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PERSPECTIVE

Carnivore conservation needs evidence-based livestock protection

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Abstract

Carnivore predation on livestock often leads people to retaliate. Persecution by humans has contributed strongly to global endangerment of carnivores. Preventing livestock losses would help to achieve three goals common to many human societies: preserve nature, protect animal welfare, and safeguard human livelihoods. Between 2016 and 2018, four independent reviews evaluated >40 years of research on lethal and nonlethal interventions for reducing predation on livestock. From 114 studies, we find a striking conclusion: scarce quantitative comparisons of interventions and scarce comparisons against experimental controls preclude strong inference about the effectiveness of methods. For wise investment of public resources in protecting livestock and carnivores, evidence of effectiveness should be a prerequisite to policy making or large-scale funding of any method or, at a minimum, should be measured during implementation. An appropriate evidence base is needed, and

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we recommend a coalition of scientists and managers be formed to establish and encourage use of consistent standards in future experimental evaluations.

Carnivores, such as lions and wolves, are killed in many regions over real or perceived threats to human interests. Combined with habitat loss and fragmentation, human-induced mortality has contributed to widespread carnivore population declines, along with declines of their important ecosystem functions [1]. Balancing the goals of nature preservation, livelihood protection, and welfare of carnivores and domestic animals depends on policies that foster coexistence between humans and carnivores in multiuse landscapes [2, 3]. Central to this aim is a need for rigorous scientific evidence that interventions are effective in preventing predation on livestock. Such policies should be based on strong inference [4, 5], otherwise, we risk wasting resources on ineffective interventions that might harm all involved.

Between 2016 and 2018, we independently published four reviews examining evidence for the effectiveness of interventions to reduce livestock predation by carnivores [6–9]. Here, we focus on the results for livestock losses or carnivore incursions into livestock enclosures (hereafter, “functional effectiveness” [8]). Since each review offered a unique perspective, we reconcile differences to synthesize three messages common to the reviews. First, despite the immense resources spent globally to protect livestock from carnivores, few peer-reviewed studies have produced strong inference about the functional effectiveness of interventions. Second, there was scant consistency of standards of evidence in our four reviews, hindering scientific consensus, and hence clear recommendations to policy-makers, about the relative functional effectiveness of different interventions. Finally, we identified several interventions that were found consistently effective, which deserve promotion in policy, even if only in the general conditions under which they have already been tested, as well as prioritization for further research under conditions in which evidence is lacking.

We suspect that the striking paucity of rigorous evaluation is due to the tendency for decisions about predator control to depend on factors other than evidence-based evaluation of whether a given intervention effectively protects livestock. These other factors—including ethics (should one implement the intervention?), feasibility (can one implement the intervention?), and perception (does one believe the intervention will work?)—might be important subsequent considerations in the implementation and decision-making processes. However, objective scientific evidence of an intervention’s functional effectiveness must remain a foundational prerequisite on which subjective inquiries later build. The lack of scientific synthesis and consensus about functional effectiveness has allowed more subjective factors to dominate decision-making about predator control and likely wasted time and money on interventions that do not optimally protect livestock. Furthermore, shifting ethics and public values in some communities are enabling the return of carnivores to landscapes worldwide or leading to the increased use of nonlethal predator control interventions. We support these initiatives from the perspective of conserving carnivores but insist that scientific evidence for functional effectiveness be considered first to ensure that interventions intended to protect livestock accomplish that goal. This will prevent the inefficient—or worse yet, counterproductive—use of limited resources to protect animals long term.

Additionally, although our reviews collectively reveal a need for more evidence, scientists alone cannot fill this gap. Livestock owners, natural resource managers, and decision-makers each have an important role to play in research partnerships to collaboratively guide the testing of predator control interventions. Here, we appeal to these groups by summarizing the advantages of evidence-based effective interventions, the best practices of scientific inference, and the role of policy in promoting effective predator control strategies. We start by synthesizing the results of our four independent reviews to provide scientific consensus on the evaluations of predator control interventions. We urge managers and policy decision-makers to use this discussion as a basis for creating policy that promotes evidence-based, effective strategies for protecting domestic animals from carnivore predation.

Synthesis of the science on functional effectiveness

Our four reviews [6–9] jointly screened >27,000 candidate studies. The four sets of inclusion criteria differed in geographic coverage, carnivore species, and standards of evidence and research design (see S1 Table), which limited overlap in the studies that passed screening (only 19% of studies were included in two or more of the four reviews; no study was included in all four, S1 Fig). The differing inclusion criteria also meant that it was not possible to conduct a quantitative comparison (meta-analysis) combining the data from our four reviews, but we suggest that such an analysis should be conducted in the future as evidence increases. Nonetheless, our reviews came to remarkably similar conclusions, irrespective of methods, suggesting that our conclusions are robust.

Among the 114 studies that passed screening in one or more reviews (S2 Table), representing >40 years of research, we found few that yielded strong inference about functional effectiveness. Surprisingly, many widely used methods have not been evaluated using controlled experiments. Also, few interventions have been compared side by side or tested singly under diverse conditions. These deficiencies in the literature are further compounded by disagreement among scientists, managers, and peer-reviewed journals about standards of evidence, such as which study designs produce strong inference [8]. We acknowledge the challenges of regional experiments amid dynamic, complex ecologies, publics, and jurisdictions. However, a handful of random-assignment experimental studies without bias ("gold standard") have proven that the obstacles are surmountable [8, 10, 11, 12].

We summarize our four sets of results by category of intervention in Fig 1. Our reviews agree that several methods have been tested numerous times with high standards of evidence and have been found effective: livestock guardian animals, enclosures for livestock, and a visual deterrent called fladry. Importantly, we should recognize that the effectiveness of different methods will vary under different contexts, and there is currently a bias among research toward certain geographic regions and predator types (Fig 2). Further, we agree that standards of evidence have been higher for nonlethal methods, and there remains a need to ensure data on all interventions are collected appropriately and consistently. As such, building on existing criticism of the lack of appropriate data collection in environmental management [13–16], our reviews collectively highlight the need to improve standards of evidence used in evaluating interventions. We need to develop a comprehensive evidence base that allows us to compare the effectiveness of interventions for reducing carnivore predation on livestock and inform consistent policy in any jurisdiction.

Importance of rigorous experimental design and evaluation

Societal values and, accordingly, policies for human–carnivore coexistence have changed over the millennia. The almost exclusive use of lethal interventions has given way to nonlethal interventions as important supplements to or replacements for prior lethal methods. Immense logistical and financial resources are invested in protecting livestock and carnivores, so the scarcity of rigorous scientific evidence for effectiveness should be a concern. We encourage governments to adopt proven methods from similar systems of carnivores and human

