Managing conflict between large carnivores and livestock

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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 also protecting carnivores. Despite much research into human-large carnivore coexistence strategies, there have been limited attempts to document the success of conflict mitigation strategies on a global scale. We present a meta-analysis of global research on conflict mitigation between large carnivores and humans, focusing on conflicts that arise from the threat that large carnivores pose to livestock industries.

Overall, research effort and focus varied between continents, aligning with the different histories and cultures that shaped livestock production and attitudes towards carnivores. Of the studies that met our criteria, livestock guardian animals were most effective at reducing livestock losses, followed by lethal control, although the latter exhibited the widest variation in success and the two were not significantly different. Financial incentives have promoted tolerance in some settings, reducing retaliatory killings. In future, coexistence strategies should be location-specific, incorporating cultural values and environmental conditions, and designed such that return on financial investment can be evaluated. Improved monitoring of mitigation measures is urgently required to promote effective evidence-based policy.

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 densely human-populated parts of Europe (Chapron et al. 2014) and Asia (Athreya et al. 2013). As human populations continue to expand in much of the world, it is becoming increasingly important to mitigate human-large carnivore conflicts to improve the conservation of large carnivores (Ripple et al. 2016), and to 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), especially ranchers feel powerless to protect their private enterprises and their industry (Naughton-Treves et al. 2003), or when restrictions are imposed on lethal control (Bergstrom et al. 2009). Lethal control is a dominant component of human-large carnivore conflict mitigation, and is implemented both 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).

Management of large carnivore populations has historically 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 allowed to graze over larger areas unsupervised (Linnell et al. 1996). This can exacerbate conflict where large carnivores are being reintroduced or where they are returning naturally. However, nonlethal control methods have been developed to mitigate human-large carnivore conflict. These methods range from deployment of livestock guardian animals, through exclusion fencing, sterilizing large carnivores, translocation, chemical and physical deterrents, to financial incentives (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 human-large carnivore coexistence strategies, 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 datasets containing unreplicated studies where 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 literature by combining the results of many studies and increasing the precision of estimate of the effect size (Cumming 2011).

Here, we investigated human-large carnivore conflict and the effectiveness of measures that are used globally to reduce conflict or reduce large carnivore killing. 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. To evaluate the effectiveness of each measure we grouped studies that assessed the same coexistence strategy and then, after omitting studies that did not provide quantifiable data, we calculated standardized effect sizes. Our primary aim was to determine which coexistence strategy was most effective at reducing human-large carnivore conflict, as measured by a reduction in livestock losses. Our secondary aim was to determine if there are viable alternatives to broad scale 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 discuss the implications for the conservation of large carnivores and ecosystems more broadly.

Methods

Data and definitions

This study was conducted as a meta-analysis (Hedges & Olkin 1985). To derive our results, we searched for literature that described efforts to mitigate human-large carnivore conflicts related to the livestock industry (see below). We defined success to mean facilitation of coexistence. Response variables were measured as change in livestock loss (e.g. percentage loss of stock, loss of stock per time period, or financial loss) and carnivore incursions into corrals or bomas. We acknowledge that levels of livestock loss may not directly correlate 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 lack of availability of appropriate, consistent data, we did not analyze changes in human tolerance or perceptions of carnivores, but we included self-reported changes in livestock losses following introduction of a mitigation measure.

Literature search

We conducted a literature search using Web of Science (All Databases) and SCOPUS using combinations of terms related to carnivores, livestock, impacts of carnivores on stock, and intervention techniques (see Table S1). Exclusion terms were also incorporated to reduce the return of irrelevant papers (e.g. invertebrate and non-terrestrial predators, disease, parasites). References from papers deemed appropriate to the analysis, as well as from review papers, were examined to source further relevant articles overlooked by the search terms. Google Scholar and the European Commission LIFE project database were also searched using a subset of the search terms. The systematic search was further supplemented by contacting several researchers and organizations involved in human-large carnivore conflict management or research 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 were then critically assessed to determine whether they provided appropriate data (see below) for inclusion in a meta-analysis. This left 43 replicated studies that provided means, sample sizes, and sufficient information to calculate standard deviations for both control and treatment. However, three were excluded as there was only one study per category (e.g., fladry, fertility control, combined methods) as a minimum of two studies are required for comparison in a meta-analysis. All papers identified were in English except three that were in French (LvE translated), Norwegian and German (abstract and figure/table captions in English).

