namibia that specifically aims to protect cheetahs (*Acinonyx jubatus*), whilst mutually benefitting surrounding farming communities and other predators by mitigating human-predator conflict (Marker et al. 2003b, Dickman et al. 2018). In Africa, cheetahs are known to persist in only 9% of their historic range, with the majority (77%) of the population roaming outside of formally protected areas (Durant et al. 2017). Southern Africa is a regional stronghold for the cheetah (Weise et al. 2017), thus improving human-cheetah coexistence on unprotected lands in Namibia is critical for future cheetah-conservation (Marker et al. 2003a).

The CCF LGD programme is centred around the breeding of LGDs in Namibia and the placement and follow-up of LGDs with farmers that were interested in participating in the programme. The selected dog breeds (i.e. Anatolian shepherd and Kangal dog) originated in Turkey and have guarded livestock from local predators, such as the brown bear (*Ursus arctos*), red fox (*Vulpes vulpes*), and grey wolf (*Canis lupus*), as well as other damage-causing species such as wild boar (*Sus scrofa*) for thousands of years (Coppinger et al. 1988, Rigg 2001, Dickman et al. 2018). The dogs are active at night and are adapted to tolerate high daytime temperatures, which make these breeds highly suited for use in Namibia´s semi-arid environment (Rigg 2001, Dickman et al. 2018). Throughout southern Africa, these LGDs are now increasingly used as a conflict mitigation tool against various species of the African predator guild with high levels of success (Marker et al. 2005, Horgan 2015, Leijenaar et al. 2015).

The purpose of this study was to assess the progress of CCF´s LGD programme using data collected between 1994 and 2018. Firstly, this study provides an overview of the growth of the programme and basic LGD demographics, including age and cause of death. Secondly, results on the effectiveness of LGDs as a conflict mitigation tool are presented and we include analyses on: 1) perceived effectiveness of LGDs in relation to age and sex differences, and 2) farmer perceptions of LGDs in relation to body condition and behavioural problems. We also explore the influence of LGDs on predator killings by farmers, and we investigate unwanted ecological effects stemming from predatory behaviour of LGDs. Thirdly, this study analysed variation in LGD behaviour and performance under different farm contexts as socio-economic and cultural factors are thought to have an influence. Lastly, we present a comparison between three survey periods (learning period: 1994-2001 (ref. Marker et al. 2005), application period: 2002-2009 (ref. Potgieter et al. 2013), evaluation period: 2010-2018 (ref. this study)) to identify and understand emerging trends in CCF´s LGD programme. This comprehensive study of 25 years of LGD use across Namibian farmlands aims to contribute to the optimisation of LGD management, with the ultimate goal being that the programme will be further reproduced, adapted and implemented in areas where there is an imminent need to mitigate predator-livestock conflicts.

Material and Methods

Study area

The farms where LGDs were placed were mostly located in the north-central area of Namibia (Fig. 1). This area hosts among the highest densities of free-ranging cheetahs (Marker 2002, Fabiano et al. 2020), but human-cheetah conflicts are pertinent (Marker-Kraus et al. 1996, Marker et al. 2003a). Other large predators present in the area are leopard (*Panthera pardus*) and brown hyena (*Hyaena brunnea*), with smaller predators including African wildcat (*Felis silvestris lybica*), bat-eared fox (*Otocyon megalotis*), black-backed jackal (*Canis mesomelas*, hereafter referred to as "jackal"), caracal (*Caracal caracal*) and serval (*Leptailurus serval*) also present. Over 80% of Namibia´s wildlife is found across these farmlands (Barnes et al. 2004).

Livestock guarding dogs have been placed on the four types of Namibian farmlands: freehold (i.e. privately owned), communal (i.e. government owned), emerging freehold (i.e. privately owned via financial loan) and resettled (i.e. leasehold with government). Livestock is free-ranging due to the semi-arid environment. Freehold farms are on average 9,000 hectares and, due to the dry conditions, the farmers allow the small stock to graze over vast areas during the day, while often stocking herds into a kraal (i.e. livestock enclosure) at night (Marker-Kraus et al. 1996, Marker et al. 2005). Cattle and game fences are predominant in the landscape to fence off properties and kraals on freehold, emerging and resettled lands. Communal land is owned by the government, but is under tribal governance (Kaakunga & Ndalikokule 2006). Communal farms are therefore not fenced, except the kraal, which is close to the homestead, with around 20 homesteads per village. Biodiversity is important to generate economic benefits on communal farmlands (Naidoo et al. 2011), yet overstocking, overgrazing and bush meat hunting may lead to high levels of human-wildlife conflict

