Conservation Biology

Review

Managing conflict between large carnivores and livestock

Lily M. van Eeden,[1] Mathew S. Crowther,[1] Chris R. Dickman,[1] David W. Macdonald,[2] William J. Ripple,[3] Euan G. Ritchie,[4] and Thomas M. Newsome[1,3,4,5]

[1]Desert Ecology Research Group, School of Life and Environmental Sciences, University of Sydney, NSW 2006, Australia
[2]Wildlife Conservation Research Unit, Department of Zoology, University of Oxford, The Recanati-Kaplan Centre, Tubney House, Tubney, Abingdon OX13 5QL, U.K.
[3]Global Trophic Cascades Program, Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331, U.S.A.
[4]Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria 3125, Australia
[5]School of Environmental and Forest Sciences, Box 352100, University of Washington, Seattle, WA 98195, U.S.A.

Abstract: *Large carnivores are persecuted globally because they threaten human industries and livelihoods. How this conflict is managed has consequences for the conservation of large carnivores and biodiversity more broadly. Mitigating human–predator conflict should be evidence-based and accommodate people's values while protecting carnivores. Despite much research into human and large-carnivore coexistence strategies, there have been few attempts to document the success of conflict-mitigation strategies on a global scale. We conducted a meta-analysis of global research on conflict mitigation related to large carnivores and humans. We focused on conflicts that arise from the threat large carnivores pose to livestock. We first used structured and unstructured searching to identify replicated studies that used before–after or control–impact design to measure change in livestock loss as a result of implementing a management intervention. We then extracted relevant data from these studies to calculate an overall effect size for each intervention type. Research effort and focus varied among continents and aligned with the histories and cultures that shaped livestock production and attitudes toward carnivores. Livestock guardian animals most effectively reduced livestock losses. Lethal control was the second most effective control, although its success varied the most, and guardian animals and lethal control did not differ significantly. Financial incentives have promoted tolerance of large carnivores in some settings and reduced retaliatory killings. We suggest coexistence strategies be location-specific, incorporate cultural values and environmental conditions, and be designed such that return on financial investment can be evaluated. Improved monitoring of mitigation measures is urgently required to promote effective evidence-based policy.*

Keywords: carnivore, human–wildlife conflict, lethal control, livestock guardian animals, nonlethal management, predator

El Manejo del Conflicto entre Carnívoros Grandes y el Ganado

Resumen: *Los carnívoros grandes son perseguidos en todo el mundo porque amenazan el sustento y las industrias humanas. En general, la forma en que se maneja este conflicto tiene consecuencias para la conservación de los grandes carnívoros y la biodiversidad. La mitigación del conflicto humano – fauna debería tener bases en las evidencias y debería acomodarse a los valores de las personas mientras protege a los carnívoros. A pesar de la amplia investigación sobre las estrategias de coexistencia entre humanos y carnívoros grandes, ha habido pocos intentos por documentar el éxito de las estrategias mitigantes del conflicto en una escala global. Realizamos un meta-análisis de la investigación global sobre la mitigación de conflictos relacionados con los carnívoros grandes y los humanos. Nos enfocamos en los conflictos que surgen de la amenaza que los carnívoros grandes presentan para el ganado. Primero utilizamos búsquedas estructuradas y no-estructuradas para identificar los estudios replicados que utilizaron el diseño antes – después o*

email lily.vaneeden@sydney.edu.au
Paper submitted October 25, 2016; revised manuscript accepted May 22, 2017.

DOI: 10.1111/cobi.12959

control – impacto para medir el cambio en la pérdida del ganado como resultado de la implementación de una intervención de manejo. Después extrajimos los datos relevantes de estos estudios para calcular un tamaño general de efecto para cada tipo de intervención. El esfuerzo y el enfoque de la investigación variaron entre los continentes y se alinearon con las historias y culturas que dieron forma a la producción ganadera y a las actitudes hacia los carnívoros. Los animales guardianes del ganado fueron los que redujeron con mayor eficiencia las pérdidas del ganado. El control letal fue el segundo control más efectivo, aunque su éxito fue el que más varió, y los animales guardianes y el control letal no difirieron significativamente. Los incentivos económicos han promovido la tolerancia de los carnívoros grandes en algunas localidades y han reducido las muertes por represalia. Sugerimos que las estrategias de coexistencia sean específicas de la localidad, incorporen los valores culturales y las condiciones ambientales, y estén diseñadas de tal forma que el retorno de una inversión financiera pueda ser evaluado. El monitoreo mejorado de las medidas de mitigación es requerido urgentemente para promover la política efectiva basada en evidencias.

Palabras Clave: animales guardianes del ganado, carnívoro, conflicto humano – fauna, control letal, depredador, manejo no-letal

Introduction

Large terrestrial carnivores play important roles in regulating ecosystems but are threatened on all continents where they occur (Ripple et al. 2014). This threat is mostly attributable to lethal control in response to conflict between large carnivores and people. In consequence, conservation of large carnivores is considered achievable only by setting aside habitat away from human settlements (Packer et al. 2013). However, coexistence between humans and large carnivores is possible, as demonstrated by increasing populations of large carnivores in parts of Europe (Chapron et al. 2014) and Asia (Athreya et al. 2013) that are densely populated by humans. As human populations continue to expand in much of the world, it is becoming increasingly important to mitigate conflicts between humans and large carnivores to improve the conservation of large carnivores (Ripple et al. 2016) and preserve their functions more broadly (Ritchie et al. 2012; Ripple et al. 2014).

