Effectiveness of community-based livestock protection strategies: a case study of human–lion conflict mitigation

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Abstract Conservation scientists are increasingly recognizing the need to evaluate the effectiveness of interventions to improve human–wildlife coexistence across different contexts. Here we assessed the long-term efficacy of the Long Shields Community Guardians programme in Zimbabwe. This community-based programme seeks to protect livestock and prevent depredation by lions *Panthera leo* through non-lethal means, with the ultimate aim of promoting human–lion coexistence. Using a quasi-experimental approach, we measured temporal trends in livestock depredation by lions and the prevalence of retaliatory killing of lions by farmers and wildlife managers. Farmers that were part of the Long Shields programme experienced a significant reduction in livestock loss to lions, and the annual number of lions subject to retaliatory killing by farmers dropped by 41% since the start of the programme in 2013, compared to 2008–2012, before the programme was initiated. Our findings demonstrate the Long Shields programme can be a potential model for limiting livestock depredation by lions. More broadly, our study demonstrates the effectiveness of community-based interventions to engage community members, improve livestock protection and ameliorate levels of retaliatory killing, thereby reducing human–lion conflict.

Keywords African lion, community-based coexistence intervention, conservation, impact evaluation, livestock depredation, Long Shields Community Guardian programme, non-lethal, Zimbabwe

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Introduction

Over the past 2 centuries, more than 75% of large carnivore populations have experienced substantial range contractions and population declines (Ripple et al., 2014). In particular, negative interactions of large carnivores with people and livestock are a significant threat to the persistence of carnivore populations (Wolf & Ripple, 2017). Conflict between people with opposing views on wildlife conservation, commonly referred to as human–wildlife conflict, arises when the needs and behaviour of wild animals negatively affect the goals and well-being of people, and vice versa (Madden, 2004). The human population is increasing, and this is likely to exacerbate conflicts involving wildlife and lead to further declines of large carnivores (Wittemyer et al., 2008). Facilitating long-term coexistence between people and wild carnivores is therefore an urgent conservation priority (Ripple et al., 2014).

The African lion *Panthera leo*, the largest predator in the savannah ecosystem, is negatively affected by the consequences of the increasing human population (Bauer et al., 2016). Lion populations are extinct in North and Central Africa and declining in East Africa, but stable in Southern Africa. Conflict with people along the boundaries of protected areas threatens the long-term viability of the remaining lion populations (Bauer et al., 2016). For example, lions kill livestock, a major source of livelihood for marginalized communities, and farmers kill lions in revenge (Dickman et al., 2014). To safeguard the species, robust interventions are needed to reduce the impact of lions on people, and the resulting retaliatory killing of lions (Bauer et al., 2016).

A diverse array of technical tools, both lethal and non-lethal, have been developed globally to minimize the negative impacts of wild carnivores (Miller et al., 2016). These interventions range from basic methods such as livestock herding (Ogada et al., 2003) to sophisticated techniques such as the use of lightweight metal collars that may protect livestock from depredation (McManus et al., 2014). However, many of these interventions have not been evaluated for

effectiveness (van Eeden et al., 2018), mainly because of the associated costs and practical difficulties (Baylis et al., 2016).

The Hwange-Matetsi Protected Area Complex in north-western Zimbabwe is of global importance for lion conservation (Cushman et al., 2018). The protected area is part of the wider Kavango Zambezi Transfrontier Conservation Area and is home to one of the world's largest remaining lion populations, with > 1,000 individuals (Bauer et al., 2016). As for many lion populations, persecution by farmers along the community–protected area interface in retaliation for livestock loss is a serious threat to this population (Loveridge et al., 2017). Over 1,000 livestock (c. 19% of the entire livestock population) were killed by large predators including lions during 2008–2013, and c. 50 lions (mostly females with dependent cubs and subadult males) were killed in retaliation by farmers and local authorities during the same period (Loveridge et al., 2017). The factors influencing the frequency and magnitude of livestock attacks by lions in this area are well studied. Livestock depredation by lions peaks during the wet months, when livestock is herded away from crop fields and closer to the protected area (Kuiper et al., 2015). The majority (> 80%) of lion attacks on livestock occur at night when many livestock are left to graze unattended rather than being securely enclosed in protective kraals (Loveridge et al., 2017).