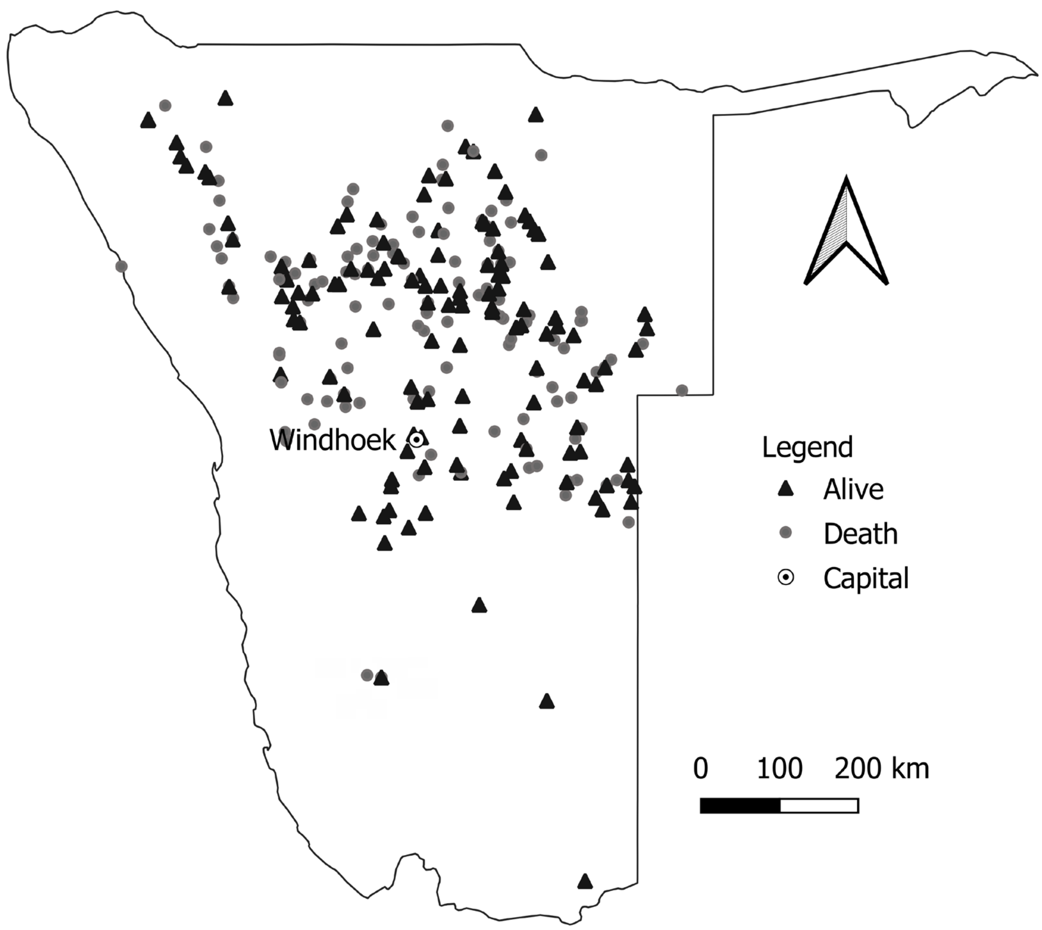

Fig. 1. Current and historic locations in Namibia where livestock guarding dogs have been placed by the Cheetah Conservation Fund between 1994 and 2018.

(Verschueren et al. 2020). Resettled farmers are previously disadvantaged Namibians that are supported by the government through land provisioning. The objective is to reduce poverty and grazing pressure in communal regions, bringing them into the conventional farming economy (Marker et al. 2005, Rust & Marker 2014), although resettled farms are typically smaller than freehold farms. Farmers on resettled land have a leasehold agreement based with the local government (Kaakunga & Ndalikokule 2006). The proportion of resettled farms is small compared with the freehold farms. Resettled farmers that have bought their farm with a government loan are emerging freehold farmers and are further supported by government loans to become freehold farmers (Rust & Marker 2014), land management is therefore similar between emerging and resettled farms. The farm types represent a range of management strategies and land space, so it is important to look at the performance of LGDs between different farm types.

Puppy placement and care

After being born in the small stock kraals at CCF, LGD puppies start bonding with small stock at four weeks of age. Puppies were placed on farms between 10-12 weeks of age after a pre-approval check of the farm and sterilization of the puppy. The young age at placement allows for the puppy to treat livestock as conspecifics (Coppinger et al. 1988, Marker et al. 2005, Dickman et al. 2018). The CCF provides vaccinations (Canine distemper (Vanguard® Plus/L using a modified live Canine Distemper Adenovirus Type 2 Parainfluenza-Parvovirus, DA_2PP) and Rabies (inactive Rabisin™)) for LGDs during the first six months, as well as some veterinary care. All farmers, except those on freehold farmland are then provided with annual vaccinations (Canine distemper (Vanguard® Plus/L using a modified live Canine Distemper Adenovirus Type 2 Parainfluenza-Parvovirus, DA_2PP) and Rabies (inactive Rabisin™)) free of charge. When the LGD is placed, CCF provides instructions on how to train and look after their LGD as they grow and develop (Potgieter et al. 2013). The farmers sign a consent form to allow CCF to monitor the LGD and if needed, return their LGD to CCF if there are any welfare issues.

Data collection

All records on LGD births, placements and deaths were recorded in the CCF LGD studbook/registry programme. Between 1994 and 2018, questionnaire surveys were carried out with farmers that had an LGD (Appendices S1, S2). Questionnaires were conducted at three months and six months after LGD placement, followed by annual visits. The puppy surveys (< six months) specifically looked at how well the puppy was bonding to the livestock and at the living conditions for the puppy. The questions asked during the annual visits (> six months) looked at livestock losses during the year prior the interview and factors that influence LGD performance, including farm type, sex and age of the LGD and the presence of other dogs on the farms. Sample sizes varied depending on the data acquired because not all farmers answered every question. Cause of death was recorded at the time of death, or closest date when CCF was informed.

Data analysis

Compiled questionnaire data were analysed descriptively to determine outcome frequencies of answers by respondents. To detect differences in average lifespan of male and female LGDs, a two-sample t-test was used. Additionally, chi-squared tests were used to determine differences in cause of death between males and females, and in LGD performance with presence and absence of other dogs. Chi-squared tests were also used to determine associations in LGD effectiveness, performance and body condition between different farm types, as well as to determine whether farmers´ expectations and economic benefits are different between farm types. Mixed effects ordinal logistic regression models were used to predict variables that determine: 1) the reduction in livestock losses, calculated as the difference between the number of livestock losses before and after LGD placement, 2) the perceived effectiveness of LGD ("poor", "fair", "good", "excellent"), 3) the condition of an LGD ("poor", "fair", "good", "excellent"), and 4) the occurrence of behavioural issues (i.e. behavioural composite; "chasing game", "biting livestock", "staying at home", "attacking people" and "other" (i.e. barking at night, playing with the stock that resulted in either injury or death of the livestock, returning to the kraal early or the farmer not being able to catch the LGD)). Explanatory variables included "age of LGD", "sex", "age at placement", "perceived effectiveness", "perceptions of economic benefit", "farmer expectations", "levels of stock association", "puppy characteristics" and "survey period" (Appendices 1, 2 describe the questions used to obtain these data). Only one explanatory variable was fitted per model. To account for the correlation of multiple questionnaires of the same

Table 1. Overview of LGDs (n = 472) placed on Namibian farmlands between 1994 and 2018 for which questionnaire data were available, including the total number of surveys completed per survey period. For the dog sex and farm types, the number of surveys represents a singular dog and only includes when the dog was first surveyed. F – freehold, C – communal, EF – emerging freehold, R – resettled, U – unknown.

