

REVIEW

A global view on evidence-based effectiveness of interventions used to protect livestock from wild cats

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Abstract

Rapid population declines of wild cats (family Felidae) are often related to widespread conflicts with people over the livestock depredation they are causing. In spite of increasing literature on wild felids, there is no overview on the evidence-based effectiveness of livestock protection interventions in reducing depredation inflicted by these animals. We collected and analyzed 92 cases from 57 publications describing the percentage of damage reduction from the application of 11 interventions to 10 felid species. We found that the effectiveness of interventions differed significantly between species. Interventions tested for cheetahs (*Acinonyx jubatus*), Iberian lynx (*Lynx pardinus*) and snow leopards (*Panthera uncia*) were very effective, reducing damage by 70–100% due to species shyness, good fit of interventions to these species and local conditions, and strong social involvement. The most variable and often the lowest effectiveness of interventions was found for leopard (*Panthera pardus*), puma (*Puma concolor*) and caracal (*Caracal caracal*), which are more common and tolerant to humans. In other felids, interventions were generally effective, but some of them reportedly failed because of local contexts and intervention performance. Much more effort is required to invigorate the research of intervention effectiveness in little studied species and regions.

KEYWORDS

carnivore, evidence-based conservation, felid, human-wildlife conflict, intervention, predator

1 | INTRODUCTION

Livestock depredation by wild cats (family Felidae) causes widespread conflicts with rural people and is responsible for their rapid population declines worldwide (Loveridge, Wang, Frank, & Seidensticker, 2010). The felids most responsible for depredation are the seven big

cats: lion (*Panthera leo*), tiger (*P. tigris*), jaguar (*P. onca*), leopard (*P. pardus*), snow leopard (*P. uncia*), puma (*Puma concolor*) and cheetah (*Acinonyx jubatus*), as well as the two smaller cats—Eurasian lynx (*Lynx lynx*) and caracal (*Caracal caracal*) (Inskip & Zimmermann, 2009; Khorozyan, Ghoddousi, Soofi, & Waltert, 2015; Krafte Holland, Larson, & Powell, 2018). Small felid species may occasionally kill poultry and small livestock (Loveridge et al., 2010), but generally they are not perceived as a

This study explores the effectiveness of diverse lethal and nonlethal interventions in protecting domestic livestock from wild cat attacks.

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problem and only Iberian lynx (*Lynx pardinus*) raises some concern (Garrote et al., 2013, 2015).

Due to their charisma and key ecological roles, felids responsible for conflicts have been subject to high research effort, except for caracal (Brodie, 2009; Macdonald et al., 2015). However, this research often does not meet practical conservation needs (Balme, Lindsey, Swanepoel, & Hunter, 2014) and surprisingly little is known about the evidence-based effectiveness of lethal and nonlethal interventions in reducing depredation by felids and other carnivores (Khorozyan & Waltert, 2019a, 2019b; Van Eeden et al., 2018). While the descriptions of depredation patterns and livestock protection interventions are numerous in the scientific literature, evidence-based intervention effectiveness is estimated very sporadically and its meta-analyses aiming to make broad inferences began only recently (Eklund, López-Bao, Tourani, Chapron, & Frank, 2017; Khorozyan & Waltert, 2019a, 2019b; Miller et al., 2016; Treves, Krofel, & McManus, 2016; Van Eeden et al., 2017; Van Eeden et al., 2018). All these reviews cover carnivores in general and conclude that available data are insufficient and methods are not standardized, but uniform framework analysis may offer a pathway to determine the best interventions (Khorozyan & Waltert, 2019a). Taxonomically focused studies of evidence-based intervention effectiveness are still nascent (Bruns, Waltert, & Khorozyan, 2020; Khorozyan & Waltert, 2020).

We are aware of only one review which summarized information about the effectiveness of interventions aimed to reduce livestock losses to five species of big cats (genus *Panthera*; Krafte Holland et al., 2018). However, this study evaluated the effectiveness indirectly using the surrogate index of effectiveness called “success ratio,” not by means of robust statistical effectiveness metrics, which were already published in regard to felids and other carnivores (Eklund et al., 2017; Miller et al., 2016; Van Eeden et al., 2017). As it appears from its name, evidence-based effectiveness of interventions has been evaluated from quantitative evidence, which is based on experimental work with treatment (with interventions) and control or counterfactual (without interventions) samples (Van Eeden et al., 2018). These tests allow to estimate the effectiveness of interventions by means of such metrics as the relative risk (Eklund et al., 2017; Khorozyan, 2020; Khorozyan & Waltert, 2019a, 2019b, 2020), odds ratio (Eklund et al., 2017), magnitude of change (Khorozyan, 2020; Miller et al., 2016) or Hedges’ *d* (Van Eeden et al., 2017). In contrast, the success ratio is a subjective ratio of the number of papers that evaluated and recommended interventions to the number of papers that only evaluated these (Krafte Holland et al., 2018). Recommended interventions are not effective by default

and only evidence-based research can make sound inferences (Van Eeden et al., 2018). For example, livestock enclosures known as bomas in East Africa and kraals in southern Africa are widely acclaimed as a solution to curb livestock losses to depredation, but only fortified ones are effective in practice and poorly constructed enclosures have no effect or even become counterproductive (Kolowski & Holekamp, 2006; Sutton et al., 2017; Weise et al., 2018).