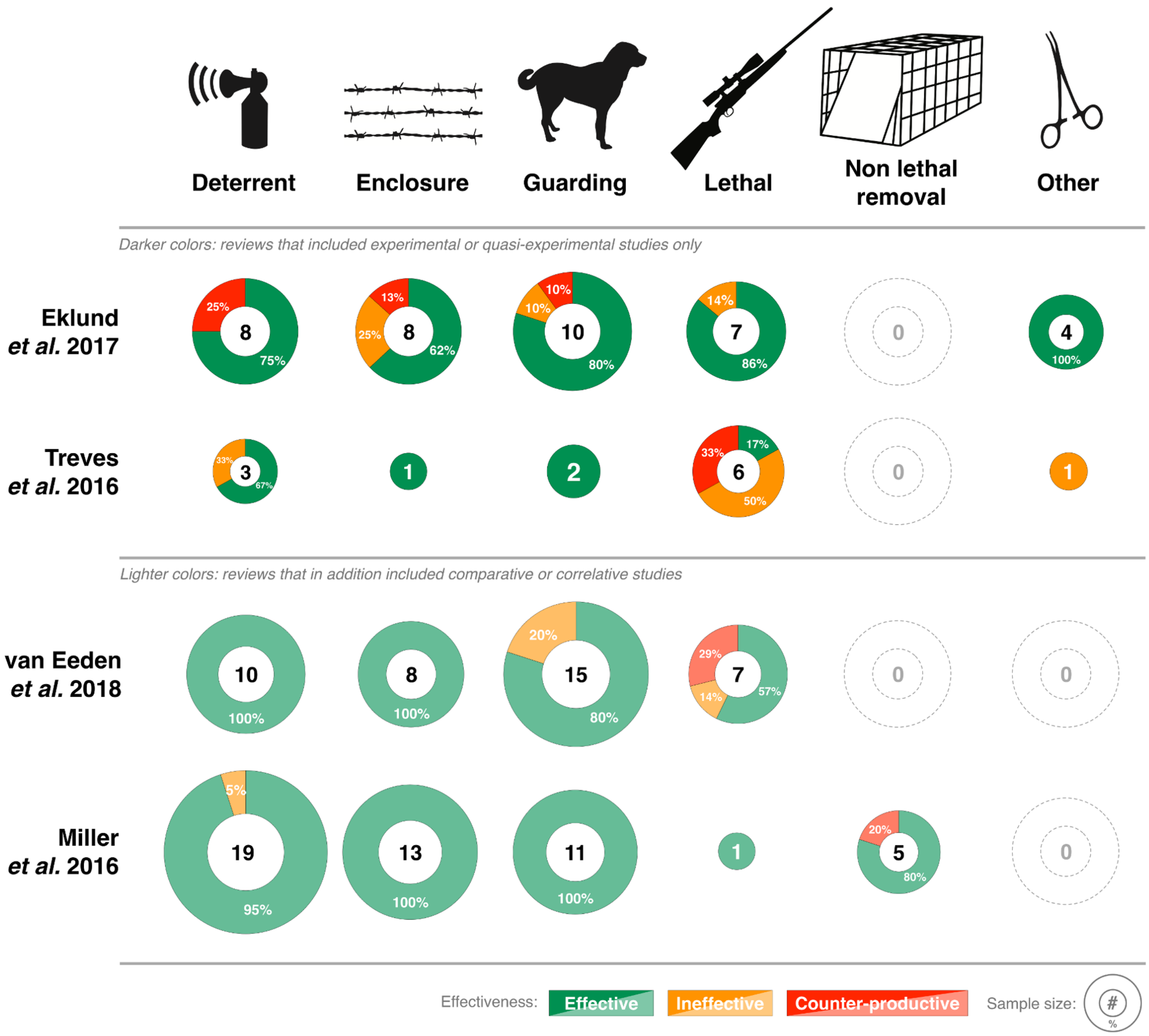

Fig 1. Percent of studies that measured interventions as "Effective," "Ineffective," or "Counter-productive" in reducing livestock loss to large carnivores, as measured by four independent reviews in 2016–2018. The sample sizes inside disks represent the number of studies or tests, as some studies reported more than one test of the same or different interventions. Darker colors represent reviews that included experimental or quasiexperimental controls; lighter colors represent reviews that also included comparative or correlative studies (see S1 Table for details). "Deterrents" include nonlethal interventions such as audio or visual deterrents, fladry, and livestock protection collars. "Enclosure/barrier" includes electrified and nonelectrified fencing and corralling. "Guarding" includes human shepherding and livestock guardian animals. "Lethal removal" includes hunting, poison baiting, and other lethal methods. "Non-lethal removal" refers to translocation of carnivores. "Other" includes carnivore sterilization and diversionary feeding. Eklund and colleagues measured effectiveness using RR and classified Effective as RR < 0.90, Ineffective = 0.90–1.10, and Counterproductive RR > 1.10. Treves and colleagues measured effectiveness as significant change in livestock loss. Note that Treves and colleagues initially contained 12 studies with 14 separate tests using gold or silver standards, but one test was subsequently removed after review of the methods found it impossible to draw strong inference [17]. van Eeden and colleagues measured effectiveness as Hedges' d and classified Effective as $d < -0.05$, Ineffective $-0.05 > d < 0.05$, and Counterproductive $d > 0.05$. Miller and colleagues measured effectiveness as percentage change in livestock loss (or carnivore behavior change) and classified Effective as $d > 0\%$ change, Ineffective = 0%, and Counterproductive $< 0\%$. RR, relative risk.

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interests, with systems in place to review and adapt management actions as new evidence becomes available. When governments contemplate large-scale implementation or funding for interventions, scientific evidence of functional effectiveness deserves priority to avoid wasting

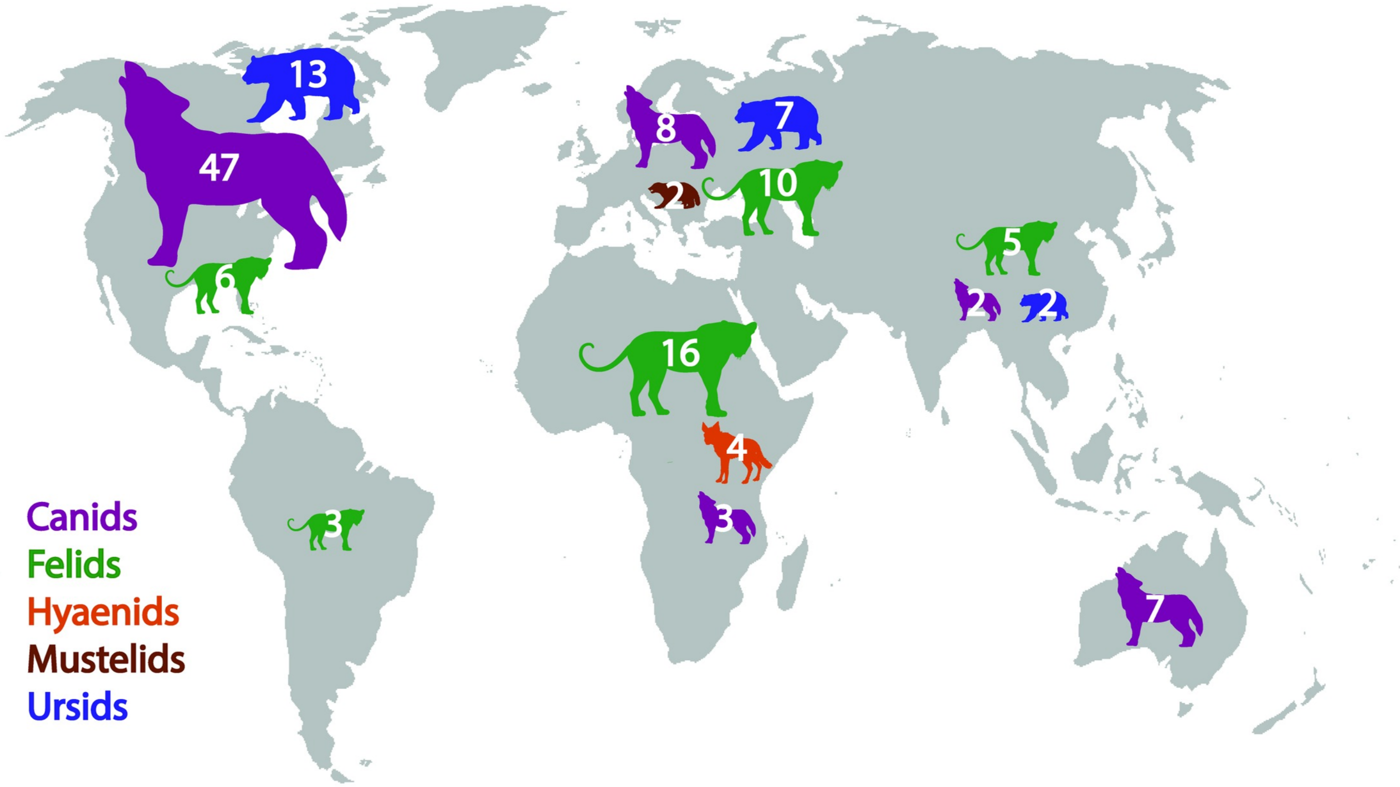

Fig 2. Number of studies included in four independent reviews published in 2016–2018, presented by carnivore family and continent. Canids include gray wolves and subspecies (*Canis lupus*), coyotes (*C. latrans*), dingoes (*C. dingo*), black-backed jackals (*C. mesomelas*), African wild dogs (*Lycaon pictus*), red foxes (*Vulpes vulpes*), and domestic dogs (*C. familiaris*). Felids include Eurasian lynx (*Lynx lynx*), cougars (*Puma concolor*), lions (*Panthera leo*), jaguars (*P. onca*), leopards (*P. pardus*), snow leopards (*P. uncia*), caracals (*Caracal caracal*), and cheetahs (*Acinonyx jubatus*). Hyaenids include spotted hyenas (*Crocuta crocuta*). Mustelids feature wolverines (*Gulo gulo*). Ursids include American black bears (*Ursus americanus*), Asiatic black bears (*U. thibetanus*), brown or grizzly bears (*U. arctos*), and polar bears (*U. maritimus*). Smaller carnivores (e.g., red foxes, hyenas, and caracals) are included in studies that investigated multiple carnivore species of varying sizes.