Predation on livestock is the main source of conflict between large carnivores and humans (Sillero-Zubiri et al. 2004; Macdonald et al. 2010). Such losses have economic impacts (Fleming et al. 2006), and large carnivores also pose a direct threat to human safety (Löe & Röskaft 2004). Furthermore, management of large carnivores is politically charged (Nie 2003; Chapron & López-Bao 2014). Ranchers feel especially powerless to protect their enterprises (Naughton-Treves et al. 2003) when restrictions are imposed on lethal control (Bergstrom et al. 2009). Lethal control is a dominant component of human and large-carnivore conflict mitigation and is implemented legally (Treves & Karanth 2003) and illegally (Liberg et al. 2011). Some governments conduct or support population culls or targeted killing of problem individuals, and illegal killing occurs often in retaliation for a livestock depredation event (Creel & Rotella 2010).

Historically, management of large-carnivore populations has been a component of livestock husbandry, and improvements in technology have allowed increasingly effective control methods (Fleming et al. 2006). In some places where large-carnivore populations have been reduced or eradicated, traditional husbandry techniques have been abandoned and livestock are allowed to graze over larger areas unsupervised (Linnell et al. 1996). This practice can exacerbate conflict where large carnivores are being reintroduced or where they are returning naturally. However, nonlethal control methods have been developed to mitigate conflict between humans and large carnivores. These methods include deployment of livestock guardian animals and exclusion fencing, sterilization and translocation of large carnivores, chemical and physical deterrents, and financial incentives such as compensation for depredated livestock (Conover 2002; Baker & Macdonald 2015).

Across all aspects of environmental management, there is a recognized need for rigorous and systematic appraisal of interventions to inform policy decisions (Pullin & Knight 2001; Sutherland et al. 2004). But there is seldom adherence to such standards, which impedes large-carnivore conservation (Treves et al. 2016). Despite much research into strategies for coexistence of humans and large carnivores, there have been few attempts to document the success of conflict-mitigation strategies on a global scale. Meta-analytical approaches allow quantitative assessments of the magnitude of direction of an experimental impact (Rosenberg et al. 2000) and have been used successfully with data sets containing unreplicated studies for which variances cannot be used in the calculation of effect sizes (Salo et al. 2010). Thus, meta-analyses can help make sense of complicated and disputed research results by combining the results of many studies and increasing the precision of the estimate of effect size (Cumming 2011).

We investigated human-large carnivore conflict and the effectiveness of measures used globally to reduce conflict with or killing of large carnivores. We focused on conflicts arising from the threat that large terrestrial carnivores pose to the livestock industry. To do so, we reviewed published and unpublished studies that

quantified the effectiveness of a given management measure. Our primary aim was to determine which coexistence strategy was most effective at reducing human and large-carnivore conflict as measured based on a reduction in livestock losses. Our secondary aim was to determine whether there are viable alternatives to broadscale lethal control of large carnivores in different parts of the world. We used our results to assess the need and capacity to change large-carnivore management and to consider the implications for the conservation of large carnivores and ecosystems more broadly.

Methods

Data and Definitions

In our meta-analysis (Hedges & Olkin 1985), we used data from studies of the success of strategies to mitigate conflict between large carnivores and humans engaged in the livestock industry. We defined success as facilitation of coexistence. Response variables were 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. Levels of livestock loss may not correlate directly with coexistence, but it is probably a key indicator given that predation on livestock is the main reason for large-carnivore persecution. Furthermore, due to a lack of appropriate, consistent data, we did not analyze changes in human tolerance or perceptions of carnivores; rather, we included self-reported changes in livestock losses following introduction of a mitigation measure.

Literature Search

We used Web of Science (All Databases) and SCOPUS to search the literature. Combinations of search terms related to carnivores, livestock, impacts of carnivores on stock, and intervention techniques (Supporting Information). We excluded certain terms in the search to reduce the return of irrelevant papers (e.g., papers on invertebrate and nonterrestrial predators and on diseases and parasites) (Supporting Information). References from papers deemed appropriate to the analysis, as well as from review papers, were examined to source further relevant articles. We also searched Google Scholar and the European Commission LIFE project database with a subset of the search terms. The systematic search was further supplemented by contacting several researchers and organizations involved in management or research of human and large-carnivore conflict to obtain unpublished data or grey literature. We placed no limits on publication date.

The database searches returned 3146 records in total, and a further 175 were added through less-structured searching. Papers that did not provide appropriate data (see below) for inclusion in a meta-analysis were excluded. This left 43 replicated studies that provided means, sample sizes, and sufficient information to calculate standard deviations for both control and treatment. Three of these studies were excluded because there were not enough replicates (e.g., fladry, fertility control, and combined methods); a minimum of 2 studies are required for comparison in a meta-analysis. There was 1 paper each in French (LvE translated), Norwegian, and German (abstract and figure and table captions in English); all others were in English.