Rigorous estimation of intervention effectiveness has come to biodiversity conservation from evidence-based medicine, which is well ahead of conservation in experimental methodology and practice (Pullin & Knight, 2001). The need for effective solutions in conservation is higher than ever before, especially in regard to conflict-causing felids most of which are globally or regionally threatened (IUCN, 2020). Therefore, a meta-analysis of evidence-based effectiveness of different interventions used to protect livestock from felids can be an important contribution enabling to better understand what works and what does not for the species of interest. We agree that the requirement for robust study designs is important (Ohrens, Bonacic, & Treves, 2019; Treves, Krofel, Ohrens, & Van Eeden, 2019), but believe that it should not be an obstacle for the meta-analyses when conditions are not optimally met. Restricting ourselves to the best available data greatly reduces the sample size and adds geographical, selection and publication biases (Haddaway, Woodcock, Macura, & Collins, 2015). In case of felids, especially those responsible for conflicts, every study with intervention applications and effectiveness data should be incorporated into research. Online resources are irreplaceable in finding grey literature such as reports, professional newsletters, theses and dissertations, which are often neglected but can unveil new information (Haddaway et al., 2015).

In this study, we make the first attempt to estimate and discuss the evidence-based effectiveness of lethal and nonlethal interventions to protect livestock from wild cat species using the relative risk as an effectiveness metric. Our primary goal was to determine how effectiveness varies between interventions and felid species. As published information about evidence-based effectiveness of interventions against carnivores is naturally limited (Eklund et al., 2017; Khorozyan & Waltert, 2019a, 2019b; Miller et al., 2016; Treves et al., 2016; Van Eeden et al., 2017), we refrained from the analysis of impacts of other factors on intervention effectiveness. We carried out a comprehensive search of scientific peer-reviewed and grey literature and performed a meta-analysis to accomplish this. We anticipate that this study will serve as a useful practical guide for felid researchers and conservationists worldwide.

2 | MATERIALS AND METHODS

2.1 | Data collection

We applied several approaches to collect as much as possible information about the effectiveness of interventions against wild cats. First, we used relevant publications from the known reviews of the evidence-based effectiveness of carnivore-targeted interventions (Eklund et al., 2017; Khorozyan & Waltert, 2019a, 2019b; Miller et al., 2016; Treves et al., 2016; Van Eeden et al., 2017). Then we read all issues of the journal Conservation Evidence (www.conservationevidence.com, 2004–2019) and the newsletters Carnivore Damage Prevention News (www.lcie.org and www.medwolf.eu, 2000–2005 and 2014–2018) and Cat News (www.catsg.org, 1984–2019). Further, we read additional papers from Human-Wildlife Conflict Resource Library of the IUCN/SSC Human-Wildlife Conflict Task Force (www.hwctf.org) placed under the topics “Electric fences,” “Other barriers,” “Livestock guarding,” “Deterrents and repellents” and “Translocation.” Lastly, we searched for relevant publications published in 1970–2019 through Web of Science (www.webofknowledge.com) and IUCN/SSC Cat Specialist Group Digital Library (www.catsg.org) using the common or Latin names of 38 recent felid species in combination with *predat* to address (de)predation and eff* to target “effectiveness,” “efficiency,” “efficacy” or “effect.” The search ended in late October 2019.

We retrieved only publications that dealt with interventions aiming to reduce livestock depredation by wild cats. We excluded the studies which (a) Implied the effectiveness from correlation research, for example, results such as “as there are more electric fences, there are less livestock losses,” and which did not conduct special (quasi-)experimental or comparative research between treatment and control samples; (b) Were carried out in captive conditions; (c) Lumped data for felids and non-felid carnivores; (d) Estimated effectiveness from owner perceptions and not from quantitative metrics; (e) Did not contain sufficient information to measure the effectiveness of interventions; or (f) Were irrelevant to livestock depredation, for example, applied fencing to separate humans and wildlife, including felids, or used translocation to establish new populations.

We compiled a dataset of cases where each case described an effect of a particular intervention on the protection of a particular livestock species from a particular felid species in a site (Bruns et al., 2020; Khorozyan & Waltert, 2019a, 2019b, 2020). When unavoidable, we also included combinations of interventions (Jamwal, Takpa, & Parsons, 2019; Quigley et al., 2015) and several felids per study (Zarco-González & Monroy-Vilchis, 2014).

We considered as livestock all domestic species that were described in source publications whether they were specified (cattle, sheep, goats, swine, yaks, horses, llamas, alpacas, poultry and dogs) or not (livestock in general). We also included semi-domesticated fallow deer (*Dama dama*) and game species kept together with livestock (Angst, 2001; Schumann, Schumann, Dickman, Watson, & Marker, 2006). We considered cases regardless of durations of intervention applications.