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resources on ineffective methods, no matter if the latter are ethical or easy to implement. When no proven method is available, scientific evaluation of functional effectiveness should coincide with implementation.

Strong inference in any scientific field demands control over potentially confounding variables and testable claims about functional effectiveness of interventions [8]. In our context, all methods present opposable hypotheses, i.e., method X works or does not work. Several experimental design components are essential to strong inference about that hypothesis, and we focus here on the three of topmost priority for yielding strong inference about livestock protection interventions: controls, randomization, and replication.

The strongest inference results from experiments that achieve the "gold standard" through "random assignment to control and treatment groups without bias (systematic error) in sampling, treatment, measurement, or reporting" [8]. This requires that an intervention be used to protect a livestock herd (treatment) and that its effectiveness is compared against a livestock herd that is not exposed to the intervention (placebo control). Both treatment and control should be replicated using multiple independent herds of livestock that are distributed so that the effects of treatment on one herd do not confound the effects on another herd, which would eliminate independence. Random assignment of treatments avoids sampling or selection bias that is common in our field [8], as in others [18]. Implementing random assignment for actual livestock herds can be challenging, but several studies have succeeded, such as those conducted by Davidson-Nelson and Gehring [10] and Gehring and colleagues [11]. In the Chilean altiplano, 11 owners of alpacas (*Vicugna pacos*) and llamas (*Lama glama*) joined a randomized reverse treatment (crossover) experiment to evaluate light devices in deterring carnivores [12]. Moreover, if large numbers of replicates are infeasible or replicates are unavoidably heterogeneous, then crossover, reverse treatment designs should help to increase the strength of inference about interventions [8, 12, S2 Table].

"Silver standard" designs provide weaker inference because of nonrandom assignment to treatment and then repeated measures of the replicate at two or more time points (before-and-after comparison of impact or quasiexperimental designs, also called case control). Both time passing and the treatment might explain changes in replicates, in addition to the extraneous "nuisance" variables present in agro-ecosystems at the outset [8].

The weakest standard of evidence is the correlative study, which compares livestock predation among herds that varied haphazardly in past protection or varied systematically if people intervened only where livestock had died. In correlational studies, confounding variables inevitably create selection or sampling bias. Although correlative studies may be useful as an initial exploratory step and help direct further research, confidence in their findings should be low, especially if there is large variation in the results. Correlative studies cannot substitute for the silver or gold standards described above.

Implementation of interventions must be consistent to avoid treatment bias. For example, the functional effectiveness of livestock-guarding dogs might vary with breed, individual, training, and maintenance of the dog. Likewise, tests of lethal methods have never controlled the simultaneous use of several methods of intervention (e.g., pooling shooting and trapping as one treatment), which is inadvisable for strong inference. Consistent maintenance of interventions throughout a study should also minimize treatment bias [18].

Well-designed experiments should incorporate evaluation along multiple dimensions. Was the intervention implemented as planned? Did attacks on livestock diminish? Measurement bias arises from systematic error in documenting implementation or losses in treatment or response variables. As in biomedical research, which sometimes uses patient self-reports as a subjective measure of effectiveness alongside objective measures of health outcomes, there are valid reasons to measure owners' perceptions of effectiveness of interventions. In human–wildlife interactions, people's attitudes can influence the adoption or rejection of interventions independently of scientific evidence [14,19]. Several of the reviews included metrics of perceived effectiveness among livestock owners, yet perception alone is not a reliable measure of functional effectiveness because of widespread placebo effects, whereby patients feel better simply because they have participated. Studies should therefore either "blind" their participants or use an independent, verifiable measure of effectiveness (i.e., livestock loss).

We recognize that gold or silver standards may be difficult to achieve. Systematic errors can be difficult to eliminate entirely, so we urge careful consideration of methods during the design process, including peer review prior to initiation. Ethical considerations about exposing animals to lethal risks may limit experimental designs. This inherent difficulty for controlled experiments may explain why some published experiments were completed in artificial settings (e.g., using captive carnivores or measuring bait consumption rather than livestock loss). Although most of our reviews omitted experiments for protecting property other than livestock, strong inference from such studies merit tests for livestock protection. Nonetheless, given that several examples of gold standard experiments overcame the complexities of people and wild ecosystems [5, 10, 11, 12], we urge greater effort and recommend government support and accolades for the highest standards of experimentation.

Incorporating science into conflict mitigation and conservation

Many governments have institutionalized support for livestock protection from predators and implemented various interventions at landscape scales. The European Council Directive 98/58/EC, concerning protection of animals kept for farming purposes, states that "animals not kept in buildings shall where necessary and possible be given protection from adverse weather conditions, predators and risks to their health." The Swedish Animal Welfare Act of 1988 mandates care should be given to injured animals as soon as possible. This obligation is in practice relevant subsequent to carnivore attacks. When trained field observers confirm livestock attacks by large carnivores, they also implement rapid response interventions, such as fladry and portable electric fences, to prevent recurrent attacks [20]. In the United States, in 2013 alone, the US Department of Agriculture killed >75,000 coyotes, 320 gray wolves (*Canis lupus*), and 345 cougars (*Puma concolor*) [21]. Similarly, in some Australian states, landowners and managers are required by law to actively control dingoes (*C. dingo*) on their property.

Given the weak state of current evidence about effectiveness, decisions to use interventions are most likely based on subjective factors (e.g., ethics, opinions, or perceptions) or nonscientific (and thus possibly biased) evidence. For example, many people have deeply rooted perceptions that an intervention is effective or not [19]. Therefore, research, promoted by policy, is needed to validate that perceptions align with measurable and scientifically defensible outcomes [14]. This is especially crucial in cases of lethal interventions, which entail multiple drawbacks, including ethical criticisms and the potential to hasten carnivore declines and impede population recoveries.

However, scientists alone cannot transform policies for implementation. The pursuit of science-based management must be truly interdisciplinary and involve carnivore ecologists, animal husbandry scientists, social scientists, natural resource managers, ethicists, and other scholars and practitioners. Political leaders can also play a role to prioritize, coordinate, and fund partnerships across government agencies and nongovernment organizations. Because we anticipate continued debate over the standards of effectiveness, we recommend a coalition be formed to clearly distinguish standards for evaluation and experimental protocols, which would be distinct from coalitions convened to consider local factors that affect decisions. Through collaboration, scientists, managers, and policy leaders can help to protect livestock within healthy ecosystems that include carnivores. Constituents worldwide increasingly support the restoration of carnivore populations and accordingly are calling for human–carnivore coexistence and minimizing conflicts [2]. Enabling coexistence through evidence-based solutions will give the public strong confidence in methods promoted by scientists and governments, particularly when implementation is difficult or the ethics are controversial.