Mitigation methods were grouped into 5 predefined categories for the meta-analysis: lethal control (several techniques), livestock guardian animals (dogs, llamas, and alpacas), fencing (installation or improvement using electrification), shepherding by humans, and deterrents. The latter group included aversive conditioning, repellents (chemical, visual, auditory), and protection devices (e.g., livestock protection collars). Forty papers describing financial incentives were discovered, including 3 that measured success, but these were not considered appropriate for comparison with other mitigation measures because the response variables were changes in farmer attitudes or retaliatory killing rather than livestock loss.

Our inclusion criteria required that studies 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 to allow time for effects to be detected. Studies in which bait takes were measured or captive carnivores were used were excluded. Some studies did not have strict control treatments. Instead, they compared the effects of an improvement or change in management such as electrification of fences or implementing coordinated rather than ad hoc lethal control. Some of the papers identified were not considered to have a sufficiently high standard of study design for inclusion in a review by Treves et al. (2016). Although we recognize obtaining randomized samples is ideal, it is often impossible given management constraints, and a range of study designs that are limited in scope can still provide valuable data when pooled in a meta-analysis (Oksanen 2001). We therefore included all relevant studies that met our criteria. This approach fits within the framework of meta-analyses (Hedges & Olkin 1985), which is specifically designed to synthesize the results of independent studies that address the same question (Cooper et al. 1994). Furthermore, it incorporates statistical procedures that account for varying quality and reliability across individual studies (Hedges & Olkin 1985).

Data Analyses

Sample sizes, means, and standard deviations were extracted from the text, tables, or figures from each article

or calculated from the data provided. Sample sizes were typically the number of treatment farms or herds or the number of years over which data were compared. Where experiments within a study were defined by area and multiple years of data were provided, we averaged data across years. For papers that contained more than one study category, each category was considered a separate study in the meta-analysis.

For each study, we calculated the standardized effect size as Hedges' d (Hedges & Olkin 1985) with MetaWin version 2.1 (Rosenberg et al. 2000). 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 (Hedges & Olkin 1985). Negative values of d indicated the treatment successfully reduced conflict (e.g., livestock loss declined), a 0 meant no effect, and positive values indicated the treatment worsened the conflict. Because the data even within categories varied with study design and intervention, data were analyzed using a random-effects model, which was chosen as the most appropriate framework because it accounts for different sizes of true effect among studies (Hedges 1983; Gurevitch & Hedges 1999). However, where pooled variance was ≤ 0, a fixed-effects model was used. The mean effect size per category was weighted based on variance and sample size. Total heterogeneity (Q_T) was calculated for each category (Rosenberg et al. 2000).

We also intended to compare other response variables, but insufficient data on these variables were available for inclusion in the meta-analysis. We therefore summarized data on change in carnivore killing as a proxy for tolerance because we considered killing suggested an unwillingness to coexist.

Results

Review

Research effort ($n = 235$) into mitigating livestock loss to large carnivores was geographically biased. For example, 47.2% of studies ($n = 111$) occurred in North America, whereas only 1 paper was identified in South America (Fig. 1a), and 11 (52.4%) of the studies in Asia were from India.

Research focus within continents varied. Studies of lethal control were most frequent in Australia (50% of all studies), studies of financial incentives were most frequent in Asia (52.4%), and studies of deterrent strategies were most frequent in North America (29.7%) (Fig. 1a). The late 1970s to early 1980s saw an increase in research into mitigating conflict with large carnivores, with a particular focus on deterrents. Since then research focus has shifted primarily toward financial incentives, lethal control, and guardian animals (Fig. 1b).

Livestock Loss

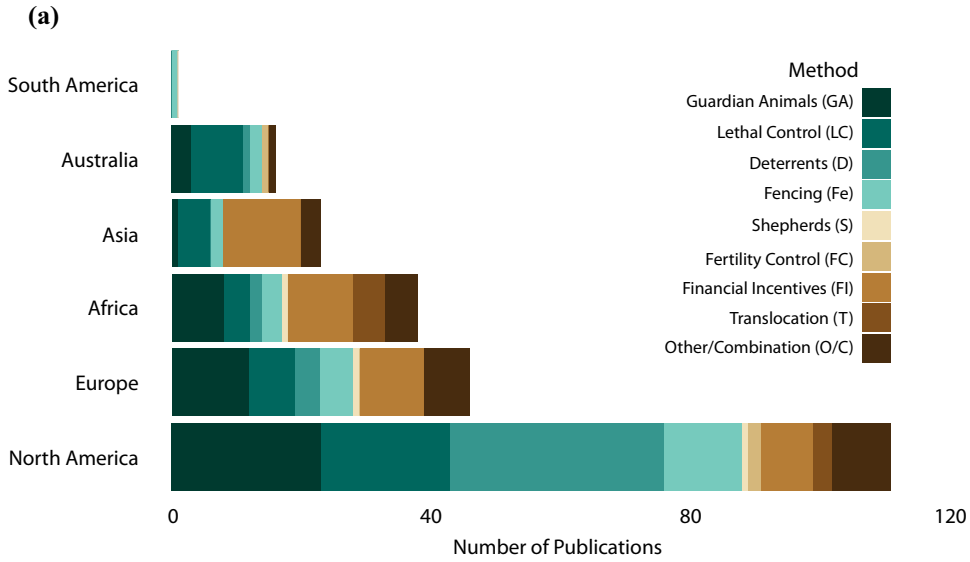
Of the 40 studies included in the meta-analysis, 13 assessed livestock guardian animals, 10 assessed deterrents, 8 fencing, 7 lethal control, and 2 shepherding. Overall, the mitigation methods assessed reduced predation on livestock by large carnivores (Fig. 2). However, in 3 individual studies (2 lethal control studies and 1 guardian animal study) livestock loss to large carnivores was higher for the treatment than the control group. Greatest mean effect size was exhibited by guardian animals (-1.33), followed by lethal control (-1.18), deterrents (-1.09), fencing (-0.82), and shepherding (-0.53). These effect sizes were not significantly different, and high variability in effect size was exhibited by lethal control (pooled variance 1.86) and guardian animals (1.60). Pooled variance was ≤ 0 for the other 3 mitigation methods. None of the Q_T values were significant ($p < 0.05$), implying that variance among effect sizes was within that expected by sampling error (Cooper 1998).