2.2 | Data analysis

We grouped interventions into aversion training, husbandry, lethal control, noninvasive management, invasive management, and their combinations (Table 1). We quantified the effectiveness of interventions as the percentage of damage reduction (DR):

$$DR = 100 \times (1 - RR) = 100 \times \left(1 - \frac{A/N_t}{B/N_c}\right)$$

where *RR* is the relative risk of damage, *A* is the metric of damage with a given intervention, *B* is the metric of damage without the intervention, *N_t* is the treatment sample size (e.g., number of livestock exposed to the intervention) and *N_c* is the control sample size (e.g., number of livestock not exposed to the intervention or before the intervention is applied). *RR* is a robust effectiveness metric, which is widely used in evidence-based medicine (Stare & Maucort-Boulch, 2016) and conservation (Bruns et al., 2020; Eklund et al., 2017; Khorozyan & Waltert, 2019a, 2019b, 2020). It represents a ratio of the probability of damage risk with the intervention to the probability of damage risk without the intervention. Interventions are counter-productive at *RR* > 1, ineffective at *RR* = 1, effective at *RR* < 1 and most effective at *RR* = 0 when *A* = 0. A negative *DR* means that *RR* > 1 and that a given intervention increases damage instead of decreasing it. We could not calculate *RR* and *DR* when there was no damage in control samples, that is, *B* = 0, for example, when Angst, Hagen, and Breitenmoser (2002) used protective collars against Eurasian lynx or Schumann et al. (2006) tested swing gates against caracals and black-footed cats (*Felis nigripes*). When studies applied a before-after approach, that is, the same population sample was considered before and after an intervention was applied, we assumed *N_t* = *N_c* unless changes in a target population were explicitly reported by the authors (Bauer, de Iongh, & Sogbohossou, 2010; Cavalcanti, Crawshaw, & Tortato, 2012; Rust, Whitehouse-Tedd, & MacMillan, 2013). We used the percentages of *A/N_t* and *B/N_c* in calculating *DR* when they were provided (Fernando, 2016; Guerisoli et al., 2017; Herfindal

TABLE 1 The categories and descriptions of livestock protection interventions against wild cats used in this study

Categories	Description
Aversion training	Acoustic deterrents: Human voices, animal and mechanical sounds, firecrackers, discharging firearms and bell collars Chemical deterrents: Pepper spray and lithium chloride Physical deterrents: Nonlethal projectiles Visual deterrents: Light, fire and scarecrows Spiritual deterrents: Mantra chanting
Husbandry	Electric fences: Fences with charged metal wires which produce electric shocks upon a contact Enclosures: Night sheds, fortified bomas/kraals, mesh coverage of openings, swing gates, and wire-fenced coops for poultry Guarding animals: Use of dogs, llamas, water buffaloes and Creole cattle breeds Herding: Presence of shepherds Mixed husbandry interventions: Guarding animals and enclosures
Invasive management	Translocation: Moving culprit individuals away from conflict sites Geofence: a system mediated by GPS collars fixed on carnivores to alert villagers of approaching individuals
Lethal control	Recreational hunting, preventive hunting or selective removal (trapping, shooting and use of poisonous protection collars)
Mixed interventions	Enclosures and capacity building
Noninvasive management	Calving control: Herd management to shorten the calving period Capacity building: Compensations, insurance and local professional training

et al., 2005; Kolowski & Holekamp, 2006). If studies reported the odds ratio (Woodroffe, Frank, Lindsey, Ole Ranah, & Romañach, 2007), we took it as an equivalent of RR because the odds ratio is similar to RR when events are rare (Stare & Maucort-Boulch, 2016), as in the case of depredation.

We used the metrics of damage described in source publications: percentage of farms with livestock loss, percentage of livestock loss to all livestock, annual financial loss from livestock loss, number of carnivore attacks, number of study units attacked by carnivores, number of livestock killed, number of mass killing events, number of carnivores killed, number of carnivores entering a

study unit, number of carnivores resuming livestock-killing after translocation, number of carnivores returning after the use of deterrents, and number of carnivore visitations.

We applied nonparametric Mann–Whitney and Kruskal–Wallis tests to compare DR across interventions and wild cat species and used one-sample χ^2 test for frequency comparisons in IBM SPSS 26.0 (IBM Corp., USA). We measured the 95% confidence interval (CI) of the median DR by bootstrapping with 1,000 repetitions in iNZight 3.2.1 (University of Auckland, New Zealand). We used the standard error (SE) to describe the variation of the mean.

3 | RESULTS

Our search yielded 158 publications which described interventions to protect livestock from wild cats and reduce depredation. Out of these, 101 publications met the exclusion criteria and we used only 57 publications for further analysis. Our dataset represented 92 cases, mostly in relation to leopard ($n = 21$), lion ($n = 18$) and puma ($n = 13$) (Table 2). This difference was statistically significant ($\chi^2 = 50.522$, $p < .001$). Ninety cases described single felid species and two cases were about the application of interventions to two felids lumped together (puma and jaguar). Intervention categories were dominated by husbandry ($n = 51$ cases; $\chi^2 = 109.391$, $p < .001$). Out of 11 interventions, the most common interventions were guarding animals ($n = 22$), enclosures ($n = 21$), deterrents ($n = 17$) and translocation ($n = 10$) ($\chi^2 = 76.826$, $p < .001$; Table 2).