Survey period	#LGD	Dog sex: Male (%)	Dog sex: Female (%)	Farm types: F (%)	C (%)	EF (%)	R (%)	U (%)	Total pup survey	Total adult survey	Total survey
1994-2001	88	68	32	63	16	2	1	14	71	125	202
2002-2009	144	56	44	47	20	22	4	7	118	275	393
2010-2018	239	51	49	38	33	16	12	1	186	773	959
Unknown	1	0	100	100	0	0	0	0	0	13	13
Total	472	55	54	45	26	16	7	6	375	1192	1567

LGD, the regression models were fitted using generalised estimating equations. The relationship between each independent variable and the outcome was expressed by an odds ratio (OR) with 95% confidence intervals. Odds ratios above one indicate higher likelihood of occurrence, and *vice versa*. A significance level of $P < 0.05$ was used. Odds ratios with confidence intervals excluding zero and P-value < 0.05 are presented in the text. An overview of summary statistics of all mixed effects ordinal logistic regression models, including the non-significant models, can be found in Table S1. Data were organized in Microsoft Excel (2010) and analysed using R Studio Statistical Software (R Core Team 2016, version 3.2.4).

Results

Programme overview and LGD demographics

Between 1994 and 2018, 634 LGDs were placed across Namibian farmlands (Fig. 1). The number of active LGDs has steadily grown over the 25-year period (Fig. 2; Table 1). Questionnaire data were available for 472 LGDs, totalling 1,567 surveys (375 under six months and 1,192 surveys over six months; Table 1). Each LGD had an average of 3.3 (±2.1, range 1-11) surveys over its lifespan. Twenty-two percent of LGDs were only surveyed once.

The average lifespan of an LGD was 56 months (four years and eight months) and was similar for

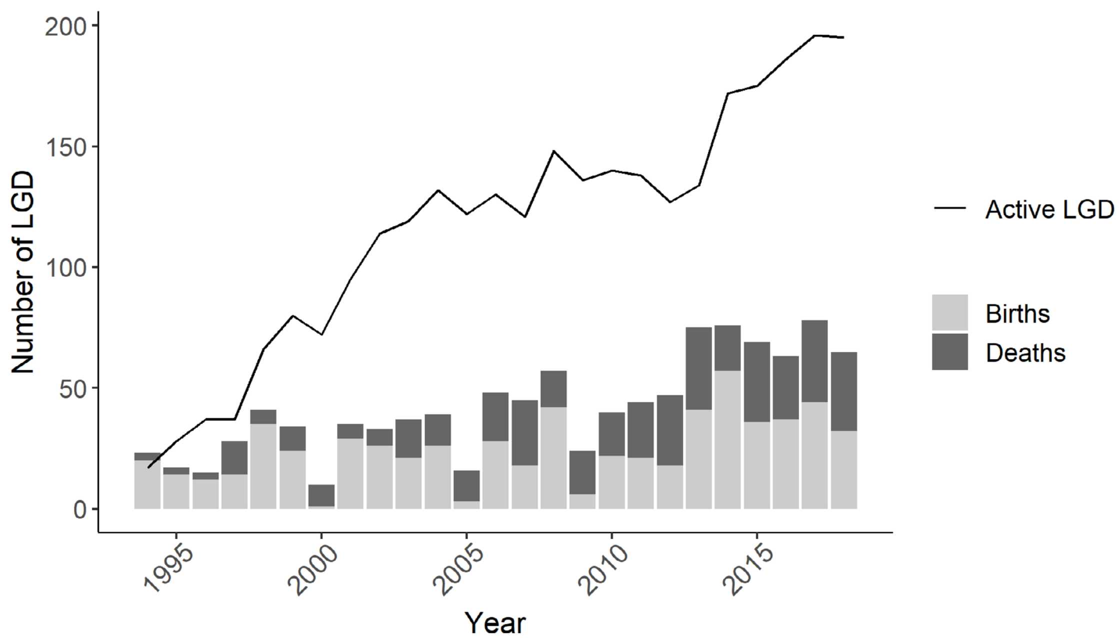

Fig. 2. The growth of the LGD programme between 1994 and 2018, including the number of puppies born (light grey bars) and the number of dog deaths (dark grey bars) per year. The black line shows the number of LGDs alive at the end of each year.

males and females (t = –0.472, P = 0.637). Thirty-two percent (n = 139) of deaths occurred before two years of age. Twenty percent reached the age of eight and older (n = 87). The maximum age was 14 years. Still born puppies and puppy death within the first week of life were excluded as this reflects breeding history more than working life history.

Table 2. Causes of death of LGDs between 1994 and 2018 on Namibian farmlands. Italicised rows indicate subcategories of main causes of death. *SCC – squamous cell carcinoma.

Death cause	LGD (%)	LGD (#)	Male (#)	Female (#)
Field accident	35	152	77	75
snake bite	*55*	*84*	*42*	*42*
road accident	*17*	*26*	*15*	*11*
unlisted	*12*	*18*	*8*	*10*
predator	*10*	*15*	*6*	*9*
environmental	*3*	*5*	*4*	*1*
livestock	*1*	*2*	*2*	*0*
dog fight	*1*	*2*	*0*	*2*
Illness/disease	19	82	37	45
SCC*	*28*	*23*	*14*	*9*
other illnesses/ diseases	*72*	*59*	*23*	*36*
Lost/missing	13	56	31	25
Unknown	12	53	30	23
Old age (> 6 years)	11	49	31	18
Malicious act	10	42	22	20
Total	100	434	230	204

The most common cause of death was "field accident" (35%, n = 152), followed by "illness/ disease" (19%, n = 82) and "lost/missing" (13%, n = 56; Table 2.). The frequency of cause of death was not different between males and females (χ^2 = 4.816, df = 5, P = 0.438). Field accidents were mostly attributed to "snake bites" (55%, n = 84) followed by "road accidents" (17%, n = 26), "unlisted" (12%, n = 18) and "predator" (10%, n = 15), which included attacks mainly from common warthog (*Phacochoerus africanus*) and chacma baboon (*Papio ursinus*). Five dogs died from environmental factors that included drowning in a body of water.

Human-wildlife conflict before and after LGD placement

The majority of farmers reported that, in the year before the LGD placement, they suffered between 1-5 livestock losses (24.7%, n = 132) and 6-10 livestock losses (30%, n = 158), while 19% (n = 103) of farmers reported livestock losses to be more than ten head of stock, and 7% (n = 36) of farmers reported livestock losses to be more than 40 head of stock. Nineteen percent (n = 105) of respondents reported to suffer no livestock losses in the year before dog placement, but acquired an LGD as a preventive measure (Fig. 3).