Large-Carnivore Killing

Although insufficient data were available for a meta-analysis, we compared studies that measured changes in retaliatory killing of large carnivores as a proxy for tolerance. Five studies (from 3 papers) on financial incentives were identified, all occurred in Kenya. These presented an average reduction in retaliatory killings of 82.6% (range 58.0–100%) when financial incentives were available. The addition of livestock guardian animals in one study in Namibia identified a 33.3% reduction in large-carnivore killing by farmers (Potgieter et al. 2016). Similarly, in one area, the Lion Guardian program in Kenya (which trains and supports community members to protect lions) reduced large-carnivore killing 100% (Hazzah et al. 2014), and in another area, when protection was combined with financial incentives killing was reduced by 97.8% (Hazzah et al. 2014).

Discussion

Our main finding that nonlethal management can be more or just as effective as lethal control suggests that coexistence with large carnivores is possible. Furthermore, some studies showed that lethal control of large carnivores actually increases livestock losses (Conner et al. 1998; Harper et al. 2008; Allen 2013; Peebles et al. 2013; Wielgus & Peebles 2014). Given that populations of large carnivores and human livelihoods supported by livestock production are both valuable, lethal control should therefore be considered only where it is likely to reduce livestock losses. Livestock guardian animals have been used in Europe for centuries, and there has been a steady increase in guardian animal research in recent decades. Guardian animal programs have been implemented with



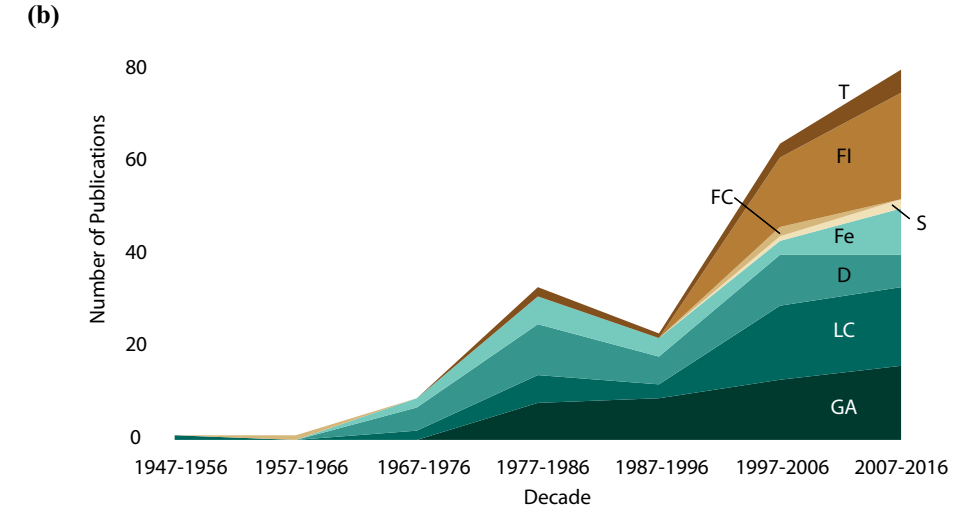


Figure 1. Number of publications per method implemented to mitigate conflict between large carnivores and livestock (a) on each continent (235 total publications) and (b) over the last 7 decades since published research on mitigating conflict with large carnivores began.

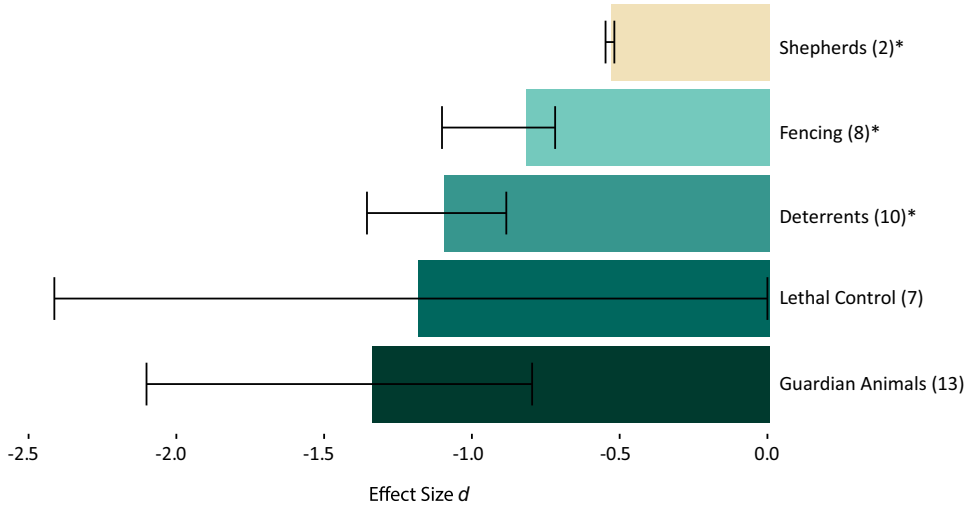


*Figure 2. Mean effect size (Hedges' d) and percentile bootstrap confidence intervals (whiskers) per method used to mitigate conflict between large carnivores and livestock (number of studies in parentheses; *, pooled variance ≤0 thus data analyzed with a fixed-effects model rather than a random-effects model).*