The estimates of DR differed significantly between felid species (Kruskal–Wallis $H = 20.154$, $p = .028$), and marginally between intervention categories ($H = 10.330$, $p = .066$) and between interventions ($H = 17.019$, $p = .074$). As shown in a heatmap (Figure 1), livestock protection from cheetahs was significantly more effective than from leopards ($U = 34.0$, $p = .006$), lions ($U = 43.5$, $p = .048$), pumas ($U = 22.0$, $p = .013$) and marginally from caracals ($U = 1.5$, $p = .063$). Effectiveness was significantly higher in jaguars vs. leopards ($U = 43.0$, $p = .042$), which was in line with marginally higher effectiveness in jaguars and pumas together vs. leopards ($U = 4.0$, $p = .061$) and pumas alone ($U = 2.0$, $p = .059$). Livestock protection from snow leopards was significantly more effective than that from leopards ($U = 12.0$, $p = .025$) and pumas ($U = 6.0$, $p = .023$) and marginally more effective than that from caracals ($U = 0.0$, $p = .060$). Additionally, effectiveness was marginally higher in interventions applied to lions vs. leopards ($U = 124.5$, $p = .068$). As a result, interventions were

TABLE 2 Distribution of 92 cases used in this study to evaluate the evidence-based effectiveness of livestock protection interventions against wild cats

Interventions	n	Caracal	Cheetah	Eurasian lynx	Iberian lynx	Jaguar	Jaguar and puma	Leopard	Lion	Puma	Snow leopard	Tiger
Calving control	1									1		
Capacity building	7					1			4		1	1
Deterrents	17						2	6	3	2		4
Electric fences	5			1	1	3						
Enclosures	21		1		1	1		6	8	3	1	
Geofence	1								1			
Guarding animals	22	2	7	2		1		5		5		
Herding	2			1				1				
Lethal control	3			2							1	
Mixed ^a	3					1					2	
Translocation	10		1			1		3	2	1		2
Total	92	2	9	6	2	8	2	21	18	13	4	7

Note: Sample size is denoted as n.

^aMixed interventions include enclosures and capacity building (n = 2, Jamwal et al., 2019) and guarding animals and enclosures (n = 1, Quigley et al., 2015).

much less effective against leopards, pumas and caracals than against many other felids (Figures 1 and 2).

The effectiveness of individual interventions in felid species is illustrated in Figure 2. Caracal studies included only the effectiveness of guarding animals, which was moderate (median DR = 61.0%, 95% CI = 50.0–72.0%). All interventions against cheetahs were effective, namely enclosures (100%), guarding animals (99.8%, 72.0–100%) and translocation (100%). In Eurasian lynx, the most effective interventions were enclosures (100%), guarding animals (93.0%, 85.9–100%) and herding (64.5%), but lethal control was ineffective (24.4%, –2.2% to 50.9%). Electric fences and enclosures were effective to curb depredation by Iberian lynx by 100% and 90.9%, respectively. Livestock was effectively protected from jaguars by means of capacity building (100%), enclosures (83.3%), guarding animals (100%) and their combination (100%), but the impact of electric fences was controversial (100%, –42.9% to 100%) and translocation was ineffective (0.0%). Jaguars and pumas were effectively kept away from livestock by deterrents (100%). In puma, only calving control was very effective (100%), translocation was less effective (66.7%), lethal control was ineffective (1.4%) and other interventions ranged from ineffective to effective (deterrents—62.5%, 25.0–100%; enclosures—63.4%, –311.1% to 85.9%; guarding animals—71.4%, –873.9% to 85.7%). In leopard, deterrents (–8.5%, –40.9% to 38.1%) and herding (–1,140.0%) were ineffective and other interventions varied greatly from ineffective to effective, such as enclosures (94.6%, –78.7% to 100%), guarding animals (62.5%, –246.7% to 100%) and translocation (25.0%, –56.6% to 75.0%). Livestock protection from lions was most effective with enclosures (96.4%, 63.5–100%), less effective with geofence (58.7%) and translocation (70.4%, 65.8–75.0%), and varied from ineffective to effective with capacity building (65.1%, 18.8–100%) and deterrents (60.2%, –97.7% to 96.2%). Capacity building (100%), enclosures (100%) and their combinations (91.2%, 90.9–91.5%) were effective to protect livestock from snow leopards. Application of capacity building (100%) and translocation (83.3%, 66.7–100%) was effective against tiger attacks, but the impact of deterrents was variable (31.3%, –322.2% to 100%).

4 | DISCUSSION

In this meta-analysis, we found the evidence-based effectiveness of livestock protection interventions to vary between the 10 felid species (Figures 1 and 2). This may guide researchers and practitioners in considering the (in)effectiveness of particular interventions for their target species. Earlier, Krafte Holland et al. (2018) compared



FIGURE 1 A heatmap showing the difference of the evidence-based effectiveness of all tested interventions between wild cat species based on the results of this study. In the pairs of significant and marginally significant relationships, effectiveness is higher in a column species than in a row species