In the year following placement of an LGD, the majority of farmers (67%, n = 657) reported no annual livestock losses, and 24% (n = 234) of farmers reported annual livestock losses between 1-5 head of stock. Seven percent (n = 64) of farmers reported annual livestock losses between 6-10 head of stock, 2% (n = 21) of farmers lost more than ten head of stock annually and 1% (n = 9) of farmers

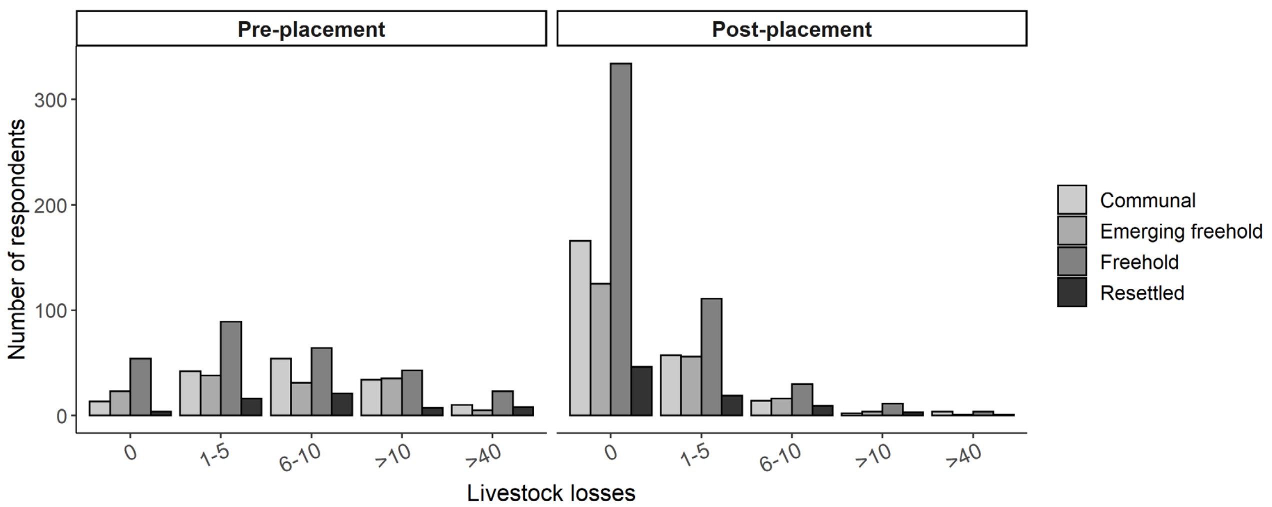

Fig. 3. Number of respondents reporting on annual livestock losses for the year before and after dog placement per farm type between 1994 and 2018 in Namibia.

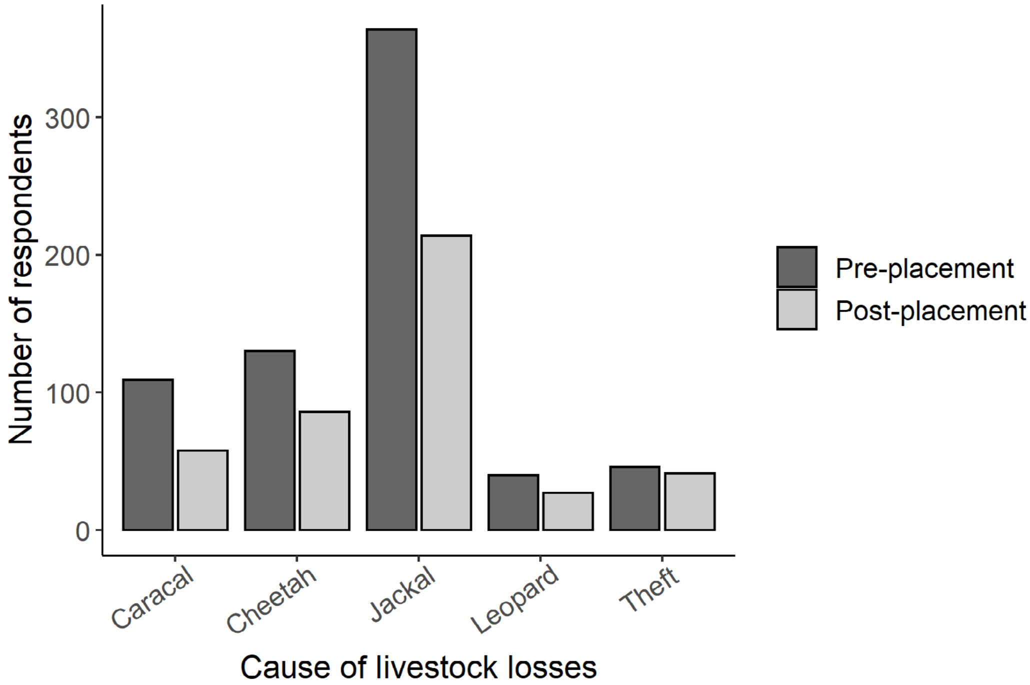

Fig. 4. Number of respondents that report different causes of livestock losses for the year before and after LGD placement between 1994 and 2018 on Namibian farmlands.

lost more than 40 head of stock annually with an LGD (Fig. 3).

Annual livestock losses in the year before the placement of an LGD were mainly attributed to jackal (67%, n = 364), followed by cheetah (25%, n = 130) and caracal (21%, n = 109). In the year after the placement of an LGD, livestock losses to jackal reduced by 45%, to cheetah by 16% and to caracal by 15% (Fig. 4).

Before the placement of an LGD, 13% of farmers reported to have used lethal control methods against predators on their farm. This number dropped to 8% after the placement of an LGD. The most common predators reported to be killed by the farmer before the placement of an LGD were jackal (68% of farmers that kill predators, n = 71), cheetah (21%, n = 22), caracal (14%, n = 15) and leopard (12%, n = 12). The same predators were targeted after the placement of an LGD: jackal (73%, n = 46), cheetah (11%, n = 7), leopard (11%, n = 7) and caracal (8%, n = 5).

LGD age and sex differences and (perceived) effectiveness

Age of LGDs did not affect livestock losses (OR = 1.00 (0.89, 1.14), P = 0.941), but the perceived effectiveness of farmers with older LGDs tended to be higher (OR = 2.29 (0.70, 7.50), P = 0.094). Livestock guarding dogs aged 13-24 months were perceived to be 2.11 (OR = 2.11 (1.06, 4.21), $P < 0.05$) times more effective compared with LGDs that were 6-12 months old. Similarly, LGDs aged 25-48 months and LGDs older than 48 months, were perceived to be 3.19 (OR = 3.19 (1.36, 7.47), $P < 0.01$), and 2.51 (OR = 2.51 (1.24, 5.06), P = 0.01) times more effective respectively, compared with LGDs that were 6-12 months old (Fig. 5).