support from government and nongovernment organizations in Europe and Africa (e.g., Marker et al. 2005; Mulej et al. 2013) and include training farmers and providing guardian dogs. The use of guardian animals has been researched more in the United States than elsewhere (Rigg 2001), and guardian animals are used by 23.5% of small-stock producers in the United States (USDA 2015). Lack of research and government support may explain limited uptake of these methods in other areas. Indeed, published research into livestock guardian animals in Australia began in 2004 (Mahoney & Charry 2004), and current government strategies continue to promote broad-scale eradication (National Project Steering Committee 2014). This highlights a clear disconnect between the evidence base and prevailing policy on predator-livestock management.

Social perceptions and public awareness are fundamental in shaping effective coexistence strategies because public behaviors and attitudes toward wildlife are not necessarily based on evidence (Marchini & Macdonald 2012). The stronger research effort into mitigating conflict in the United States, a pattern also observed by Can et al. (2014) for research on bear (*Ursus* spp.) management, may be partly due to public pressure that led to U.S. President Richard Nixon's ban on poison baiting in 1972 (Flores 2016). Around this time, there was an increase in research overall and in particular on new technologies such as visual, chemical, and auditory deterrents (Fig. 1b). This was likely a response to increased pressure to abandon methods that the public perceived to be cruel or unethical. In contrast, in Australia, where poison baiting is still the dominant management method, public knowledge of lethal dingo (*Canis dingo*) control is complicated by labeling of the dingo as a wild dog. Portraying the dingo as a feral dog potentially prevents public opposition by masking the issue as management of an invasive pest rather than the destruction of a species that has been present for >3500 years and thus generally considered native (Letnic et al. 2012). Such comparisons reveal the importance of public engagement in linking science and policy for improving wildlife management.

Livestock loss needs to be managed, but because perception of risk is ultimately more important than actual losses (Naughton-Treves et al. 2003), other response variables should be considered when developing coexistence strategies to promote tolerance of carnivores. Financial incentives successfully promoted a reduction in predator killing in an African setting (Maclennan et al. 2009; Hazzah et al. 2014; Bauer et al. 2015). Insufficient data were available to compare other mechanisms, but the high success rate of the Lion Guardian program (Hazzah et al. 2014) promotes the value of community-engagement programs that seek to build tolerance for carnivores. Propensity to kill large carnivores may have little connection with perceived livestock loss and may be more closely associated with fear, personal and social motivations, and internal and external barriers to killing carnivores (Naughton-Treves et al. 2003; Marchini & Macdonald 2012).

Strategies to manage conflict between humans and large carnivores must be context-specific. Along with the evidence of success in Kenya, financial incentives have been the focus of mitigation research in Asia, suggesting this method may be effective in developing nations (Dickman et al. 2011). Considering cultural and economic factors is crucial in mitigating conflict in all contexts. However, values surrounding livestock production and social identity in Western countries may make conflict yet more political and less likely to be resolved with financial incentives (Naughton-Treves et al. 2003). Returning to traditional husbandry methods, including increased human presence, can be a culturally appropriate means of promoting coexistence (Dorresteijn et al. 2015), as is occurring in the United States with the employment of range riders (mounted herdsmen) (Bangs et al. 2006). The Lion Guardian project that began in Kenya further applies traditional conflict-mitigation techniques and builds tolerance for lions by incorporating Maasai community cultural values and belief systems (Hazzah et al. 2014). In a biological approach, innovative techniques such as mimicry are used to deter predators. Similar to the masks worn on the back of forest workers' heads to deter tiger attacks (Rishi 1988), researchers are now experimenting with painting eyes on the hind quarters of cattle (Jordan 2016), a technique that can deter ambush predators but not pursuit predators. These examples highlight the potential for innovation and adaptive mitigation strategies tailored to local contexts.

Limitations

Although we sought to be as comprehensive as possible, there are biases that may have affected our results. Publication bias was observed in that the publications we found presented only significant results. It is possible that research that yielded nonsignificant results was never published or that nonsignificant results were omitted from the publications we did find. We used only English search terms, which may cause bias toward English-speaking countries. Furthermore, comparable and consistent data are required for a meta-analysis, and although the effect size d for replicated BACI research was chosen to incorporate the broadest range of studies, many lethal control studies used correlative approaches and thus could not be compared with other mitigation methods. This feature of the analysis revealed that research on conflict mitigation needs to be consistent, standardized, experimental, and should measure appropriate response variables.