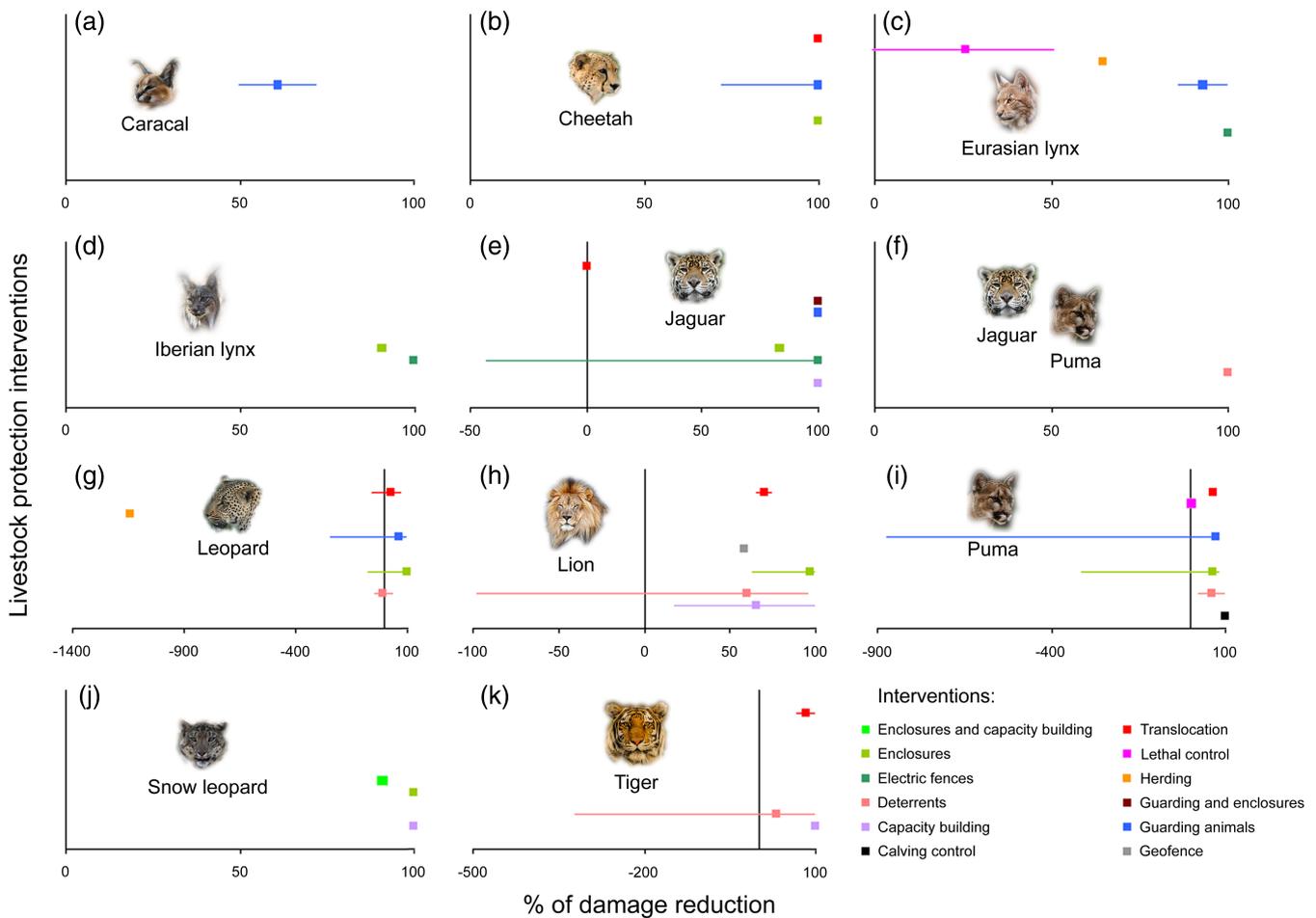


FIGURE 2 The medians and 95% confidence intervals of the % of damage reduction resulting from the application of livestock protection interventions to wild cats. Interventions are aligned on the same levels throughout the graphs

the effectiveness only between interventions and not between the five big cat *Panthera* species what makes our results incomparable. We re-analyzed 39 papers used by

these authors in their study and found out that only eight of them provide quantitative information on evidence-based effectiveness in compliance with our criteria (see

Section 2). Seven of these eight papers were used in our study as well (Athreya, Odden, Linnell, & Karanth, 2010; Bauer et al., 2010; Goodrich & Miquelle, 2005; MacLennan, Groom, Macdonald, & Frank, 2009; Tumenta, de Jongh, Funston, & Udo de Haes, 2013; Weilenmann, Gusset, Mills, Gabanapelo, & Schiess-Meier, 2010; Woodroffe et al., 2007).

4.1 | Cheetah, Iberian lynx and snow leopard: The highest effectiveness of interventions

All interventions tested against cheetahs, Iberian lynx and snow leopards were very effective by reducing damage by 70–100%.

Depredation by cheetahs or their killing were successfully prevented by guarding dogs, swing gates and translocation. Being physically delicate and naturally shy, cheetahs tend to retreat when facing large dogs attentive and protective to their flocks (Potgieter, Kerley, & Marker, 2016; Rust et al., 2013). Cheetahs can enter livestock farms through the passes made underneath the fence by digging species, but with swing gates this is not possible as diggers get access through the swing gates and do not dig (Schumann et al., 2006). In a single translocation study, three out of 23 translocated individuals were livestock raiders and none of them resumed depredation implying a success (Weise et al., 2015a). However, this result should be treated with great caution as many cheetahs, including one livestock raider, died after translocation from human persecution or natural causes and another livestock raider suffered from health problems. Also, farmers from whose lands cheetahs were removed began to experience new conflicts after 1–2 years and new translocations were requested (Weise et al., 2015a). All this makes translocations a risky endeavor with a short-term effect on cheetahs.