Age at placement did not affect livestock losses. The reduction in livestock loss with an LGD placed at the age of 0-8 weeks (OR = 0.74 (0.33, 1.64), P = 0.448), older than 12 weeks (first placement; OR = 1.02 (0.28, 3.69), P = 0.971) and older than 12 weeks (rehomed; OR = 1.51 (0.65, 3.52), P = 0.333) were similar compared with the reduction in livestock losses with an LGD placed at the age of 9-12 weeks.

The sex of LGDs did not affect the reduction in livestock losses (male : female OR = 0.98 (0.49, 1.99), P = 0.96), or perceived effectiveness (male : female OR = 0.80 (0.44, 1.45), P = 0.451).

Condition of LGD, behavioural problems and farmer perceptions

Overall, LGDs across Namibian farms were reported to be in “good“ (71%, n = 771) or “excellent“ (22%, n = 239) condition, with only a minority of LGDs being in “poor“ (1%, n = 11)

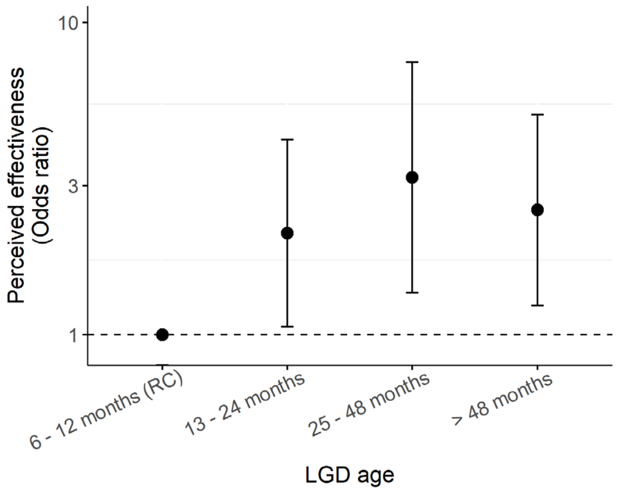

Fig. 5. Perceived effectiveness of different LGD age categories compared with LGDs with the age of "6-12 months old" (RC = Reference category). Odds ratios above one indicate higher likelihood of perceived effectiveness.

or "fair" (6%, n = 65) condition. Dogs having any type of frequent behavioural issues ("behavioural composite") were reported in 28% (n = 334) of the surveys. The main behavioural issues were "staying at home" (40%, n = 133) and "other" (30%, n = 99), followed by "chasing game" (26%, n = 88) and "biting livestock" (19%, n = 63). A minority of LGDs with behavioural issues (4%, n = 12) attacked people. The main behavioural issue with the puppies was that they played too roughly with the stock (48%, n = 698).

Forty-one percent of the surveys (n = 359) mentioned wildlife killings by LGDs. The most common species that LGDs killed were jackal (82%, n = 294), followed by chacma baboon (11%, n = 39), caracal (5%, n = 18), common warthog (4%, n = 15) and cheetah (4%, n = 14). Rarer cases of wildlife killings included African wild cat, bat-eared fox, honey badger (*Mellivora capensis*), common ostrich (*Struthio camelus*), scrub hare (*Lepus saxatilis*), springbok (*Antidorcas marsupialis*), steenbok (*Raphicerus campestris*) and calves of kudu (*Tragelaphus strepsiceros*).

Surveys indicated that LGDs generally showed a preferred degree ("good" and "excellent") of stock protectiveness (92%, n = 978). Most surveys reported that the LGD was part of their stock (96%, n = 994), was submissive to their stock (93%, n = 946) and bonded with their stock (97%, n = 997). Farmers mostly (89%, n = 963) kept the LGD with their stock in kraals at night and 62% (n = 657) reported the presence of a herder working with the LGD (Table 3). The variables indicating LGD association with the livestock described above did not affect the degree of livestock losses (Table S1). Most (89%) surveys indicated that LGDs performance was "good" (53%, n = 590) or "excellent" (36%, n = 397). Over half (55%, n = 613) of the surveys included LGDs that worked alongside other dogs (mongrels). The presence of other dogs did not affect the LGD´s working ability ($\chi^2 = 1.86$, df = 4, $P = 0.76$). Most farmers reported that the LGD met their expectations (93%, n = 1018), that the LGD effectively guarded livestock (94%, n = 970), that the LGD were economically beneficial (93%, n = 946), and that they would recommend the LGD programme to others (99%, n = 975; Table 3).

Farmers that perceived performance of the LGD as "poor" or "fair" were 77% (OR = 0.23 (0.07, 0.73), $P < 0.05$) and 69% (OR = 0.31 (0.13, 0.77), $P < 0.05$) more likely to have dogs in a worse condition, respectively, compared with farmers that perceived performance of the LGD as "excellent". Farmers that perceived performance of the LGD as "good"

Table 3. Outcome frequencies of behavioural composite, stock association, and farmer perceptions of LGDs placed on Namibian farmlands between 1994-2018.

Predictor		Yes (%)	No (%)	Surveys (#)
Behavioural composite		28	72	1,192
Stock association	overnight with stock	89	11	1,081
	part of stock	96	4	1,032
	submissive to stock	93	7	1,017
	bonded with stock	97	3	1,024
	working with herder	62	38	1,065
	other dogs present	56	44	1,090
Farmer perceptions	meet expectations	93	7	1,093
	effectively guarded	94	6	1,035
	economic benefit	93	7	1,018
	recommend LGD	99	1	987