Limits in available data prevented separate analyses for different groups. For example, insufficient data were available to draw comparisons between carnivore groups

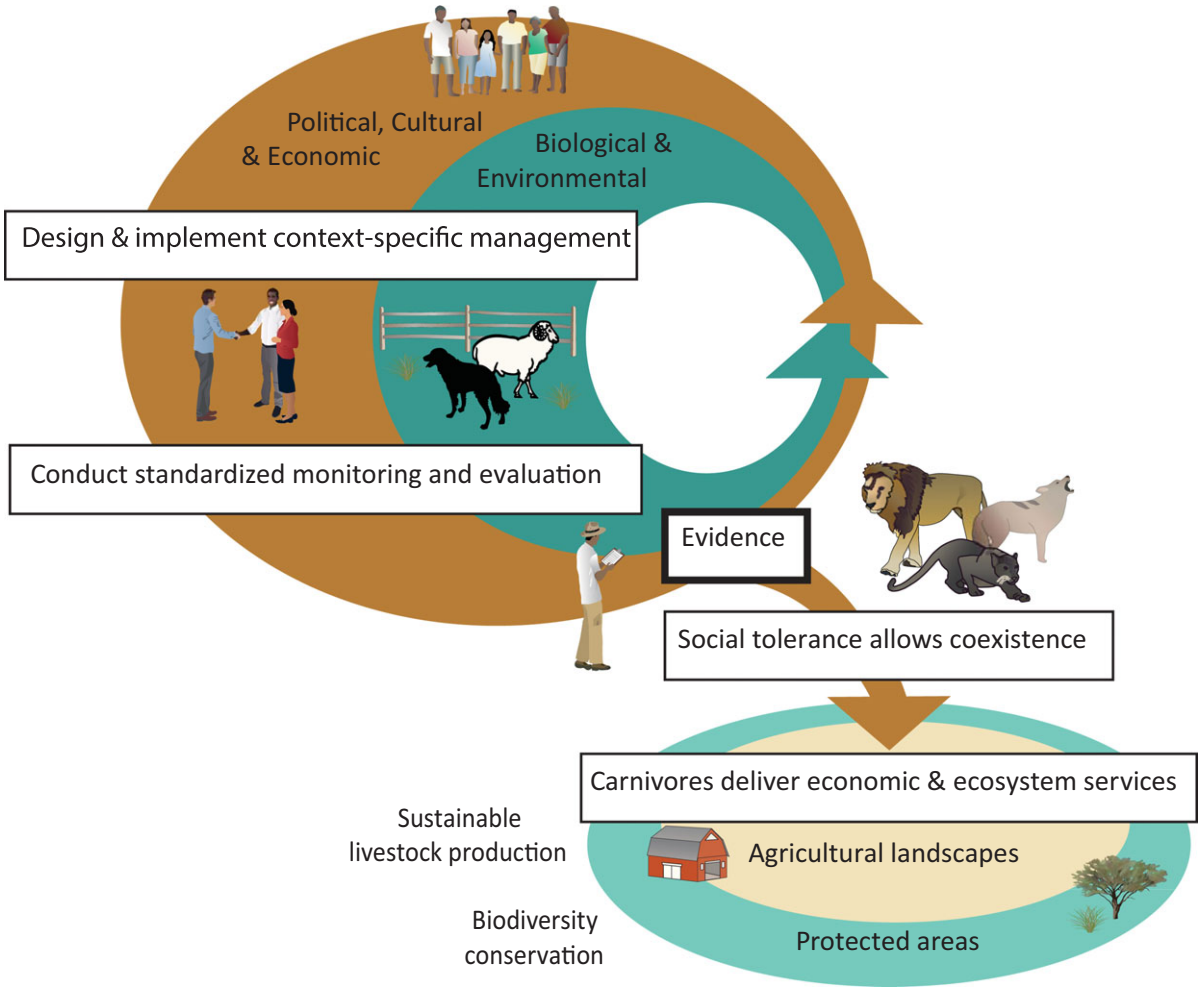


Figure 3. Adaptive and context-specific management to facilitate coexistence of humans with large carnivores so as to allow carnivore provision of ecosystem services across landscapes to benefit biodiversity and rural livelihoods.

or geographic locations. Such information is needed to inform context-specific management. Variation in effect sizes within groups was partly attributable to environmental variation, such as presence of alternative prey or vegetation cover. A range of other locally specific factors (cultural, economic) will affect the appropriateness of different methods to manage carnivore conflict in different settings. Despite these shortfalls, however, our results provide a useful synthesis of existing research and evidence of varying effectiveness. It reveals historic research trends and gaps in the existing knowledge base that highlight the need for more appropriate monitoring of mitigation effort.

Implications

Current evidence suggests that livestock guardian animals may be the tool most likely to achieve the intended management objective (i.e., a reduction in livestock loss and minimization of negative effects to carnivore populations) in a range of contexts. Thus, nonlethal methods are beneficial to livestock production and reduce pressure on carnivore species by allowing coexistence. Indeed, our meta-analysis results suggest that in spite of limited data, there was evidence that challenges the assumption that lethal control reduces livestock loss more effectively than nonlethal methods (not considering financial cost-effectiveness). To conserve carnivores, a stronger evidence base needs to be built upon which to challenge current management practices that are detrimental to the environment and exacerbate threats to carnivore species (Fig. 3). Advocates of carnivore conservation might therefore consider investing in appropriate monitoring and reporting on conflict mitigation to build on the evidence for nonlethal management presented here.