In 2012, in collaboration with local traditional leaders, we introduced a community-based coexistence programme known as Long Shields Community Guardian (hereafter the Long Shields programme) in north-western Zimbabwe. We collaborated with local communities to ensure that the programme's aims, actions and outcomes were relevant to all stakeholders and aligned with the interests of the community, and that the programme was locally appropriate and consistent with norms and customs.

The Long Shields programme was modelled on the Lion Guardians programme in Amboseli, Kenya, which aims to provide non-lethal solutions, such as educational outreach and deterring lions, to reduce the impact of lions on people and promote coexistence (Hazzah et al., 2014). To illustrate the inputs, activities, target audiences and desired outcomes of the Long Shields programme, we followed the theory of change methodology, which involves a logical, ordered sequence for programme design and evaluation (Woodhouse et al., 2015). The theory of change framework has been used elsewhere in other conservation contexts (Morehouse et al., 2020) and can be particularly useful for structuring data collection and prioritizing the activities and goals of future programmes.

As part of a broader evaluation, we hypothesized that the programme would improve farmers' attitudes towards lions and facilitate human–lion coexistence by (1) reducing livestock loss to lions (both perceived and actual), (2) reducing the risk to human safety, and (3) creating awareness of the programme and its demonstrated efforts. Results to date suggest that hazing or chasing so-called problem lions is an effective method for deterring young lions from communal farmlands (Petracca et al., 2019) and that the programme is well received within the target communities. Consequently, there has been a positive shift in farmers' attitudes towards lions (Sibanda et al., 2021). Evidence from other areas also suggests that assisting farmers in building sturdy livestock enclosures and alerting them of approaching lions are both effective methods for limiting livestock depredation (Lichtenfeld et al., 2014).

To establish whether the Long Shields programme was effective in mitigating livestock depredation by lions, we examined the long-term trends before (2008–2012) and after (2013–2017) the implementation of the programme, and compared levels of livestock depredation between participating and non-participating farmers. We also examined the temporal trends in retaliatory killings of lions by local farmers before and after programme implementation. We hypothesized that as a result of the programme's activities there would be (1) a significant decrease in livestock depredation by lions for participating farmers (treatment group) in comparison to non-participating farmers (non-treatment group), and (2) a significant reduction in retaliatory killings of lions by participating farmers after the introduction of the programme.

Study area

Our study was implemented in three rural communities in communal lands in north-western Zimbabwe (Fig. 1): Mabale (Dingani Chieftainship: 480 km²), Tsholotsho (Matupula and Siphoso Chieftainships: 2,171 km²) and Victoria Falls (Mvuthu and Shana Chieftainships: 655 km²). Mabale and Tsholotsho rural communities are adjacent to Hwange National Park, and Victoria Falls communal area is adjacent to Zambezi National Park. Both Hwange and Zambezi National Parks are part of the Hwange-Matetsi Protected Area Complex. The Sikumi Forest Land provides a buffer between Mabale and Hwange National Park, and Fuller Forest Land lies between Victoria Falls and Zambezi National Park. Differences in human settlement density across the study sites are summarized in Supplementary Table 1.