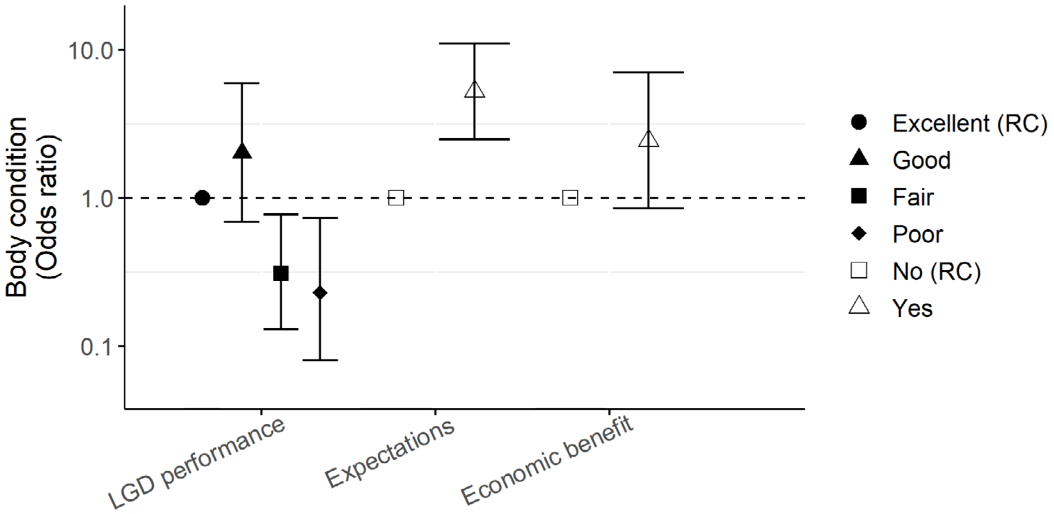

Fig. 6. The effect of LGD performance, farmer expectations of LGD, and economic benefit of LGD on the body condition of LGDs. The reference category (RC) for LGD performance is "excellent performance", while for expectations and economic benefit this is "not meeting expectations" and "no economic benefit", respectively. Odds ratios above one indicate higher likelihood of occurrence and *vice versa*.

had similar perceptions of LGD body condition as farmers who perceived performance of the LGD as "excellent" (OR = 2.02 (0.69, 5.92), P = 0.201). Farmers who reported that the LGD met their expectations were 5.22 times more likely to have dogs in a better condition compared with farmers who reported that the LGD did not meet their expectations (OR = 5.22 (2.48, 10.99), $P < 0.001$). The condition of the LGD tended to be better when farmers perceived the LGD to have an economic benefit to their livelihood (OR = 2.43 (0.85, 6.99), P = 0.097; Fig. 6).

Farmers that perceived performance of the LGD as "poor" were 5.95 times more likely to have LGDs that chased game, compared with farmers that perceived LGD performance as "excellent" (OR = 5.95 (1.28, 27.56), $P < 0.05$; Fig. 7). Farmers that perceived performance of the LGD as "poor" or "fair" were 7.03 (OR = 7.03 (1.76, 28.11), $P < 0.001$) and 3.58 (OR = 3.58 (1.74, 7.36), $P < 0.01$) times more likely to have LGDs that stayed at home respectively, compared with farmers that perceived performance of the LGD as "excellent" (Fig. 7). Farmers that perceived performance of LGDs as

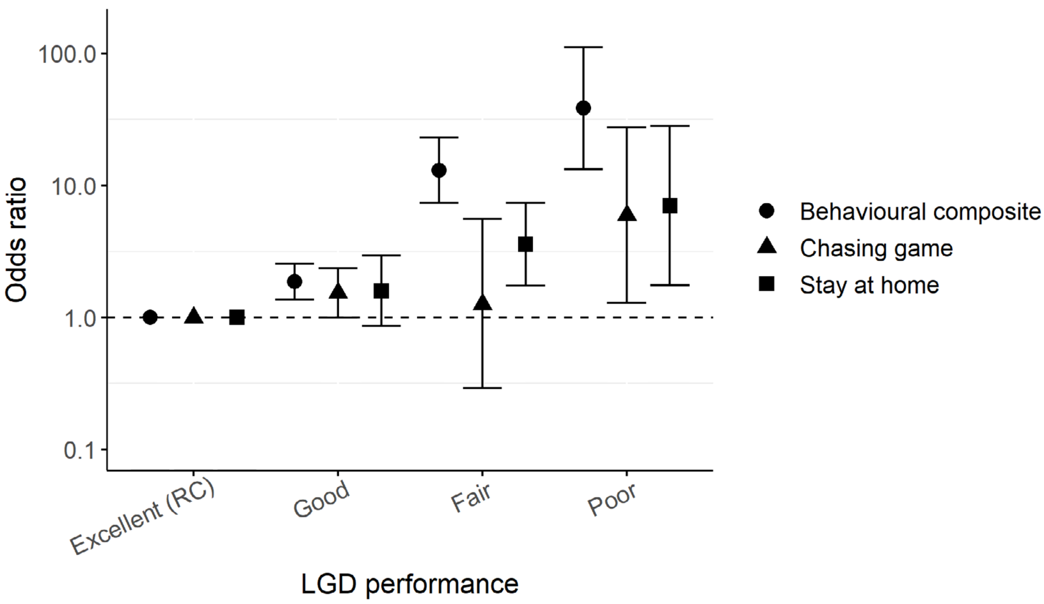

Fig. 7. The effect of LGD perceived performance on the occurrence of behavioural composites (circle), chasing game (triangle), and staying at home (square), compared with a reference category (RC) "excellent performance". Odds ratios above one indicate higher likelihood of occurrence and *vice versa*.

"poor", "fair" or "good" were 38.43 (OR = 38.43 (13.24, 111.58), $P < 0.001$), 13.04 (OR = 13.04 (7.38, 23.06), $P < 0.001$) and 1.86 (OR = 1.86 (1.37, 2.54), $P < 0.001$) times more likely to have dogs with more behavioural composites respectively, compared with farmers that perceived performance of the LGD as "excellent" (Fig. 7).

There were no other significant associations between behavioural issues ("chasing game", "biting livestock", "staying home", "attacking behaviour", "other") and farmer perception of LGD performance, expectations or perceptions of economic benefit (Table S1).

Comparison between farm types

There were no significant differences in livestock losses after LGD placement between farm types ($\chi^2 = 16.46$, df = 12, $P = 0.17$; Fig. 3). However, farmers on communal and emerging freehold farmland reported more frequently "good" and "excellent" performance of LGDs compared with farmers on freehold and resettled farmland ($\chi^2 = 22.06$, df = 9, $P < 0.01$). On freehold farmland, more LGDs were in excellent condition ($\chi^2 = 20.63$, df = 9, $P < 0.05$), but farmers on freehold farmland reported more frequently the occurrence of different behavioural problems ($\chi^2 = 21.86$, df = 3, $P < 0.001$; Table 4). Farmers´ expectations and economic benefit of LGDs were similar for different farm types (Expectations: $\chi^2 = 2.96$, df = 3, $P = 0.40$, economic benefit: $\chi^2 = 1.68$, df = 3, $P = 0.64$).