We recommend that future researchers strive to measure the success of mitigation methods with standardized, experimental, and appropriate response variables under different contexts. We excluded many studies from our

analysis because success was measured as either financial investment or management effort. These response variables do not reflect management objectives. Mitigation should reduce livestock loss and facilitate coexistence, so response variables should directly measure these outcomes. Without such evidence, the capacity for management change is hindered as are human livelihoods and the conservation of large carnivores.

Acknowledgments

We thank individuals and organizations who contributed unpublished data, including L. van Bommel and Walking for Lions.

Supporting Information

A list of the search terms used (Appendix S1) and studies included in the analysis (Appendices S2 and S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Allen LR. 2013. Wild dog control impacts on calf wastage in extensive beef cattle enterprises. Animal Production Science **54:**214–220.

Athreya V, Odden M, Linnell JDC, Krishnaswamy J, Karanth U. 2013. Big cats in our backyards: persistence of large carnivores in a human dominated landscape in India. PLOS ONE **8**(e57872) https://doi.org/10.1371/journal.pone.0057872.

Baker SE, Macdonald DW. 2015. Managing wildlife humanely with learned food aversions. Pages 260–275 in Macdonald DW, Feber RE, editors. Wildlife conservation on farmland: conflict in the countryside. Oxford University Press, Oxford.

Bangs E, et al. 2006. Non-lethal and lethal tools to manage wolf-livestock conflict in the northwestern United States. Pages 7–16 in Timm RM, O'Brien JM, editors. Proceedings of the 22nd Vertebrate Pest Conference. University of California, Davis, California.

Bauer H, Müller L, Van Der Goes D, Sillero-Zubiri C. 2015. Financial compensation for damage to livestock by lions *Panthera leo* on community rangelands in Kenya. Oryx **51:**106–114.

Bergstrom BJ, Vignieri S, Sheffield SR, Sechrest W, Carlson AA. 2009. The Northern Rocky Mountain gray wolf is not yet recovered. BioScience **59:**991–999.

Can ÖE, D'Cruze N, Garshelis DL, Beecham J, Macdonald DW. 2014. Resolving human-bear conflict: a global survey of countries, experts, and key factors. Conservation Letters **7:**501–513.

Chapron G, et al. 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes. Science **346:**1517–1519.

Chapron G, López-Bao JV. 2014. Conserving carnivores: politics in play. Science **343:**1199–1200.

Conner MM, Jaeger MM, Weller TJ, McCullough DR. 1998. Effect of coyote removal on sheep depredation in northern California. Journal of Wildlife Management **62:**690–699.

Conover MR. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. Lewis Publishers, CRC Press, Boca Raton.

Cooper H, Hedges LV, Valentine JC. 1994. The handbook of research synthesis and meta-analysis. Russell Sage Foundation, New York.

Cooper H. 1998. Synthesizing research: a guide for literature reviews. Applied social research methods. Sage, Thousand Oaks.

Creel S, Rotella JJ. 2010. Meta-analysis of relationships between human offtake, total mortality and population dynamics of gray wolves (*Canis lupus*). PLOS ONE **5**(e12918) https://doi.org/10.1371/journal.pone.0012918.

Cumming G. 2011. Understanding the new statistics: effect sizes, confidence intervals, and meta-analysis. Routledge, New York.

Dickman AJ, Macdonald EA, Macdonald DW. 2011. A review of financial instruments to pay for predator conservation and encourage human-carnivore coexistence. Proceedings of the National Academy of Sciences **108:**13937–13944.

Dorresteijn I, Schultner J, Nimmo DG, Fischer J, Hanspach J, Kuemmerle T, Kehoe L, Ritchie EG. 2015. Incorporating anthropogenic effects into trophic ecology: predator–prey interactions in a human-dominated landscape. Proceedings of the Royal Society of London B: Biological Sciences **282:** https://doi.org/10.1098/rspb.2015.1602.

Fleming PJS, Allen LR, Lapidge SJ, R A, Saunders GR, Thomson PC. 2006. A strategic approach to mitigating the impacts of wild canids: proposed activities of the Invasive Animals Cooperative Research Centre. Australian Journal of Experimental Agriculture **46:**753–762.

Flores D. 2016. Coyote America: a natural and supernatural history. Basic Books, New York.

Gurevitch J, Hedges LV. 1999. Statistical issues in ecological meta-analyses. Ecology **80:**1142–1149.

Harper EK, Paul WJ, Mech LD, Weisberg S. 2008. Effectiveness of lethal, directed wolf-depredation control in Minnesota. Journal of Wildlife Management **72:**778–784.

Hazzah L, Dolrenry S, Naughton L, Edwards CT, Mwebi O, Kearney F, Frank L. 2014. Efficacy of two lion conservation programs in Maasailand, Kenya. Conservation Biology **28:**851–860.

Hedges LV. 1983. A random effects model for effect sizes. Psychological Bulletin **93:**388–395.

Hedges LV, Olkin I. 1985. Statistical methods for meta-analysis. Academic Press, Orlando, Florida.

Jordan NR. 2016. iCows: can intimidating eye patterns painted onto cows reduce lion attacks? Experiment, New York. Available from https://experiment.com/projects/i-cows-can-intimidating-eye-patterns-painted-onto-cows-reduce-lion-attacks (accessed October 2016).