Supporting information

S1 Table. Methods used by authors' reviews. Methods have been simplified for comparison. Refer to the original articles for a full account of methods used and justification for the use of these methods.
(DOCX)

S2 Table. Studies included in the four reviews.
(DOCX)

S1 Fig. Overlap of studies included in each of the four independent reviews that evaluated evidence of functional effectiveness of interventions in reducing carnivore attacks on livestock.
(TIF)

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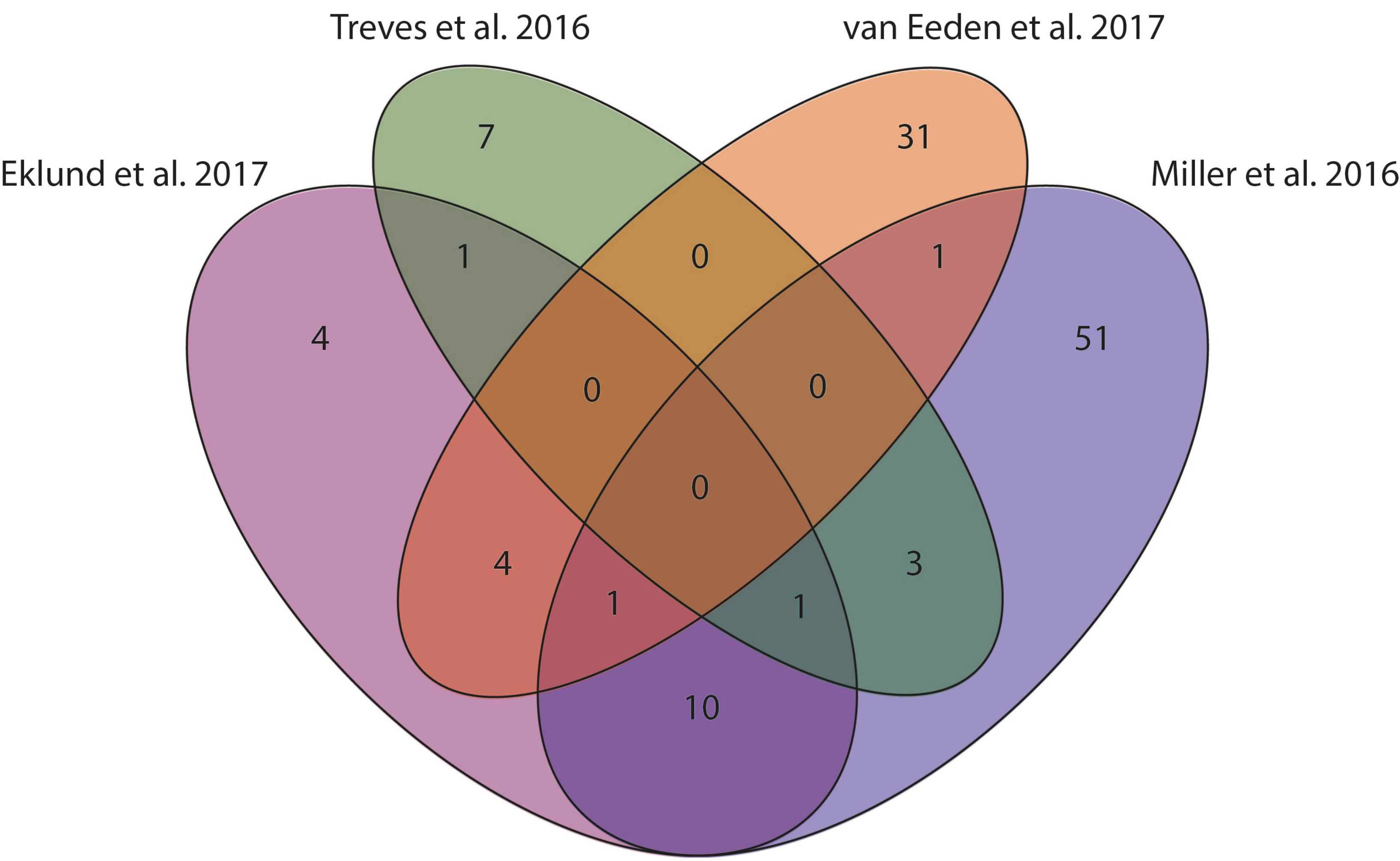
Treves et al. 2016
van Eeden et al. 2017
Eklund et al. 2017
Miller et al. 2016
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Table S1. Studies included in the four reviews.