Comparison between surveys

The overall reduction in stock loss after dog placement was similar across the different survey periods (survey 1994-2001 *vs.* survey 2010-2018: OR = 1.05 (0.17, 6.48), $P = 0.951$; survey 2002-2009 *vs.* survey 2010-2018: OR = 1.06 (0.49, 2.29), $P = 0.875$; Fig. 8). However, reduction in stock loss as a result of theft was 43% lower in the survey 2002-2009 compared with the survey 2010-2018 (OR = 0.57 (0.36, 0.91), $P < 0.5$).

The LGDs in the survey periods 1994-2001 and 2002-2009 were 2.21 (OR = 2.21 (1.49, 3.30), $P < 0.001$) and 1.63 times (OR = 1.63 (1.15, 2.31), $P < 0.01$) more likely to be in better condition respectively, compared with the LGDs in the survey 2010-2018 (Fig. 8).

Reports on behavioural problems ("biting livestock", "staying home" and "attacking people") remained generally similar across surveys, but LGDs were 4.47 times less likely to chase game in the 2010-2018 period compared with the 1994-2001 period (OR = 4.47 (1.82, 10.98), $P < 0.01$), and reports of "other" behaviours were 51% more likely during the 2010-2018 period, compared with the 2002-2009 period (OR = 0.49 (0.26, 0.91), $P < 0.5$). Reports on behavioural composites in the 1994-2001 period and the 2002-2009 period were 3.49 (OR = 3.49 (2.27, 5.37), $P < 0.001$) and 2.11 (OR = 2.11 (1.47, 3.01), $P < 0.001$) times more likely, respectively, compared with reports on behavioural composites in the survey period 2010-2018 (Fig. 8).

Table 4. Outcome frequencies of LGD performance, body condition and behavioural composite under different farming contexts.

	Farm type (%)				Surveys (#)
	Communal	Emerging freehold	Freehold	Resettled	
Performance					
excellent	32	39	34	33	399
good	60	57	54	56	650
fair	5	2	10	10	92
poor	2	2	2	1	34
Body condition					
excellent	16	18	25	13	232
good	78	74	67	82	825
fair	4	8	7	5	72
poor	2	0	1	1	15
Behavioural composite					
yes	15	16	25	10	252
no	85	84	75	90	940

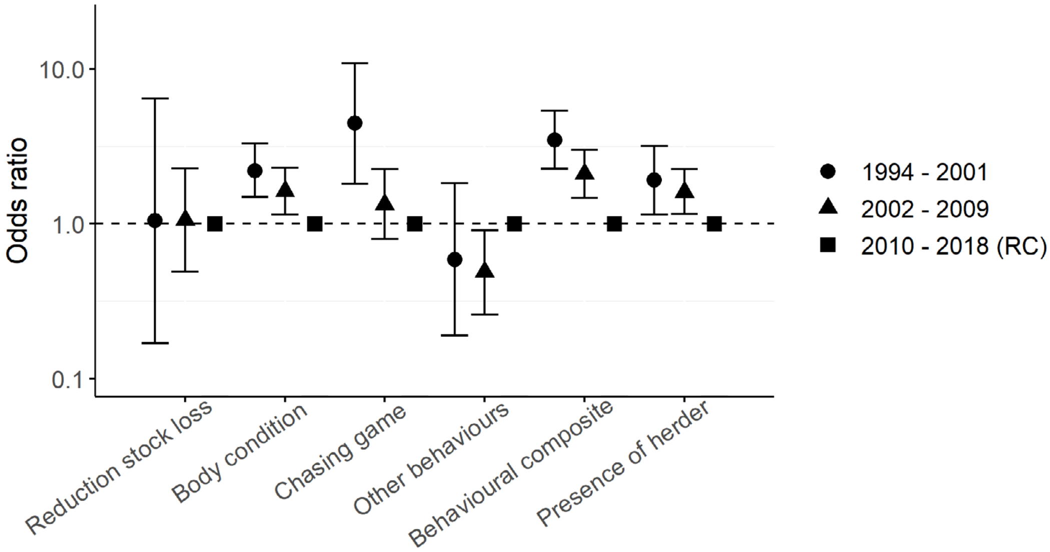

Fig. 8. Comparison between surveys for different variables relating to LGD working ability, with the survey period "2010-2018" as reference category (RC). Odds ratios above one indicate a higher likelihood of occurrence and *vice versa*.

The presence of herders in the periods 1994-2001 and 2002-2009 was 92% (OR = 1.92 (1.15, 3.19), $P < 0.1$) and 61% (OR = 1.61 (1.16, 2.26), $P < 0.1$) respectively, more likely compared with the presence of herder in the survey period 2010-2018 (Fig. 8). Other variables were not different between survey periods (Table S1).

Discussion

The 25 years of use of LGDs across Namibian farmlands demonstrate a highly successful programme in mitigating human conflicts with cheetahs and other predators. Moreover, this long-term monitoring dataset is unique and provides important insights into LGD management, their performance, and the expansion of an LGD programme, which can be applied elsewhere to address imminent human-predator conflicts.

The use of LGDs has previously been demonstrated to be an effective and well-tested method to address conflict mitigation (Coppinger et al. 1988, Marker et al. 2005, Gehring et al. 2009, van Bommel & Johnson 2012). This is further supported by our results, with 91% of farmers reporting little to no livestock losses after LGD placement. Furthermore, the high effectiveness of LGDs and the consequent reduction in predator killings by farmers (albeit small) suggest a move towards an increased positive perception of farmers towards wildlife conservation, which is key to facilitate sustainable coexistence (Potgieter et al. 2013, Rust et al. 2013). Yet, conservation perceptions are often deeply rooted in past-experiences and socio-cultural values (Dickman 2010). Changing these perceptions may require a thorough and holistic approach, including educational outreach and stakeholder involvement alongside non-lethal conflict mitigation tools, such as the use of LGDs (Jacobson et al. 2006, Marker & Boast 2015).

Performance of LGDs best predicted body condition and the occurrence of behavioural problems. Farmers tended to care less for LGDs that showed poor performance, while body condition is precisely key for LGD effectiveness (Horgan 2015). One exception was the finding that freehold farmers reported more behaviour issues but the dogs were typically in good or excellent condition. Socio-economic factors may influence perceptions and expectations, which highlights the importance of considering farm type and context-specific factors when evaluating LGD programmes (potential explanatory factors are discussed below).