Letnic M, Ritchie EG, Dickman CR. 2012. Top predators as biodiversity regulators: the dingo *Canis lupus dingo* as a case study. Biological Reviews **87:**390–413.

Liberg O, Chapron G, Wabakken P, Pedersen HC, Hobbs NT, Sand H. 2011. Shoot, shovel and shut up: cryptic poaching slows restoration of a large carnivore in Europe. Proceedings of the Royal Society of London B: Biological Sciences **279:**910–915.

Linnell JDC, Smith ME, Odden J, Kaczensky P, Swenson JE. 1996. Strategies for the reduction of carnivore - livestock conflicts: a review. Norsk Institutt for Naturforskning (NINA) Oppdragsmelding, Trondheim.

Löe J, Röskaft E. 2004. Large carnivores and human safety: a review. AMBIO: A Journal of the Human Environment **33:**283–288.

Macdonald DW, Loveridge AJ, Rabinowitz A. 2010. Felid futures: crossing disciplines, borders, and generations. Pages 599–650 in Macdonald DW, Loveridge AJ, editors. Biology and conservation of wild felids. Oxford University Press, Oxford.

Maclennan SD, Groom RJ, Macdonald DW, Frank LG. 2009. Evaluation of a compensation scheme to bring about pastoralist tolerance of lions. Biological Conservation **142:**2419–2427.

Mahoney S, Charry AA. 2004. The value of alpacas in reducing newborn lamb-fox predation: a preliminary survey. Pages 1–7 in Proceedings of the 7th Australasian Farm Business Management Network conference. AFBM Network, Orange, New South Wales.

Marchini S, Macdonald DW. 2012. Predicting ranchers' intention to kill jaguars: case studies in Amazonia and Pantanal. Biological Conservation **147:**213–221.

Marker LL, Dickman AJ, Macdonald DW. 2005. Perceived effectiveness of livestock-guarding dogs placed on Namibian farms. Rangeland Ecology & Management **58:**329–336.

Mulej J, et al. 2013. Overall evaluation and monitoring of the project conservation achievements. University of Ljubljana, Ljubljana, Slovenia.

National Project Steering Committee. 2014. National wild dog action plan: promoting and supporting community-driven action for landscape-scale wild dog management. Barton, Australian Capital Territory.

Naughton-Treves L, Grossberg R, Treves A. 2003. Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. Conservation Biology **17:**1500–1511.

Nie MA. 2003. Beyond wolves: the politics of wolf recovery and management. University of Minnesota Press, Minneapolis.

Oksanen L. 2001. Logic of experiments in ecology: Is pseudoreplication a pseudoissue? Oikos **94:**27–38.

Packer C, et al. 2013. Conserving large carnivores: dollars and fence. Ecology Letters **16:**635–641.

Peebles KA, Wielgus RB, Maletzke BT, Swanson ME. 2013. Effects of remedial sport hunting on cougar complaints and livestock depredations. PLOS ONE **8**(e79713) https://doi.org/10.1371/journal.pone.0079713.

Potgieter GC, Kerley GIH, Marker LL. 2016. More bark than bite? The role of livestock guarding dogs in predator control on Namibian farmlands. Oryx **50:**514–522.

Pullin AS, Knight TM. 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology **15:**50–54.

Rigg R. 2001. Livestock guarding dogs: their current use world wide. Occasional paper 1. SSC Canid Specialist Group, International Union for Conservation of Nature, Gland, Switzerland.

Ripple WJ, et al. 2016. Saving the world's terrestrial megafauna. BioScience **66:**807–812.

Ripple WJ, et al. 2014. Status and ecological effects of the world's largest carnivores. Science **343:**1241484.

Rishi V. 1988. Man, mask and man-eater. Tigerpaper **15:**9–14.

Ritchie EG, Elmhagen B, Glen AS, Letnic M, Ludwig G, McDonald RA. 2012. Ecosystem restoration with teeth: What role for predators? Trends in Ecology & Evolution **27:**265–271.

Rosenberg MS, Adams DC, Gurevitch J. 2000. MetaWin: statistical software for meta-analysis. Sinauer Associates, Sunderland, Massachusetts.

Salo P, Banks PB, Dickman CR, Korpimäki E. 2010. Predator manipulation experiments: impacts on populations of terrestrial vertebrate prey. Ecological Monographs **80:**531–546.

Sillero-Zubiri C, Reynolds J, Novaro A. 2004. Management and control of wild canids alongside people. Pages 107–122 in Macdonald DW, Sillero-Zubiri C, editors. Biology and conservation of wild canids. Oxford University Press, New York.

Sutherland WJ, Pullin AS, Dolman PM, Knight TM. 2004. The need for evidence-based conservation. Trends in Ecology & Evolution **19:**305–308.

Treves A, Karanth KU. 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conservation Biology **17:**1491–1499.

Treves A, Krofel M, McManus J. 2016. Predator control should not be a shot in the dark. Frontiers in Ecology and the Environment **14:**1–9.

USDA. 2015. Sheep and lamb predator and nonpredator death loss in the United States. Fort Collins, Colorado.

Wielgus RB, Peebles KA. 2014. Effects of wolf mortality on livestock depredations. PLOS ONE **9**(e113505) https://doi.org/10.1371/journal.pone.0113505.