The study area is semi-arid, with a mean annual rainfall of 600 mm (interannual CV = 25%; Guerbois et al., 2013). Crop cultivation and livestock-rearing are the two primary sources of livelihoods. Common livestock reared include cattle *Bos taurus*, donkeys *Equus asinus*, sheep *Ovis aries* and goats *Capra hircus* (Sibanda et al., 2020). Some farmers herd their livestock and pen them at night as is traditional, but previous studies have found evidence of some less careful herding practices (e.g. Kuiper et al., 2015; Loveridge et al., 2017). Livestock is grazed on designated rangeland usually located within the communal lands. Farmers in

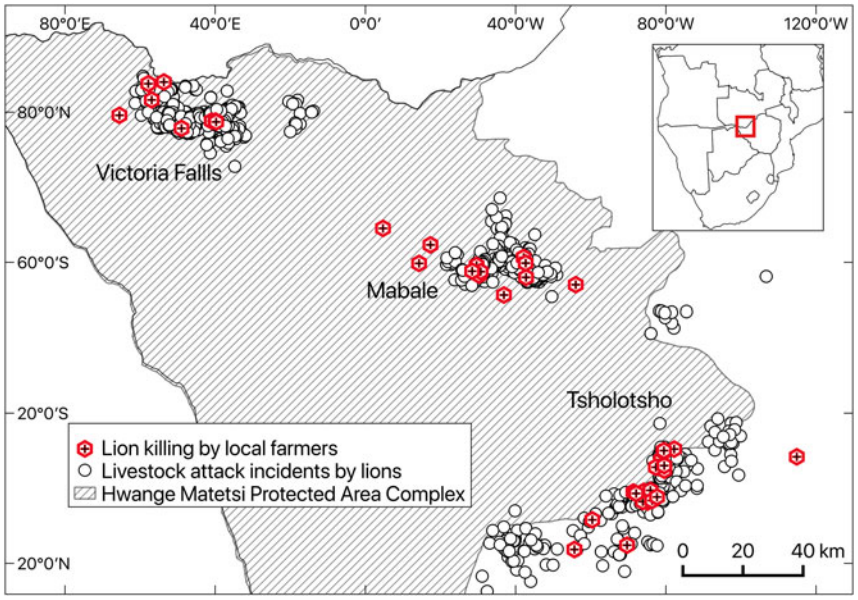

FIG. 1 The study area in north-western Zimbabwe, showing three communal areas where the Long Shields Community Guardian programme was implemented, with locations of lion *Panthera leo* attacks on livestock and retaliatory killings of lions during 2008–2017.

Tsholotsho and Victoria Falls graze their livestock on communal grazing areas located within the communal land, whereas limited grazing opportunities in Mabale drive farmers to graze their livestock within a protected area (Sikumi Forest Land) in search of quality forage and water for their animals (LS, pers. obs., 2020). Human population and development are increasing (Guerbois et al., 2013), and the need to access the Sikumi Forest Land for grazing has contributed to an increase in attacks on livestock by wild carnivores (Perrotton, 2015).

The Zimbabwe Parks and Wildlife Management Authority and the Rural District Councils are responsible for managing wildlife outside the Park. Lethal control (i.e. shooting) is often the preferred method for dealing with so-called problem animals, especially for dangerous species such as the lion (Loveridge et al., 2010). Legal prosecution of farmers for killing lions is uncommon; only two farmers were prosecuted for illegally killing a lion during the study period. Farmers do not receive financial compensation from the government for livestock or crop losses to wild animals (Sibanda et al., 2020). Tsholotsho, Mabale and Victoria Falls are all part of the Communal Areas Management Programme for Indigenous Resources, a community-based natural resources management programme that seeks to provide benefit through Rural District Councils to communities living alongside wildlife areas, such as the provision of water sources and the renovation of local schools, clinics and roads (CAMPFIRE, 2016). Although the Communal Areas Management Programme for Indigenous Resources recorded significant success since it was initiated in the early 1980s, more recently most farmers, particularly in our study area, have felt strongly negative towards it, claiming they receive few direct benefits (Western et al., 2019).