In Iberian lynx, sheep and poultry losses were very effectively prevented by using electric fences in grazing plots and mesh in coops, and only incomplete modifications allowed lynx to attack coops (Garrote et al., 2013, 2015).

Killing of snow leopards by pastoralists ceased due to the implementation of a livestock insurance program (Gurung et al., 2011) and livestock losses were reduced completely or almost completely by means of the use of night sheds, local professional training programs and covering of roof and wall openings in sheds by mesh (Jamwal et al., 2019; Kuksin & Kuksina, 2009). An incentive program that motivated local people to sell high-valued hand-crafted wool products succeeded to reduce the killings of snow leopards to nil (Mishra et al., 2003).

Well-organized and socially compliant management of capacity building programs was the main reason of a sharp decline in livestock losses and conflicts with snow leopards, and high effectiveness of night sheds and mesh closure demonstrates how affordable and locally available simple approaches may provide a solution for these big cats.

4.2 | Eurasian lynx, jaguar, lion and tiger: Most interventions are effective, but some fail

In most of the other felids, interventions were generally effective, but some of them were unsuccessful (Figure 2). The use of electric fences, shepherds and guarding dogs was effective against Eurasian lynx, but selective removal and recreational hunting was not able to reduce sheep losses significantly due to the replacement of removed individuals by newcomers (Herfindal et al., 2005; Stahl, Vandel, Herrenschmidt, & Migot, 2001). Low effectiveness of removal is particularly striking in depredation hotspots which have persistently favorable conditions for livestock killing, such as grazing near forests (Stahl et al., 2001). Also, hunting is impractical because of low depredation rates by lynx and low numbers of sheep saved by lynx removal (Herfindal et al., 2005).

Depredation by jaguars or their killing were significantly reduced in most electric fence applications and also due to the use of guarding animals (water buffalo *Bubalus bubalis*, Creole cattle breed and donkeys), various sounds and scarecrows (when lumped with pumas), and compensations for livestock losses (Quigley et al., 2015; Rosas-Rosas & Valdez, 2010; Zarco-González & Monroy-Vilchis, 2014). However, a single translocation effort was unsuccessful as all translocated jaguars returned home and resumed livestock killing (Rabinowitz, 1986) and one test of using electric fences was ineffective because of incomplete fence coverage, escalated depredation rates during the study period and a possible sampling bias (Cavalcanti et al., 2012).

Livestock losses to, or killing of, lions were effectively reduced by the use of night sheds, strobe light, siren sounds, fortification of bomas by metal chains, stones or local wood materials, translocation, geofence (a device triggering alarm SMS messages when lions cross it) and some compensation programs (Bauer et al., 2010; Bauer, Müller, Van Der Goes, & Sillero-Zubiri, 2017; Hazzah et al., 2014; Lesilau et al., 2018; Lichtenfeld, Trout, & Kisimir, 2015; Stander, 1990; Sutton et al., 2017; Tumenta et al., 2013; Walking for Lions, 2016; Weise et al., 2018, 2019). Compensations become ineffective in preventing lion killing when they fail to improve animal husbandry

or stop payments in culturally sensitive indigenous societies (Hazzah et al., 2014; MacLennan et al., 2009). Moreover, bells put on cattle to avert lion attacks by their ringing do instead provoke attacks by creating an association between bell sounds and prey availability (Loveridge et al., 2017).

For tiger, the most effective interventions were translocation, compensations, visual (light), acoustic (firecrackers) and chemical (lithium chloride, pepper) deterrents (Aziz, 1998; Goodrich & Miquelle, 2005; Miller et al., 2011; Salkina, 2000). At the same time, airshots and firecrackers may also fail to deter tigers (Goodrich, Seryodkin, Miquelle, & Bereznuik, 2011; Salkina, 2000).

4.3 | Leopard, puma and caracal: Low effectiveness and tolerance to humans

Effectiveness of livestock protection interventions against leopard, puma and caracal, which are most common and tolerant to humans, was found to be the most variable and often the lowest (Figures 1 and 2). Leopard attacks were effectively prevented only by some applications of guarding dogs, acoustic deterrents (beating of aluminum sheets), fortified bomas, night sheds, swing gates, and translocation to low-density areas (Athreya, 2012; Fernando, 2016; Lichtenfeld et al., 2015; Potgieter et al., 2016; Schumann et al., 2006; Weise et al., 2015b; Woodroffe et al., 2007). Dogs and shepherds are futile against leopards if they only raise alarm and cannot properly protect their stock (Athreya, 2012; Khorozyan et al., 2017). Leopard translocations are ineffective when individuals are moved to the areas with medium to high density of conspecifics, which can kill the intruders or expose them to more conflicts with humans by ousting to marginal habitats (Athreya et al., 2010; Weilenmann et al., 2010). Even when translocation is considered successful in terms of a low recurrence of livestock raiding by removed leopards, depredation can be initiated by newcomers who have arrived to occupy vacant tenures (Weise et al., 2015b). Bomas made from sturdy poles are easily penetrable for leopards and thus counter-productive against leopard attacks in comparison with bush bomas (Kolowski & Holekamp, 2006). Moreover, leopards appear to be indifferent to scarecrows, fire, flash lights and chanting mantras what makes these deterrents ineffective (Fernando, 2016; Woodroffe et al., 2007).