Author	Year	Title	Country	Intervention	Carnivore	Livestock type	Duration of study	Journal/Source	Eklund et al. (2017)	Miller et al. (2016)	Treves et al. (2016)	van Eeden et al. (in press)
Acorn & Dorrance	1994	An evaluation of anti-coyote electric fences	Canada	Fencing	Coyote	Sheep	3 years	Proceedings of the 16th Vertebrate Pest Conference				1
Allen	2013	Wild dog control impacts on calf wastage in extensive beef cattle enterprises	Australia	Lethal control	Dingo	Cattle	3-4 years	Animal Production Science				1
Allen	2014	More buck for less bang: reconciling competing wildlife management interests in agricultural food webs	Australia	Lethal control	Dingo	Cattle	33 years	Food Webs				1
Allen & Sparkes	2001	The effect of dingo control on sheep and beef cattle in Queensland	Australia	Lethal control	Dingo	Sheep, Cattle		Journal of Applied Ecology		1		
Andelt	1992	Effectiveness of livestock guarding dogs for reducing predation on domestic sheep	United States	Guardian animals	Coyote	Sheep	1 year	Wildlife Society Bulletin	1			1
Andelt	1999	Relative effectiveness of guarding-dog breeds to deter predation on domestic sheep in Colorado	United States	Guardian animals	Coyotes, dogs, mountain lions, black bears, foxes	Sheep	8 year comparison	Wildlife Society Bulletin				1
Andelt & Hopper	2000	Livestock guard dogs reduce predation on domestic sheep in Colorado	United States	Fencing, Guardian animals	American black bear	Sheep		Journal of Range Management		1		
Anderson et al	2002	Grizzly bear-cattle interactions on two grazing allotments in northwest Wyoming	United States	Lethal control, translocation, aversive conditioning	Grizzly bear	Cattle	2 years	Ursus		1		
Angst	2001	Electric fencing of fallow deer enclosures in Switzerland - a predator proof method	Switzerland	Fencing	Lynx	Deer	4 years	Carnivore Damage Prevention News				1
Angst et al	2002	Übergriffe von Luchsen auf Kleinvieh und Gehegetiere in der Schweiz. Teil II: Massnahmen zum Schutz von Nutztieren	Switzerland	Shepherds	Lynx	Sheep, Goats, Deer	8 years	Report: KORA				1
Athreya et al	2010	Translocation as a tool for mitigating conflict with leopards in human-dominated landscapes of India	India	Translocation	Leopard	Goats, Cattle		Conservation Biology		1		
Azevedo & Murray	2007	Evaluation of potential factors predisposing livestock to predation by jaguars	Brazil	Zoning, Land-use	Jaguar, Puma	Cattle, Water Buffalo, Goats, Fowl, Dogs, Cats	3 years	Journal of Wildlife Management		1		
Bagchi & Mishra	2006	Living with large carnivores: predation on livestock by the snow leopard (*Uncia uncia*)	India	Zoning, Land-use	Snow leopard	Yak, Cattle, Cattle–yak hybrid, Horse, Donkey, Sheep, Goat	2 years	Journal of Zoology		1		
Bauer et al	2015	Financial compensation for damage to livestock by lions on community rangelands in Kenya	Kenya	Financial Incentives	Lion	Cattle, Sheep, Goats, Donkeys	12 years	Oryx				1
Bauer et al	2010	Assessment and mitigation of human-lion conflict in West and Central Africa	Benin, Cameroon	Enclosure	Hyena, Lion	Cattle, Sheep, Goat	2 years	Mammalia	1	1		
Beckmann et al	2004	Evaluation of deterrent techniques and dogs to alter behavior or "nuisance" black bears	United States	Deterrents	American black bear		5 years	Wildlife Society Bulletin		1		
Bjorge & Gunson	1985	Evaluation of wolf control to reduce cattle predation in Alberta	Canada	Lethal control	Wolf	Cattle	6 years	Journal of Range Management				1
Blejwas et al	2002	The effectiveness of selective removal of breeding coyotes in reducing sheep predation	United States	Lethal control	Coyote	Sheep	2.8	Journal of Wildlife Management	1			
Bradley & Pletscher	2005	Assessing factors related to wolf depredation of cattle in fenced pastures in Montana & Idaho	United States	Preventive husbandry	Wolf	Cattle	8 years	Wildlife Society Bulletin		1		
Bradley et al	2015	An evaluation of wolf-livestock conflicts and management in the Northwestern United States (MS thesis)	United States		Wolf			MSc Thesis: University of Montana			1	
Bradley et al	2005	Evaluating wolf translocation as a nonlethal method to reduce livestock conflicts in the northwestern United States	United States	Translocation	Wolf	Unclear	13 years	Conservation Biology		1		
Bradley et al	2015	Effects of wolf removal on livestock depredation recurrence and wolf recovery in Montana, Idaho, and Wyoming	United States	Lethal control, Translocation	Wolf	Sheep, Cattle, Other	1850 days	Journal of Wildlife Management	1			
Breck et al	2002	A shocking device for protection of concentrated food sources from black bears	United States	Deterrents	Wolf	Sheep	3 years	Wildlife Society Bulletin		1		
Breck et al	2006	Non-lethal radio activated guard for deterring wolf depredation in Idaho: summary and call for research	United States	Deterrents	American black bear			Proceedings of the 20th Vertebrate Pest Conference		1		
Breck et al	2011	Domestic calf mortality and producer detection rates in the Mexican wolf recovery area: implications for livestock management and carnivore compensation schemes	United States	Calving time	Mexican wolf	Cattle	4 years	Biological Conservation		1		
Bromley & Gese	2001	Surgical sterilization as a method of reducing coyote predation on domestic sheep	United States	Sterilization	Coyote	Lambs	5-23 days	Journal of Wildlife Management	1			
Ciucci & Boitani	1998	Wolf and dog depredation on livestock in central Italy	Italy	Fencing	Wolf			Wildlife Society Bulletin		1		
Conner et al	1998	Effect of coyote removal on sheep depredation in northern California	United States	Lethal control	Coyote	Sheep		Journal of Wildlife Management			1	
Davidson-Nelson & Gehring	2010	Testing fladry as a nonlethal management tool for wolves and coyotes in Michigan	United States	Fladry	Wolves and Coyotes	Sheep, Cattle	75 days	Human-Wildlife Interactions	1		1	
deCalesta & Cropsey	1978	Field test of a coyote-proof fence	United States	Fencing	Coyote	Sheep	1 year	Wildlife Society Bulletin				1
Dorrance & Bourne	1980	An evaluation of anti-coyote electric fencing	Canada	Fencing	Coyote	Sheep	5 years	Journal of Range Management				1
Edgar et al	2006	Efficacy of an ultrasonic device as a deterrent to dingoes (*Canis lupus dingo*): a preliminary investigation	Australia	Deterrents	Dingo	None (captive experiments)		Journal of Ethology		1		
Ellins	2005	Conditioned prey aversions (book chapter in Living with Coyotes)	United States	Deterrents	Coyote	Sheep	2 years	Book Chapter: Living with Coyotes				1
Espuno et al	2004	Heterogeneous response to preventive sheep husbandry during wolf recolonization of the French Alps	France	Guardian dogs and/or night time corralling	Wolf	Sheep	7 years	Wildlife Society B		1	1	
Gehring et al	2010	Utility of livestock-protection dogs for deterring wildlife from cattle farms	United States	LGDs	Wolf	Cattle	Multiple years	Wildlife Research	1	1	1	
Gehring et al	2006	Are viable non-lethal management toold available for reducing wolf-human conflict? Preliminary results from field experiments	United States	Deterrents, Fladry	Wolf	Sheep, Cattle	2 years	Proceedings of the 22nd Vertebrate Pest Conference		1		
Goodrich & Miquelle	2005	Translocation of problem Amur tigers *Panthera tigris altaica* to alleviate tiger-human conflicts	Russia	Translocation	Tiger		Multiple years	Oryx		1		
Gula	2008	Wolf depredation on domestic animals in the Polish Carpathian Mountains	Poland	None: correlative	Wolf	Sheep	6 years	Journal of Wildlife Management		1		
Gusset et al	2009	Human-wildlife conflict in northern Botswana: livestock predation by endangered African wild dog	Botswana	Enclosures	African Wild Dog			Oryx		1		
Gustavson et al	1982	A 3-year evaluation of taste aversion coyote control in Saskatchewan	Canada	Deterrents	Coyote	Sheep	4 years	Journal of Range Management				1
Hansen & Smith	1999	Livestock-guarding dogs in Norway Part II: different working regimes	Norway	Guardian animals	Brown bear	Sheep	3 months	Journal of Range Management		1		
Harper et al	2008	Effectiveness of lethal, directed wolf-depredation control in Minnesota	United States	Lethal control	Wolf	Cattle, Sheep, Turkey	20 years	Journal of Wildlife Management	1	1		
Hawley et al	2009	Assessment of shock collars as nonlethal management for wolves in Wisconsin	United States	Deterrents	Wolf	Bait	28 days	Journal of Wildlife Management	1	1		
Hazzah et al	2014	Efficacy of two lion conservation programs in Maasailand, Kenya	Kenya	Financial incentives and other	Lions	Cattle	11 years	Conservation Biology				1
Herfindal et al	2005	Does recreational hunting of lynx reduce depredation losses of domestic sheep?	Norway	Lethal control	Lynx	Sheep	6 years	Journal of Wildlife Management		1	1	
Herrero & Higgins	1998	Field use of capsicum spray as a bear deterrent	United States and Canada	Deterrents	American black bear, brown bear		10 years	Ursus		1		
Huygens & Hayashi	1999	Using electric bear fences to reduce Asiatic black bear depredation in Nagano prefecture, central Japan	Japan	Fencing	Asiatic black bear		5 years	Wildlife Society Bulletin		1		
Huygens et al	2004	Relationships between Asiatic black bear kills and depredation costs in Nagano prefecture, Japan	Japan	Lethal control	Asiatic black bear			Ursus		1		
Iliopolous et al	2009	Wolf depredation in central Greece	Greece	Shepherds	Wolf	Sheep, Goats	21 months	Acta Theriologica	1	1		
Jankovsky et al	1974	Field trials of coyote repellents in western Colorado	United States	Deterrents	Coyote	Sheep	4 months	Proceedings of the Western Section of the American Society of Animal Science				1
Jelinski et al	1983	Coyote predation on sheep, and control by aversive condition in Saskatchewan	Canada	Deterrents	Coyote	Sheep	2 years	Journal of Range Management				1
Karanth et al	2013	Patterns of human-wildlife conflicts and compensation: insights from Western Ghats protected areas	India	Night watching, fencing, scare devices, guard animals	Tiger, Leopard, Fox		2 years	Biological Conservation		1		
Kavcic et al	2013	Supplemental feeding with carrion is not reducing brown bear depredations on sheep in Slovenia	Slovenia	Supplemental feeding	Brown bear			Ursus			1	
Kolowski & Holecamp	2006	Spatial, temporal, and physical characteristics of livestock depredation by large carnivores along a Kenyan reserve border	Kenya	Enclosure	Hyena, Leopard	Goat, Sheep	14 months	Biological Conservation	1	1		
Krofel et al	2011	Effectiveness of wolf (*Canis lupus*) culling as a measure to reduce livestock depredations	Slovenia	Lethal control	Wolf			Acta Silvae et Ligni			1	
Krogstad et al	2000	Protective measures against depredation on sheep: shepherding and use of livestock guardian dogs in Lierne. Final report - 2000.	Norway	Guardian animals	Lynx & wolverine	Sheep	4 years	Report: NINA				1
Lance et al	2010	Biological, technical, and social aspects of applying electrified fladry for livestock protection from wolves (*Canis lupus*)	United States	Fladry	Wolf	Cattle	49 days	Wildlife Research	1	1		
Landa et al	1999	Factors associated with wolverine *Gulo gulo* predation on domestic cheep	Norway	Change livestock	Wolverine	Sheep	3 years	Journal of Applied Ecology	1			
Landriault et al	2009	Age, sex, and relocation distance as predictors of return for relocated nuisance black bears *Ursus americanus* in Ontario, Canada	Canada	Translocation	American black bear		15 years	Wildlife Biology		1		
Landry & Raydelet	2010	Efficacité des chiens de protection contre la prédation du lynx dans le Massif jurassien: Présentation préliminaire des résultats de l'enquête de terrain	France	Guardian animals	Lynx	Sheep	23 years	Report: Pôle Grands Prédateurs				1
Leigh	2007	Effects of sversive conditioning behavior of nuisance Louisiana black bears (Thesis)	United States	Deterrents	American black bear			Louisiana State University		1		
Lichtenfeld et al	2015	Evidence-based conservation: predator-proof bomas protect livestock and lions	Tanzania	Fencing (bomas and fortified bomas)	Lions	Cattle, Shoats, Donkeys	10 years (9296 boma months)	Biodiversity & Conservation	1			1
Linhart et al	1982	Electric fencing reduces coyote predation on pastured sheep	United States	Fencing	Coyote	Sheep	Average 65.67 nights	Journal of Range Management				1
Linhart et al	1984	Efficacy of light and sound stimuli for reducing coyote predation upon pastured sheep	United States	Deterrents	Coyote	Sheep	2 years	Protection Ecology				1
Linhart et al	1992	Electronic frightening devices for reducing coyote predation on domestic sheep: efficacy under range conditions and operational use	United States	Deterrents	Coyote	Sheep	5 years	Proceedings of the 15th Vertebrate Pest Conference				1