Methods

Experimental design

We used a quasi-experimental design with before–after control–intervention measurements (Thiault et al., 2017), sampling treatment and non-treatment groups of farmers simultaneously before and after the introduction of the Long Shields programme. This design is commonly applied to estimate the causal effects of an intervention on a target population when random assignment to a treatment is not possible (Gertler et al., 2011). Our study involved a total of 99 villages, each with 10–75 farmsteads, all located within a 20-km radius of the Park boundary. Of these, 47% (n = 46; Mabale = 9, Tsholotsho = 15 and Victoria Falls = 22) were part of the Long Shields programme, and the remaining 53% (n = 53; Mabale = 18, Tsholotsho = 29 and Victoria Falls = 6) were not. We selected villages to be included in the programme non-randomly, based on previous significant livestock depredation, because we considered it ethically unacceptable to randomly allocate villages affected by potentially life-threatening situations to treatment or non-treatment groups.

Long Shields Community Guardian programme

We introduced the community-based programme in six key stages. Firstly, we conducted a baseline survey to examine the attitudes of farmers towards lions, and underlying factors (Sibanda et al., 2020). In consultation with local traditional leaders, we used the theory of change framework to develop a logical model of behavioural change (Supplementary Fig. 1). We then recruited 14 local farmers (12 men, two women) as Community Guardians, who were selected from

a shortlist of candidates recommended by local traditional leaders and the wider community. We selected candidates based on previous direct experience with lions (e.g. people who had physically chased a lion), literacy, residency within the local area and good standing in the community. Community Guardians were then trained by the Trans-Kalahari Predator Project (WildCRU, University of Oxford, Oxford, UK) in lion tracking and the use of radio-telemetry, GPS data collection protocols (e.g. livestock depredation assessment) and conflict mitigation techniques (e.g. herding, kraal fortification).

As part of the programme's early warning system, during 2013–2017 we identified 21 lions (males = 14; females = 7; Mabale = 6; Tsholotsho = 9; Victoria Falls = 6) across nine prides/coalitions and fitted them with GPS collars to monitor their movement. Only one or two individuals were collared per pride/coalition, and lions were selected for collaring based on their home ranges significantly overlapping with the local farming communities outside the protected areas and whether the animals were likely to disperse. The collars recorded the lions' locations every 2 hours. Whenever lions were within 3 km of a protected area boundary, Community Guardians sent a warning message (via WhatsApp; Meta Platforms, Menlo Park, USA) to a network of farmers within treatment villages. Lions that crossed the Park boundary and approached human settlements would be hazed (chased) by the Community Guardians and volunteers within the treatment villages using a vuvuzela, a plastic horn that produces an irritating sound of c. 127 decibels (Petracca et al., 2019). A long-term dataset collected using a combination of spoor and camera-trap surveys suggest the lion population density (c. 2.5 lions/100 km^2) remained constant throughout the study period (WildCRU, unpubl. data). The Long Shields programme was piloted in Mabale communal area for 6 months before expanding to Tsholotsho in January 2013 and Victoria Falls in June 2016.

Monitoring of livestock depredation and lion mortality

We monitored livestock attacks by lions and retaliatory lion killing by farmers over a 10-year period (January 2008–December 2017). We define an attack as an event in which a carnivore killed or injured one or more livestock species. The majority of livestock depredation and lion mortalities were reported directly to programme personnel, with an incident report form used to collect event details. For all incidents (attacks on livestock or lion mortality), we recorded the date and time of the incident, the date when it was reported, GPS coordinates of the household and/or incident site, the predator species most likely involved, livestock species attacked (cattle, donkey, sheep, goat), whether the incident occurred within or outside a kraal, circumstances leading to retaliatory lion killing, and the cause of lion mortality (e.g. wire snare, shooting or poison). To assess the accuracy of carnivore identification by the farmers, we showed each farmer pictures of different carnivores and their paw prints, which they were asked to identify. To validate incidents of livestock loss, we verified each event by visiting the incident site. We also confirmed all incidents with the village head who, as part of their official civil responsibilities, keeps a register of all livestock losses to wild carnivores in the village.