The most effective interventions against pumas were calving control (shortening of the period of calving and calf availability) and deterrents including diverse sounds and scarecrows (when lumped with jaguars) and strobe lights (Breck et al., 2011; Ohrens et al., 2019; Zarco-González & Monroy-Vilchis, 2014). However, the use of nonlethal

projectiles was ineffective to ward off the pumas which demonstrated flexible and adaptable behavior in a human-dominated landscape (Alldredge, Buderman, & Blecha, 2019). The effectiveness of guarding dogs and night sheds against pumas varied from very high to nil depending on whether losses were measured in absolute numbers or as percentages of living stock, what may produce disparate estimates if treatment and control samples are very different (Andelt, 1999; Andelt & Hopper, 2000; Guerisoli et al., 2017; Mazzolli, Graipel, & Dunstone, 2002). Even when night sheds are effective, farmers can be reluctant to use them if they prefer to hunt down carnivores, show negative attitudes to carnivores and conservation, and have a lack of knowledge, resources and motivation to improve husbandry practices (Guerisoli et al., 2017). In a single study, guarding llamas (*Lama glama*) were counter-productive against pumas as these camelids are naturally aggressive and effective mostly towards canids (Meadows & Knowlton, 2000). Remedial sport hunting failed to reduce depredation by pumas by increasing immigration of young males (Peebles, Wielgus, Maletzke, & Swanson, 2013).

In regard to livestock killing by caracals, the use of guarding dogs reduced the proportion of farms with conflicts by 72% and the numbers of caracals killed in retaliation by 50%, what is a modest result due to high adaptability and resilience of this felid to human pressures (Potgieter et al., 2016).

4.4 | What makes interventions effective

Our study demonstrates that the evidence-based effectiveness of interventions depends on local applications and target felid species. But can we identify the key characteristics that make interventions successful in broader terms? The duration of the period during which interventions remain most effective is an important characteristic of interventions (Khorozyan & Waltert, 2019b). Even though we did not address this parameter explicitly, it is clear that the effectiveness of interventions used against wild cats has been determined by their performance rather than by duration. Among noninvasive management interventions, capacity building programs are effective only when they properly address local needs and expectations in balance with conservation issues (Gurung et al., 2011; Hazzah et al., 2014; MacLennan et al., 2009; Rosas-Rosas & Valdez, 2010). Calving control is very effective as it shortens the calving season and thus reduces the period of availability of calves as an easy prey (Breck et al., 2011), but more studies are required to test it in different settings. Invasive interventions, including translocations and geofences (Table 1), are expensive and

intrinsically risky. Translocations are effective when animals are moved to remote areas with low densities of conspecifics, sufficient availability of natural prey, and minimal scopes of potential conflicts with local people (Athreya et al., 2010; Weilenmann et al., 2010; Weise et al., 2015b). Development, standardization and dissemination of successful translocation protocols are of utmost importance (Weise et al., 2015b). It is premature to judge about the effectiveness of geofences as we are aware of only one application to lions, but apparently they can be effective when many or, ideally, all local livestock-killing individuals are radio-collared and tracked, what is often unrealistic (Weise et al., 2019).

Husbandry interventions are most commonly used by local people, but their effectiveness is not always as high as expected (Krafte Holland et al., 2018). Guarding dogs work well against felids and other carnivores if they are properly cared and trained for trustworthiness, protectiveness and attentiveness (Potgieter et al., 2016; Rust et al., 2013), but become a nuisance otherwise (Khorozyan et al., 2017). Other animals also can protect livestock, but with some limitations: llamas, alpacas and donkeys have a much stronger dislike for canids, but still can effectively protect from felids in some sites, and buffaloes need permanently wet habitats (Marker, 2000; Meadows & Knowlton, 2000; Quigley et al., 2015). Herding is effective against shy species like Eurasian lynx, but not against large and tolerant ones like leopard, especially if shepherds cannot properly protect their stock (Angst et al., 2002; Khorozyan et al., 2017). The effectiveness of enclosures depends on materials and technical specifications used to prevent the trespassing by felids. Chain-linked bomas are proved to be well-protected from many carnivore species including felids (Lichtenfeld et al., 2015; Sutton et al., 2017), but wire and bush fencing is not effective against agile and promptly climbing species like leopards and snow leopards, unless the top parts and holes are fully covered to prevent access (Kolowski & Holekamp, 2006; Kuksin & Kuksina, 2009). Electric fences are very effective, but possibly only in protecting small areas (Angst, 2001; Garrote et al., 2015; Quigley et al., 2015); incomplete fencing of large grazing areas does not reduce depredation losses as felids keep on trespassing through the unfenced areas (Cavalcanti et al., 2012). To be effective and practical, electric fences should be properly constructed and their applications require careful preliminary cost-benefit analyses (Frank & Eklund, 2017).