Author	Year	Title	Country	Intervention	Carnivore	Livestock type	Duration of study	Journal/Source	Eklund et al. (2017)	Miller et al. (2016)	Treves et al. (2016)	van Eeden et al. (in press)
Maclennan et al	2009	Evaluation of a compensation scheme to bring about pastoral tolerance of lions	Kenya	Financial incentives	Lions	Cattle, Donkeys, Sheep, Goats	6 years	Biological Conservation				1
Mahoney & Charry	2007	The use of alpacas as new-born lamb protectors to minimise fox predation	Australia	Guardian animals	Dingo and fox	Lambs	14 weeks	Extension Farming Systems Journal				1
Marker et al	2005	Survivorship and causes of mortality for livestock-guarding dogs on Namibian Rangeland	Namibia	Guardian animals	Cheetah		7 years	Rangeland Ecology and Management		1		
Martin and O'Brien	2000	The use of bone oil (Renardine) as a coyote repellent on sheep farms in Ontario	Canada	Deterrents	Coyote	Sheep	4-5 years	Proceedings of the 19th Vertebrate Pest Conference				1
Mazzolli et al	2002	Mountain lion depredation in southern Brazil	Brazil	Night enclosure	Puma	Sheep, Swine	3 years	Biological Conservation	1	1		
McManus et al	2014	Dead or alive? Comparing costs and benefits of lethal and non-lethal human-wildlife conflict mitigation on livestock farms	South Africa	Lethal control	Black-backed jackal, caracal, leopard		3 years	Oryx		1		
Meadow & Knowlton	2000	Efficacy of guard llamas to reduce canine predation on domestic sheep	United States	Guardian animals	Coyote	Sheep	80 weeks	Wildlife Society Bulletin				1
Mech et al	2000	Assessing factors that may predispose Minnesota farms to wolf depredations on cattle	United States	Preventive husbandry	Wolf	Cattle		Wildlife Society Bulletin		1		
Michalski et al	2006	Human-wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredationon livestock	Brazil	Preventive husbandry	Jaguars & Pumas	Cattle	4 years	Animal Conservation		1		
Miller	1987	Field tests of potential polar bear repellents	Canada	Deterrents	Polar Bear		2 months	International Conference on Bear Restoration		1		
Musiani et al	2003	Wolf depredation management: current methods and research needs	United States and Canada		Wolf			Wildlife Society Bulletin			1	
Musiani et al	2003	Wolf depredation trends and the use of fladry barriers to protect livestock in western North America	Canada	Fladry	Wolf	Cattle/bait	60 days	Conservation Biology	1	1		
Nass & Theade	1988	Electric fences for reducing sheep losses to predators	United States	Fencing	Coyotes and dogs	Sheep	Average 4.1 years treatment	Journal of Range Management				1
National Project Steering Committee	2014	National Wild Dog Action Plan - Brindabella Wee Jasper case study	Australia	Lethal control	Dingo	Sheep	20 years	Report: National Wild Dog Action Plan				1
Obbard et al	2014	Relationships among food availability, harvest, and human-bear conflict at landscape scales in Ontario, Canada	Canada		American black bear			Ursus			1	
Odden et al	2008	Vulnerability of domestic sheep to lynx depredation in relation to roe deer density	Norway	Wild prey availability	Lynx	Sheep	9 years	Journal of Wildlife Management		1		
Odden et al	2013	Density of wild prey modulates lynx kill rates on free-ranging domestic sheep	Norway	Wild prey availability	Lynx	Sheep	16 years	PLoS ONE		1		
Ogada et al	2003	Limiting depredation by African carnivores: the role of livestock husbandry	Kenya	Husbandry	Lions, leopards, cheetahs, spotted hyenas	Cattle, Sheep, Goats	1 year	Conservation Biology		1		
Otstavel et al	2009	The first experience of livestock guarding dogs preventing large carnivore damages in Finland	Finland	Guardian animals	Lynx, Brown bear, Wolf	Sheep, Cattle, Poultry, Horses, Alpaca, Donkey		Estonian Journal of Ecology		1		
Palmer et al	2010	Replication of a 1970s study on domestic sheep losses to predators on Utah's summer rangelands	United States	Guardian animals, Shepherds	Coyotes, cougars, black bears	Sheep	4 months	Rangeland Ecology and Management	1			1
Peebles et al	2013	Effects of remedial sport hunting on cougar complaints and livestock depredations	United States	Lethal control	Cougar			PLoS ONE			1	
Rigg et al	2011	Mitigating carnivore-livestock conflict in Europe: lessons from Slovakia	Slovakia	Night enclosure, Guardian animals	Brown bear, wolf	Sheep	3 years	Oryx	1	1		
Rossler et al	2012	Shock collars as a site-aversive conditioning tool for wolves	United States	Deterrents	Wolf	Cattle, Sheep, Horse	2 years	Wildlife Society Bulletin		1		
Rust et al	2013	Perceived efficacy of livestock-guarding dogs in South Africa: implications for cheetah conservation	South Africa	Guardian animals	Cheetah	Sheep, Goats, Cattle	2 years and 2 months	Wildlife Society Bulletin				1
SagØr et al	1997	Compatability of brown bear *Ursus arctos* and free-ranging sheep in Norway	Norway	Lethal control	Brown bear	Sheep	12 years	Biological Conservation		1	1	
Salvatori & Mertens	2012	Damage prevention methods in Europe: experiences from LIFE nature projects	Italy, Spain, Portugal, France, Croatia	Guardian animals, Fencing	Brown bear and wolf	Bulls, cattle, goats, sheep, bee-hives, orchards		Hystrix		1		
Sampson & Brohn	1955	Missouri's program of extension predator control	United States	Lethal control	Coyotes	Not specified	8 years	The Journal of Wildlife Management				1
Schultz et al	2005	Experimental use of dog-training shock collars to deter depredation by gray wolves	United States	Deterrents	Wolf		4 years	Wildlife Society Bulletin		1		
Shivik et al	2003	Nonlethal techniques for managing predation: primary and secondary repellents	United States	Deterrents, Fladry	Wolf	None (baits)	2 months	Conservation Biology		1		
Stahl et al	2001	The effect of removing lynx in reducing attacks on sheep in the French Jura Mountains	France	Lethal control	Lynx	Sheep	Average 7.22 months	Biological Conservation		1		1
Stahl et al	2002	Factors effecting lynx predation on sheep in the French Jura	France	Land-use, wild prey	Lynx	Sheep	4 years	Journal of Applied Ecology		1		
Stander	1990	A suggested management strategy for stock-raiding lions in Namibia	Namibia	Translocation, Lethal control	Lions	Cattle	3 years	South African Journal of Wildlife Research		1		
Suryawanshi et al	2013	People, predators and perceptions: patterns of livestock depredation by snow leopards and wolves.		Land-use	Snow leopard, wolf	Yak, Horse	5 years	Journal of Applied Ecology		1		
Swanson & Scott	1973	Livestock protectors for sheep predator control	United States	Deterrents	Coyotes	Sheep	3 years	Proceedings of the Western Section of the American Society of Animal Science				1
Treves et al	2011	Forecasting environmental hazards and the application of risk maps to predator attacks on livestock	United States	Land-use	Wolf	Cattle	7 years	Bioscience		1		
Tumenta et al	2013	Livestock depredation and mitigation methods practised by resident and nomadic pastoralists around Waza National Park, Cameroon	Cameroon	Night enclosure	Lions	Cattle, Sheep, Goat		Oryx		1		
Valeix et al	2012	Behavioural adjustments of a large carnivore to access secondary prey in a human-dominated landscape	Botswana	Wild prey availability	Lions	Cattle	2 years	Journal of Applied Ecology		1		
van Bommel	2013	Guardian dogs for livestock protection in Australia	Australia	Guardian animals	Dingo	Goats, calves, lambs and poultry	Varied (up to 30 years)	Thesis: The University of Tasmania				1
van Bommel & Johnson	2012	Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems	Australia	Guardian animals	Dingo	Sheep, Goat	7 months	Wildlife Research		1		
van Bommel et al	2007	Factors affecting livestock predation by lions in Cameroon	Cameroon	Preventive husbandry	Lions	Cattle, Sheep, Goat	2 months	African Journal of Ecology		1		
van Liere et al	2013	Farm characteristivs in Slovene wolf habitat related to attacks on sheep	Slovenia	Night enclosure	wolf	Sheep	5 months	Applied Animal Behaviour Science		1		
Wagner & Conover	1999	Effect of preventive coyote hunting on sheep losses to coyote predation	United States	Lethal control	Coyote	Lambs	3-6 months	The Journal of Wildlife Management	1			1
Walking for Lions	2016	Quarterly Report	Botswana	Deterrents	Lions	Includes cattle	2 months	Report: Walking for Lions				1
Williamson et al.	2002	Non-lethal radio activated guard for deterring wolf depredation in Idaho: summary and call for research		Deterrent	Wolf	Cattle	Several days to several months	Proceedings of the 20th Vertebrate Pest Conference		1		
Wilson et al	2005	Natural landscape features, human-related attractants, and conflict hotspots: a spatial analysis of human-grizzly bear conflicts	United States	Calving, fencing	Grizzly bear	Cattle, Sheep, Beehives	15 years	Ursus		1		
Woodroffe et al	2006	Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: a case-control study	Kenya	Shepherds, Guardian animals, Scarecrows, Fencing	Lion, Leopard, Hyena	Cattle, sheep and goats, camels, donkeys	4.5 years	Biodiversity & Conservation	1	1		
Woodroffe et al	2005	Livestock predation by endangered African wild dogs (*Lycaeon pictus*) in northern Kenya	Kenya	Land-use, preventive husbandry	African Wild Dog	Goat, Sheep, Cattle	3 years	Biological Conservation		1		
Wooldridge	1980	Polar bear electronic deterrent and detection systems	Canada	Deterrent	Polar bear		4 years	Bears: Their Biology & Management		1		
Zarco-González & Monroy-Vilchis	2014	Effectiveness of low-cost deterrents in decreasing livestock predation by felids: a case study in Central Mexico	Mexico	Deterrents	Puma and jaguar	Cattle, goats	2 months	Animal Conservation	1	1		1