Across all respondents, the main behavioural issue reported for adult LGDs was "staying at home", while LGD puppies often played too roughly with livestock. In some cases, this behaviour continued as the puppy grew and resulted in stock loss from injuries sustained from the dog playing roughly. Playful LGD puppies may be more likely to continue this behaviour with livestock as adults, while puppies that show more independent behaviour may be more effective as LGDs (Fratkin et al. 2013, McConnell 2018). This suggests that personality differences may affect individual performance of LGDs and may need more consideration when addressing behavioural problems. We encourage the use of a herder from an early age to correct unwanted behaviours. Another prevalent behavioural issue was "chasing game", with 41% of surveys including records of wildlife killings by LGDs, mainly jackals. In most cases, this was a single incident, but some surveys included reports of 50 or more jackals killed, which raises concern about the unwanted ecological impacts of LGDs. Wildlife killings by LGDs are widely reported in the literature, but the frequency of these interactions and the outcome for the species involved is often overlooked (Smith et al. 2020). It has been suggested that LGDs can function as surrogate top predators, affecting distribution and behaviour of herbivores and mesopredators significantly (van Bommel & Johnson 2016). Herders accompanying LGDs could reduce unwanted ecological impacts and may be key to resolving this issue (Drouilly et al. 2020), but further research is recommended. Selecting suitable farmers and herders may be critical to ensure good performance of LGDs.

Intrinsic factors, such as the sex of the LGDs were not significant in the LGD's ability to protect livestock, which supports earlier findings (Marker et al. 2005, Potgieter et al. 2013, Leijenaar et al. 2015). This is not surprising as all LGDs in this study were sterilised before being placed on farms. By sterilising LGDs, it discourages the dogs from straying away from livestock, thereby increasing livestock protection (Marker et al. 2005). Furthermore, neutering also improves the trainability and attentiveness of male LGDs (Marker et al. 2005).

The age at placement did not affect LGD performance. This suggests that moving LGDs between farms has little effect on their effectiveness, as they have already been bonded with livestock from an early age (Marker et al. 2005). The performance of LGDs throughout their lifespan was generally high and perceived effectiveness remained similar until death. In Australia, Maremma sheepdogs were found to become less active and less effective with increasing age (van Bommel & Johnson 2014). Older LGDs may stay closer to the flock than younger ones because of reduced mobility (Zingaro et al. 2018), which may increase farmers´ perceptions of LGD effectiveness. Additionally, the majority (80%) of LGDs in this study died before the age of eight, which prevented us from extending our inference about the effectiveness and perceived perceptions of older LGDs. Addressing causes of early deaths will be key to improve cost-effectiveness, particularly because of the high proportion of LGDs that died before the age of two (32%). The leading cause of death was "field accidents", with 55% being a result of snake bite. Behavioural training may induce aversion to snakes and the presence of herders could prevent LGDs from being bitten (Rust et al. 2013). Beside field accidents, 19% of the dogs died from illness and/or disease, of which 28% was attributed to lingual squamous cell carcinoma, possibly caused from the high degree of radiation from the sun in the Namibian environment (Lester et al. 2008). Ongoing research continues to better understand this problem, including genetics of LGDs and testing water and soil sources from the various farms where LGDs have grown up.

The reduction in livestock losses after LGD placement was similar for different farm types. However, we identified slight differences in perceived performance, body condition and behavioural problems, which may be attributed to socio-economic and cultural variables associated with different farming contexts. For example, farmers on freehold farmland may have better access to provide care for LGDs and may have the economic ability to provide a herder. Environmental differences such as wildlife abundance may also induce problematic behaviours such as "chasing game". Farming context may also relate with other variables, such as herd size, which has been found to be negatively correlated with LGD performance (Horgan 2015), and vegetation type, which may influence the spatial association between LGDs and livestock (Zingaro et al. 2018). Further research will be of interest to identify novel factors influencing LGD performance.

Overall, there was no significant difference between the survey periods in terms of livestock losses, suggesting that the LGD programme is continuing to have a positive influence on Namibian farmers. Livestock losses to theft, however, significantly increased during 2010 and 2018 compared with the earlier years, and merits further investigation outside the scope of this study. Over time, the occurrence of behavioural issues such as chasing game and behavioural composites decreased significantly. This suggests that the programme´s response to farmer education on corrective behaviour has been successful. Unexpectedly, body condition decreased over time as well as the presence of herders. These are important findings for CCF´s LGD programme to address in the future. The rapid expansion of the LGD programme may have put logistical constraints on LGD monitoring, yet body condition for LGDs between 2010-2018 was still mostly (94%, n = 681) reported to be "good" or "excellent".

Record keeping is essential to ensure that accurate monitoring is carried out, especially for long-term studies (Parfitt 2013). The results in this study relied heavily on the farmers´ perceptions of LGD effectiveness and perceived livestock depredation, so the accuracy of this study is limited to the data provided by the farmers at the time of the surveys. Livestock guarding dog performance could be underestimated due to modesty of farmers in their responses (Jakobsen & Jensen 2015), while it could also be overestimated due to social-desirability bias, i.e. respondents may give answers to please the interviewers rather than to give truthful answers (Leggett et al. 2003).

In conclusion, LGDs have been used in Namibia for the past 25 years with high success in mitigating human-wildlife conflict between livestock farmers and predators. The degree of LGD effectiveness has remained high since 1994 and the programme has rapidly expanded within and outside the country. Further expansion of the programme will be critical in protecting the world´s largest free-ranging population of cheetahs and has promising applications beyond the cheetah´s range to assist other predators in conflict with farmers and ranchers. Twenty-five years of LGD work in Namibia has been instrumental to better management of guarding dog programmes, ultimately contributing towards sustainable coexistence between farmers and predators.

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Supplementary online material

Appendix S1. Questionnaire form for LGDs older than 6 months (https://www.ivb.cz/wp-content/uploads/JVB-vol.-69-3-2020-Marker-E.-et-al.-Appendix-S1-1.pdf).

Appendix S2. Questionnaire form for LGDs younger than 6 months (https://www.ivb.cz/wp-content/uploads/JVB.-vol.-69-3-2020-MarkerE.-et-al.-Appendix-S2.pdf).

Table S1. Summary statistics of mixed effects ordinal logistic regression models (https://www.ivb.cz/wp-content/uploads/JVB-vol.-69-3-2020-MarkerE.-et-al.-Table-S1-1.pdf).