The use of acoustic, visual and other deterrents is a common way to provoke fear or anxiety in carnivores and thus to avert them from causing a damage. However, their effectiveness is inconclusive as it is not clear whether the effects are caused by deterrent

characteristics or by behavioral responses of carnivores at the species, local or individual levels. At this stage, trial-and-error applications of deterrents to target species seem to be most reasonable. The effectiveness of deterrents is short-term and lasting only several months due to easy habituation of carnivores, particularly felids, to deterrent signals especially when they are static and harmless (Khorozyan & Waltert, 2019b; Miller et al., 2016). Such habituation is faster in human-dominated areas where carnivores are exposed and adapted to artificial novelties (Blumstein, 2016), so it would be practically important to study how the effectiveness of deterrents is affected by fine-scale human densities and associated aspects of carnivore behavior. We also suggest to conduct long-term studies, of at least 1 year duration, so as to understand when felids become habituated and make the effectiveness decrease (Khorozyan & Waltert, 2019b).

Lethal control cannot effectively reduce depredation losses if it destroys carnivores indiscriminately upon encounters and does not reduce carnivore population size (Herfindal et al., 2005; Peebles et al., 2013). Selective removal, that is, elimination of actual or potential culprit individuals like those living near grazing grounds, is more targeted and effective (Stahl et al., 2001). However, the effectiveness of selective removal is still much lower than that of nonlethal interventions, especially husbandry. The effects of lethal control are short-term and further decreasing as vacant places have been occupied by new immigrants which also can kill livestock (Peebles et al., 2013; Stahl et al., 2001). Therefore, it is of particular importance to apply alternative nonlethal interventions in conflict areas where lethal control is believed to be most feasible and socially acceptable (Guerisoli et al., 2017).

4.5 | Data validation and importance of grey literature for meta-analysis

Our review allows to validate the framework of most effective noninvasive interventions against carnivores by considering independent studies (Khorozyan & Waltert, 2019a). This framework suggests that the most effective interventions against Eurasian lynx, cheetahs and lions are physical deterrents, electric fences, guarding animals and calving control. We found only two studies not included in this framework, which described the use of guarding dogs against Eurasian lynx (Otvstavel et al., 2009) and cheetahs (Potgieter et al., 2016). Both these studies indicated a 100% reduction of damage to livestock if measured in terms of livestock losses, and a 63% reduction of damage from the proportion of farms reporting conflicts with cheetahs

(Potgieter et al., 2016). This result shows that the framework of most effective interventions is a useful tool to guide and validate further actions in protecting livestock from felids and other carnivores.

Grey literature, including newsletters, reports, dissertations and theses, was an important source of information for our study accounting for 13 out of 57 (23%) source publications. Most of them (10 of 13) were retrieved from the IUCN/SSC Cat Specialist Group Digital Library and the newsletters Cat News and Carnivore Damage Prevention News, often solely from these sources. The value of grey literature was added by an unbiased representation of six felid species, namely the Eurasian lynx, leopard, lion, puma, snow leopard and tiger. Therefore, we encourage researchers to use such general and taxonomically focused depositaries in order to increase sample size and find novel information which is often overlooked by traditional scientific search of the literature.

4.6 | Study limitations and recommendations

We are aware of several limitations of this study, which are the small sample size, publication bias, geographical bias, and nonuse of ecological and environmental variables. We had only 92 cases over 10 felid species and 2–21 (median 7) cases per species taking into account an intensive search over the scientific and grey literature (Table 2). This confirms an insufficient level of original research and systematic reviews on the evidence-based effectiveness of interventions against felids and carnivores in general, but it tends to grow fast in recent years (Bruns et al., 2020; Eklund et al., 2017; Khorozyan & Waltert, 2019a, 2019b, 2020; Miller et al., 2016; Treves et al., 2016; Van Eeden et al., 2017).

Publication bias, which means a tendency to publish mostly positive results and thus inflate the effectiveness, is apparently minimal in our study as we referred to many publications with low effectiveness, ineffectiveness and even counter-productive results (Figure 2). Geographical bias is an objective reality as species have been unequally studied across the countries and smaller areas. From this study, it is particularly noteworthy to mention a strong deficiency or absence of studies on the effectiveness of livestock protection interventions in regard to lion in West/Central Africa and India, cheetah in West/North Africa and Iran, tiger outside of the Russian Far East, Eurasian lynx in Asia, snow leopard in Mongolia, China and Central Asian countries, and caracal throughout its range in Africa and Asia. We invite researchers to invigorate this research of little studied species and regions.

We refrained from the inclusion of additional variables, such as habitats, body mass and others, in this study because such variables can be related to species ecology and it is more sensible to compare intervention effectiveness between species than, say, between their habitats. Also, spatial variables such as land use and habitats are usually assessed over large scales while intervention effectiveness studies are fine-scale, and this inconsistency can make spatial variables insensitive to effectiveness-related data (Khorozyan & Waltert, 2020). We are not aware of studies investigating the relationships between intervention effectiveness and ambient factors, and all they deal with species and interventions—what we also do in this study. And, finally, we believe that limited information on evidence-based effectiveness in felids and other carnivores makes multivariate analyses premature and simple case-by-case comparisons are most informative and relevant at this stage (Eklund et al., 2017; Khorozyan & Waltert, 2019a, 2019b; Miller et al., 2016; Treves et al., 2016; Van Eeden et al., 2017, 2018).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Igor Khorozyan conceived the study design, collected and analyzed data, and drafted the article. Matthias Waltert coordinated the study, participated in the design of the study and helped draft the article. All authors gave final approval for publication.

DATA AVAILABILITY STATEMENT

The original dataset collected for this study is available in Supporting Information.

ETHICS STATEMENT

Not applicable.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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