Evaluating programme success

To examine the effects of the Long Shields programme, we used generalized linear mixed-effect models (GLMMs; Zuur et al., 2009) with a Poisson distribution in *R 4.0.0* (R Core Team, 2019). The models were fitted using the function *glmer* in package *lme4* (Bates et al., 2015). The number of livestock lost to lions (mean per village per year) was the response variable. The following variables and their interactions were included in the model as fixed effects: location (Mabale, Tsholotsho or Victoria Falls), treatment status (treatment or non-treatment) and time in relation to programme implementation (before or after). The effect we were most interested in was the interaction between treatment and time, as this tested the null hypothesis that there was no difference between treatment and control in the temporal trend. To control for clustering, we included village in the models as a random effect variable. To test the effectiveness of the community-based programme, we performed the likelihood ratio test (Bolker et al., 2009), comparing models with and without the effect of interest. We validated models to evaluate the presence of over- or under-dispersion through the inspection of residuals. Finally, to examine the association between the number of livestock lost to lions and the number of lions killed in retaliation (and vice versa), we performed a Pearson correlation test in *R*, using each year (i.e. the number of livestock or lions killed in that year) as a data point.

Results

Depredation

Over the 10-year period, a total of 1,987 domestic animals were attacked by lions in 990 confirmed incidences (mean = 16.59 ± SD 4.24 animals per month). The majority of livestock depredation incidents involved cattle (67%), followed by donkeys (17%), sheep or goats (14%) and other animals (e.g. pigs; 2%). The highest number of incidents (40%) occurred in Victoria Falls, followed by Tsholotsho (34%) and Mabale (26%). The proportion of lion attacks on livestock inside and outside protective

enclosures varied across the three communal areas (χ^2 = 93.52, df = 2, P < 0.001), with Mabale having the greatest number of incidents inside kraals (32%). The majority of lion attacks on livestock occurred during the night (61%) and outside kraals (83%).

Long Shields programme activities

During 2013–2017, the programme sent a total of 2,262 early warning messages (mean = 38 per month) alerting farmers to approaching lions. Fifty-one farmers were assisted in recovering missing livestock (n = 386 livestock). Across the same period 21 lions were hazed to encourage them to return into the protected area on a total of 116 occasions (mean = 5.5 chases per lion). More than half of the chases (53%) were in Tsholotsho, followed by Mabale (40%) and Victoria Falls (7%). One hundred and four farmers approached Community Guardians seeking assistance to reinforce their kraals during this period.

Effectiveness of the Long Shields programme in limiting livestock losses

Mean livestock losses to lions were significantly reduced in the period after initiation of the Long Shields programme in participating villages (likelihood ratio test for GLMM: χ^2 = 98.63, df = 6, P < 0.001). Mean livestock losses to lions per village per year for participating farmers in Tsholotsho decreased from 19.27 before to 12.73 after the programme was implemented. In Victoria Falls, this was 17.55 for participating farmers before vs 11.23 after programme implementation. In Mabale, however, mean livestock loss to lions for participating farmers increased from 13.44 per village per year before to 25.44 after programme implementation. (Fig. 2). In addition, mean livestock losses for non-participating farmers in Tsholotsho decreased slightly after the programme was implemented, but the decrease was less pronounced than for participating farmers (Fig. 2).