Table S1

Supplementary Information

Carnivore conservation needs evidence-based livestock protection

Van Eeden et al.

Table S1. Methods used by authors' reviews. Methods have been simplified for comparison. Refer to the original articles for a full account of methods used and justification for the use of these methods.

	Miller et al. 2016 [1]	**Treves et al. 2016 [2]**	**Eklund et al. 2017 [3]**	**Van Eeden et al. 2018 [4]**
Databases searched and other sources	• Web of Science (All databases) • Carnivore Ecology and Conservation database • Snow-ball sampling	• Google scholar • Snow-ball sampling	• Zoological Record	• Web of Science (All databases) • SCOPUS • Google Scholar • European LIFE Commission Project database • Snow-ball sampling • Contacted authors and organizations
Search methods and terms	• Compound search terms included the technique (e.g., deterrent) or a specific intervention (e.g., aversive stimuli or behavior conditioning) plus 1 of 7 general keywords related to livestock depredation conflict: Human–carnivore conflict, livestock depredation, human–carnivore coexistence, mitigation, depredation management, depredation prevention, or depredation control.	• Repeated searches, followed by a snowball method using the reference lists of >100 articles identified in the search. • Searched using key words: (Control, Damage, Depredation, Lethal, Non-lethal, Removal, or Livestock) AND (Predat*, Carnivor*).	• Searched using the subject descriptors: Carnivora OR Canidae OR Felidae OR Hyaenidae OR Mustelidae OR Procyonidae OR Ursidae OR Viverridae • These items were then refined using the following search string: "depredation OR stock OR poultry OR damage OR mitigation OR conflict OR control OR cull OR cow OR bull OR	Combinations of search terms from the following categories: • **Carnivore:** Bear*, Canid*, *Canis*, Carnivore*, Cheetah*, Cougar or puma, Coyote*, *Crocuta*, Dingo*, Fox*, Hyena or hyaena, Jaguar*, Leopard*, Lion*, *Lycaeon* or *Lycaon*, Lynx*, *Panthera*, Predat*, Tiger*, *Uncia*, Wild dog*, Wildlife, Wolf, Wolves. • **Livestock:** Beef, Calf, Calves, Cattle, Chicken, Cows, Farm*, Lamb*,

Table S1

	• Searches followed the formula: (technique or intervention) and (conflict keyword). • **Deterrents:** Aversive stimuli, Behavior conditioning, Behavior modification, Disruptive stimuli, Repellent. • **Indirect management of land or prey:** Buffer zone, Core zone, Grazing areas, Land use conflict, Wild prey, Wild ungulate. • **Predator removal:** Contraception, Lethal control, Population control, Problem animal, Retaliation, Retaliatory killing, Translocation • **Preventive husbandry:** Barrier, Grazing, Guard animal, Guard dog, Guards, Herd, Herder, Hotspot, Husbandry, Livestock breed, Penning, Sensory deterrent or repellent, Separation, Shepherd.		calf OR calves OR chicken OR hen OR ewe OR lamb OR pet OR cat OR hound OR pony OR ponies OR mule OR reindeer OR llama OR yak OR buffalo OR livestock OR cattle OR sheep OR goat OR horse OR pig OR dog OR attack OR camel OR donkey".	Poultry, Sheep, Stock. • **Impact:** Conflict, Damag*, Loss. • **Intervention:** 1080, Bait*, Chemical repellent, Compensation, Condition NEAR/2 aversion, Control, Cull, Denning, Dogging, Donkey, Farm*, Fenc*, Fladry, Guard* dog, Hunt*, Husbandry, Insurance, Livestock guard*, Livestock protect*, Llama, M-44, Management, Non$lethal, Poison, Protection collar, Range rid*, Scaring, Shoot*, Sterili*, Translocat*, Trap* • **Excluded terms:** Arthropod, Beetle*, Fish*, *flies, *fly, Hemiptera, Heteroptera, Insect*, Parasit*, Pesticide.
Publications	Peer-reviewed	Peer-reviewed	Peer-reviewed	Peer-reviewed, gray literature, and raw data
Languages	English	English and Slovenian	English	English search terms only; 3 non-English language studies were identified and included.
Time period	All years (through 2015).	All years (through 2016).	1990-2016	All years (through 2016).
Geographic scope	Global	North America and Europe	Global	Global