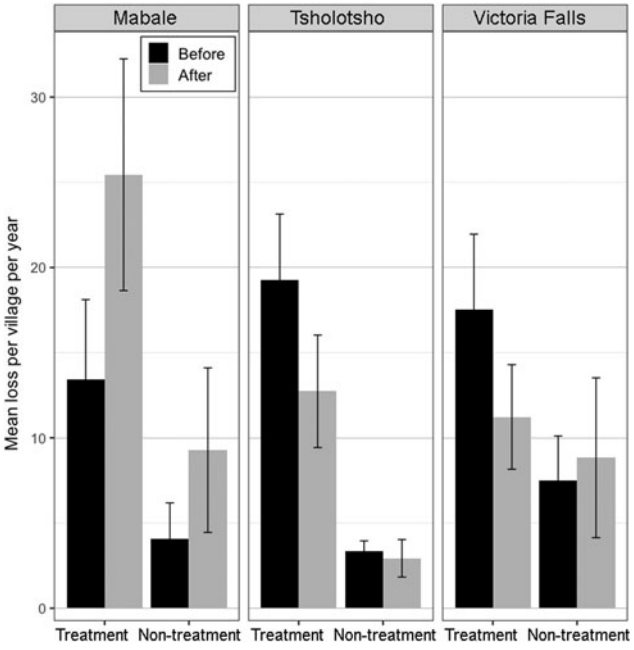

FIG. 2 Mean number of livestock lost to lions per village per year during 2008–2017 before (2008–2012) and after (2013–2017) the introduction of the community-based Long Shields programme, for farmers participating (treatment) and not participating (non-treatment) in the programme. Error bars represent standard errors (SE).

Lion mortality before and after programme implementation

During 2008–2017, a total of 46 lions (males = 26; females = 20) were killed in conflict-related incidents in Mabale (n=13), Tsholotsho (n = 23) and Victoria Falls (n = 10). Of these, 63% (n = 29, mean = 5.8 lions per year) were killed before (2008–2012) and 37% (n = 17, mean = 3.4 lions per year) after the Long Shields programme was implemented (2013–2017). Thus, the number of lions killed in retaliation declined by 41%. Most of these lions (67%, n = 31) were shot as problem animals by officials of national parks authorities or rural district councils. Farmers were directly involved in the illegal killing of 15 lions, using either snares (n = 12), spears (n = 2) or poison (n = 1). More collared lions were killed in Mabale than elsewhere (Table 1). The proportion of lions illegally killed by farmers declined significantly after the implementation of the programme (χ^2 = 5.33, df = 1, P = 0.02), but the number of lions legally shot by officials remained unchanged (Table 1). There was only a weak association between the number of livestock killed by lions and the number of lions killed in retaliation by farmers (*rs* = 0.54, df = 8, P = 0.11).

Discussion

Our findings indicate that farmer participation in the Long Shields programme is a significant factor in reducing livestock loss to lions. Since the inception of the Long Shields programme in 2013, participating farmers in Tsholotsho and Victoria Falls recorded an overall decrease in livestock loss to lions compared to non-participating farmers. We suggest this is because participating famers were alerted to approaching lions via the Long Shields programme and consequently moved their livestock to areas with lower depredation risk. In addition, using vuvuzelas to haze lions that crossed over the Park boundary into village settlements, encouraging farmers to report missing livestock to prevent attacks, and assisting them to repair livestock kraals to avoid night-time predation may have also contributed to a decline in livestock depredation.

TABLE 1 Lion *Panthera leo* mortality in north-western Zimbabwe before (2008–2012) and after (2013–2017) the introduction of the Long Shields programme across three communities. Numbers are presented separately for collared and non-collared individuals.

	Mabale				Tsholotsho				Victoria Falls				*Total*	
	Before		After		Before		After		Before		After		Before	After
Collared?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No		
Shooting[1]	1	2	3	1	1	7	2	4	0	5	0	5	16	15
Snare	2	1	1	0	2	6	0	0	0	0	0	0	11	1
Poison	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Spear	1	0	0	0	0	0	0	1	0	0	0	0	1	1
Total	4	3	4	1	4	13	2	5	0	5	0	5	29	17

[1]Problem animal control by officials.

Although our overall findings indicate that losses to lions have decreased since the implementation of the Long Shields programme, the impact of the programme varied across study sites. Participating farmers in Mabale experienced an increase in livestock depredation over the course of the study. The reasons are difficult to discern, but this could be related to several large-scale demographic factors (e.g. increase in human population and land-use change) that were beyond the scope of the study design. In all three sites, distinct social norms and regulations dictate local livestock grazing practices (Sibanda et al., 2020). Farmers in Tsholotsho and Victoria Falls graze their livestock in specifically designated rangeland areas located within the communal lands. In contrast, farmers in Mabale graze their livestock within Sikumi Forest Land, a wildlife area where an agreement with the local forestry authorities allows farmers to graze cattle up to 3 km inside the forest boundary (Guerbois et al., 2013). The risk of livestock depredation by lions is generally higher in these wildlife areas (Valls-Fox et al., 2018). Further, Guerbois et al. (2013) reported that the human population density in Mabale has been rising rapidly, with a 60% increase during 2000–2010. As a consequence of this increase in the human population and the conversion of land into crop fields, the number of farmers who depend on Sikumi Forest Land for water and grazing is increasing (Perrotton, 2015). There are reports that farmers are now venturing up to 7 km into the wildlife area to find high-quality pasture, thereby visiting areas that are frequently used by lions (Valls-Fox et al., 2018). The observed increase in livestock depredation rates in Mabale may thus be attributed to the expansion of the local human population and the cascading implications for livestock management practices that bring livestock and lions into closer contact.

Another possible reason for the increased livestock losses in Mabale could be the local implementation of measures to control so-called problem animals. Our intervention relied on placing GPS collars on individual lions in a pride to determine when the pride was close to human settlements, so that warning messages could be sent to farmers and hazing initiated (Petracca et al., 2019). However, if lions continued to pose a threat, often after repeated attacks on livestock, the communities could request assistance from the local authorities who may legally shoot and kill individual lions classified as problem animals. The shooting of lions as a control measure occurred throughout our study period, with a total of 15 lions being shot since the inception of the Long Shields programme (Mabale = 4, Tsholotsho = 6, Victoria Falls = 5; Table 1). However, in Mabale the majority (75%, 3 individuals) of these lions were fitted with GPS collars (50% of the collared individuals in the area). This compromised our ability to effectively monitor the movement of livestock-predating lions and hindered the implementation of the early warning system in that area. We thus recommend that conservationists consider possible differences or risks across study sites when designing interventions.

Our findings indicate that in Tsholotsho, livestock losses to lions were reduced after programme implementation even for non-participating farmers (Fig. 2). We suggest three possible reasons: (1) lions may have been generally deterred from using communal land, which also benefited non-participating villages, (2) the exchange of alert messages warning of approaching lions prompted non-participating farmers to move their grazing livestock to a lower-risk area, or (3) the efficacy of using night-time kraals was communicated by participating farmers to their non-participating counterparts (Sibanda et al., 2021). These findings suggest that the impacts of the Long Shields programme may have expanded beyond the initial target area. Similar effects were observed in Assam, India, where farmers who did not participate in a community-based human–elephant conflict mitigation programme recorded a reduction in crop losses after they exchanged information on crop protection measures with peers who were programme participants (Zimmermann et al., 2009). Future research should examine communication channels and broader social networks to gain further insights into this sharing of information amongst communities (Sibanda et al., 2021).

The number of lions killed in retaliation for depredation decreased by 41% after the start of the Long Shields