Table S1

Carnivore species considered	• Large carnivores with body mass >15 kg [5]. • 28 species (all considered)	• Free- ranging, native carnivores of North America and Europe > 5 kg. • 6 species (final review)	Terrestrial mammalian large carnivore species with body mass >15 kg (Ripple, Estes (5), plus coyotes and wolverines. • 30 species (all considered)	• Focused on large carnivores as defined by Ripple, Estes (5) but some studies considered small *and* large species (e.g. foxes, coyotes). • 11 species (final review)
Definition of technique effectiveness	Change in livestock losses or the potential for an attack (e.g., percent reduction in livestock losses or carnivore visits to a pasture) after techniques were applied.	Whether intervention will protect property owners from future losses.	Change in livestock losses (number of livestock killed, the number of livestock units attacked) or the potential for an attack (manipulation of carnivore behaviour/movement in a way that is expected to reduce exposure of livestock to carnivore predation).	• Change in livestock loss (e.g., percent loss of stock, loss of stock per period, or financial loss) and carnivore incursions into corrals or bomas. • Change in number of retaliatory killings of carnivores. • Facilitation of coexistence measured as reduction in livestock loss or retaliatory killing of carnivores.
Inclusion criteria	• Primary literature that provided numeric metrics (or values for calculating numeric metrics) of effectiveness • Reviews were omitted from analysis • Correlative studies were included.	Criteria for including studies: 1. Studies used experimental or quasi- experimental control with a design that allowed strong inference; 2. Studies occurred on working livestock operations with free-ranging, native carnivores, and 3. Studies verified livestock losses. • Correlative studies were excluded, as well as those based only on unverified estimates of livestock loss	Included studies were: • Included an empirical study of wild (i.e., not captive) carnivores; • Included a quantitative evaluation of interventions to prevent/reduce depredation of livestock (excluding apiaries); • Included a matched control to which the treatment was compared, i.e. have an experimental or quasi-experimental design. Experimental studies include a	• Did not analyze changes in human tolerance or perceptions of carnivores; rather, included self-reported changes in livestock losses following introduction of a mitigation measure. • Studies had to be replicated with a before–after or control–impact (BACI) design. • Studies had to be field trials on livestock and at least 2 months in duration. • Excluded studies involving

Table S1

		(e.g. self- reported livestock losses or perceptions of effectiveness), and analyses in which n ≤ 4 subjects (farms or livestock herds) completed the test.	randomized case-control study design, quasi-experimental studies include a case-control study design that was not assigned randomly. • Correlative studies were excluded. • Included a description of the methods used to implement the intervention (treatment) and of a study design sufficient for replication	bait or captive carnivores • Some studies that were included did not have strict control treatments; instead compared the effects of an improvement or change in management such as electrification of fences or implementing coordinated rather than ad hoc lethal control.
Data screening and harvesting	Recorded measures of effectiveness, amount of time techniques were effective, large carnivore species involved and country where the study occurred.	• Regarding criterion (1), described in the text why any test was deemed unreliable based on selection, treatment, measurement, or reporting biases (see above). • Regarding criterion (2), defined a working livestock operation as one in which livestock, land, and predators were managed in ways characteristic of a private livestock producer. That criterion excluded tests with captive predators [6]. • Regarding criterion (3), excluded studies measuring self- reported livestock losses or perceptions of effectiveness from Table 1.	• 48,894 titles retrieved from primary search. • Initial manual screening of titles reduced number to 27,781. • Second manual screening (English language, depredation of domestic animals by included carnivores) left 562 publications. • Two authors read papers in full to identify correlational, quasi-experimental, or experimental studies, and identify quantitatively evaluated studies.	• Database searches returned 3146 records; 175 were added through less-structured sampling. • Mitigation methods were grouped into 5 predefined categories for the meta-analysis: lethal control, livestock guardian animals, fencing, shepherding by humans, and deterrents (e.g. aversive conditioning, repellents, and protection devices. • 40 papers describing financial incentives were discovered, including 3 that measured success, but these were not considered appropriate for comparison with other mitigation

Table S1

		• After close reading, excluded >11 studies because they did not provide reliable inference. Several tests were excluded because they were not peer-reviewed, published descriptions of all methods and results.		measures because the response variables were changes in farmer attitudes or retaliatory killing rather than livestock loss.
Statistical units of effectiveness	• Measures of livestock loss (e.g. number or percent livestock stock killed) • For studies reporting the effectiveness on a community of predators, reported the effectiveness for the predator community as a whole.	Livestock loss: number of livestock injured or killed by carnivores.	Mean number of animals or livestock units (e.g. herds) depredated by carnivores, or number of trespasses by carnivores.	• Measures of livestock loss, e.g. percent loss of stock, loss of stock per period, or financial loss.

Table S1

Data Analysis	• Compared the effectiveness of techniques by calculating the magnitude of change between conditions before and after a technique was applied. Calculated the magnitude of change (D) as the percentage deviation from initial conditions following the formula (adapted from Jones and Schmitz (7): $D = ([B – A]/B) \times 100$ where B represents a quantitative measure of conditions (the change in livestock losses or the potential for an attack; e.g., no. of livestock killed) before the mitigation technique was applied and A represents conditions after the technique was applied. • This metric afforded a common basis for comparing different techniques by standardizing measures of change in terms of a proportion to facilitate data integration from different studies that used different units in their response metrics.	Counted tests in various categories. Did not perform a quantitative meta-analysis of effects, because there is no standard for consistent application of treatments and because the variety of methods used even within one category (e.g. different types of traps, or breeds of livestock- guarding dogs [LGDs]) would introduce uncontrollable variation. Furthermore, tests using the silver standard offer weaker inference than those using the gold standard but to an unknown degree.	• Relative risk (or risk ratio, RR) for carnivore depredation or incursions in treatment vs. control groups for each study [8]. • RR defined as the ratio between the probability of depredation by large carnivores in the treatment group and the probability of livestock depredation by large carnivores in the control group: $\text{Relative Risk(RR)} = \frac{a/(a+b)}{c/(c+d)}$ where *a* is the number of depredated animals/units in the treatment group, *b* is the number of unharmed animals/ units in the treatment group, *c* is the number of depredated animals/units in the control group, and *d* is the number of unharmed animals/units in the control group. • With no difference in the risk of depredation between treatment and control, the relative risk is 1. When RR > 1, the risk of depredation is more likely to occur in the treatment group. When RR < 1 depredation risk is	• Sample sizes, means, and standard deviations were extracted from the text, tables, or figures from each article or calculated from the data provided. • Calculated the standardized effect size as Hedges' *d* [10] with MetaWin version 2.1 [11]. Hedges' *d* is an estimate of the standardized mean difference between control and treatment and accounts for variation in study effort such that it is not biased by small sample size [10]. Negative values of *d* indicated the treatment successfully reduced conflict (e.g., livestock loss declined). • Data were analyzed using a random-effects model except where pooled variance was 0 (fixed-effects model used). The mean effect size per category was weighted based on variance and sample size. Total heterogeneity (Q_T) was calculated for each category [11]. • Summarized data on change in carnivore killing as a proxy for tolerance

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			higher in the control group. • For calculation of RR used the mean number of animals in treatment and control herds, as reported in the original studies (n = 1), or calculated from the reported true numbers for several herds (n = 11), as well as the number of livestock units (n = 2). Reported odds-ratios were converted to RR using an online odds ratio to risk ratio calculator [9], and Hazards Ratio were reported as in original study. Five papers did not report herd sizes; paper authors of two of these studies provided this data.	because killing suggested an unwillingness to coexist.
Number of studies included	67	12	21	37

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