programme in 2013. This includes a reduction in the illegal killing of lions using wire snares, probably because lions found in proximity to villages were deterred by non-lethal methods (Petracca et al., 2019). Farmers may also perceive the actions of their local Community Guardians as effective in mitigating depredation risk and therefore be less inclined to take retaliatory action themselves. In addition, for fear of repercussions or arrest by wildlife authorities, farmers may have been hesitant to illegally kill lions that they knew were being closely monitored. Our findings are comparable to those in Amboseli, Kenya (Hazzah et al., 2014), where the retaliatory killing of lions by farmers decreased by almost 99% 8 years after the Lion Guardian programme was implemented. Involving local people in lion conservation and recruiting influential young warriors as Lion Guardians were factors contributing to the decline in lion killings. Active participation of local communities in decision-making and planning can increase trust and foster a sense of stewardship towards carnivores (Morehouse et al., 2020). Collaborative approaches can also ensure that the aims, actions and outcomes of interventions are relevant for all stakeholders and aligned with the interests of the community (Chase et al., 2004). Similarly, in the Long Shields programme, local farmers were directly involved in selecting the Community Guardians and informing the design of the programme. The importance of this approach, and the resulting outcomes, cannot be overstated.

We found that the legal shooting of lions by government officials remained constant over time, suggesting that authorities did not change their policy or behaviour in response to the implementation of the Long Shields programme. This may reflect a situation in which government officials shoot perceived problem animals to appease affected communities (Hoare, 1995), in a so-called ritual palliative response, which has been described as common in addressing human–elephant conflict (Hoare, 2012). In our study area, this may negatively affect local lion populations. We therefore recommend further research into this aspect of lion management, including examining the barriers to and opportunities for policy change, and related capacity-building for behaviour change, amongst wildlife managers.

We found only a weak correlation between the number of livestock depredated by lions and the number of retaliatory lion killings by farmers. This suggests that farmers do not necessarily kill lions that attack their livestock. This could be attributed to farmers being aware that killing lions is illegal and punishable by imprisonment. In addition, most farmers lack the skills and weapons to kill a lion, and the killing of lions is not a strong cultural tradition in this area (unlike in other areas in East Africa; Loveridge et al., 2010).

Although our findings are encouraging, we acknowledge there are some limitations. The allocation of villages to the Long Shields programme was not random: we focused the programme on villages that had experienced higher levels of livestock depredation. Non-random treatment allocation may result in regression to the mean, a statistical phenomenon that makes natural variations in data appear like a real change (Barnett et al., 2005). However, in our study this is not likely to be a problem because villages that experienced higher levels of livestock depredation had been in this situation for some time prior to the commencement of the study; they did not happen to experience high impacts at the time of the study.

Conclusion

Using farmers' reports of livestock depredation and retaliatory killing of lions, we examined the effectiveness of the community-based Long Shields Community Guardians programme, which aims to promote human–lion coexistence. Overall, we found that participating farmers reported a significant reduction of livestock loss to lions, compared to those not included in the programme. The primary mechanism resulting in the decrease in livestock depredation was the alerting of farmers to the presence of lions, and farmers consequently moving their livestock to areas of lower risk (Sibanda et al., 2021). The Long Shields programme did not have a detectable effect on depredation by other carnivores because it was designed specifically to prevent incidents involving lions. As hypothesized, the number of retaliatory lion killings by farmers was reduced by 41% since the inception of the Long Shields programme, which we attribute to the alerts farmers received of approaching lions and the fact that lions were hazed to encourage them away from human settlements (Petracca et al., 2019). Our findings indicate that the Long Shields programme, and particularly the collaborative and participatory approach used for its development, is an effective conservation model that could be applied at a larger scale to promote human–lion coexistence. We conclude that livestock depredation by lions can be effectively reduced through locally relevant community-based approaches, and this conservation model could be implemented in other contexts to address the negative impacts of lions on people and vice versa.

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Author contributions Study design and fieldwork: LS, EvdM, BD, LJM, JEH, RHP, AJL; data analysis and writing: LS, PJJ, EvdM, CH, DWM, AJL.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. Our experimental design was approved by the Social Science and Humanities Interdivisional Research Ethics Committee of the University of Oxford (ref. R52851/RE001), and we acquired research permits from the Research Council of Zimbabwe (ref. 02786) and the Zimbabwean Ministry of Rural Development ref. (P/13/3).

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