Mitigation methods were grouped into five predefined classifications for the meta-analysis. These were: lethal control (range of 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 physical protection devices (e.g. livestock protection collars). Forty papers describing financial incentives were discovered, including three that measured success, but these were not considered appropriate for comparison with other mitigation measures as the response variables were changes in farmer attitudes or retaliatory killing, rather than livestock loss.

Studies included in the meta-analysis comprised replicated studies with a before-after or control-impact (BACI) design. For inclusion, studies had to be field trials on livestock (not measuring bait takes or using captive carnivores) and at least two months in duration to allow time for effects to be detected. Some studies did not have strict control treatments, but rather investigated an improvement or change in management, for example, by electrification of fences, or coordinated versus *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). However, we recognize that while obtaining randomized samples is ideal, it is often unobtainable given constraints around management, and that 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 analysis

Necessary data (sample sizes, means and standard deviations) were extracted from the text, tables or figures from each article or calculated from the data provided. The definition of

sample size typically comprised the number of treatment farms or herds, or number of years over which data were compared. Where experiments within a study were defined by area, but multiple years of data were provided, data were averaged across years. For papers that contained more than one study category, each was considered a separate study for the meta-analysis.

For each study, we calculated the standardized effect size as Hedges' *d* (Hedges & Olkin 1985) using MetaWin V2.1 (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* indicate that the treatment was successful in reducing conflict (e.g. livestock loss reduced), zero means no effect, and positive values indicate the treatment worsened the conflict. As the data even within categories varied with study design and intervention used, data were analyzed using a random-effects model, which was chosen as the most appropriate framework as it accounts for differing true effect size among studies (Hedges 1983; Gurevitch & Hedges 1999). However, where pooled variance was less than or equal to zero, a fixed effects model was used. The mean effect size per category is weighted based on variance and sample size and *QT* is calculated as a measure of heterogeneity (Rosenberg et al. 2000).

We also intended to compare other response variables, but insufficient data were available for inclusion in the meta-analysis. We therefore summarized data measuring change in carnivore killing as a proxy for tolerance, as killing was considered to suggest unwillingness to coexist.

Results

Review

Research effort (n = 235) into mitigating livestock loss to large carnivores was geographically biased, with 47.2% of studies (n = 111) occurring in North America, compared with one paper identified for South America (Fig. 1a). Eleven (52.4%) of the studies in Asia were from India.

Research focus within continents also varied, with studies of lethal control most frequent in Australia (50% of all studies), studies of financial incentives most frequent in Asia (52.4%), and studies of deterrent strategies most frequent in North America (29.7%) (Fig. 1a). The late 1970s to early 1980s saw an increase in research into mitigating large carnivore conflict, with a particular focus on deterrents. Research focus has now primarily shifted towards 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, ten assessed deterrents, eight fencing, seven lethal control and two shepherding.

Overall, the mitigation methods assessed had an effect in reducing predation on livestock by large carnivores (Fig. 2). However, three individual studies (two lethal control studies and one guardian animal study) resulted in an increase in livestock loss to large carnivores for the treatment compared with 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 less than or equal to zero for the other three mitigation

methods. None of the *QT* values were significant ($P < 0.05$), implying that variance among effect sizes is within that expected by sampling error (Cooper 1998).

Large carnivore killing

While 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 three papers) on financial incentives were identified, all were located 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, the Lion Guardian program in Kenya (which trains and supports community members to protect lions, http://lionguardians.org) saw a 100% reduction in large carnivore killing, and a 97.8% reduction when combined with financial incentives (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 found that lethal control of large carnivores actually increased livestock losses (Conner et al. 1998; Harper et al. 2008; Allen 2013; Peebles et al. 2013; Wielgus & Peebles 2014). Given that large carnivore populations and human livelihoods supported by livestock production are both valuable, lethal control should therefore only be considered where it's likely to reduce livestock losses. We discuss the implications of this finding for the on-going management and conservation of large carnivores.

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 support from government and non-government 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 received more research attention in the US than anywhere else in the world (Rigg 2001) and they are used by 23.5% of small stock producers (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, as public behaviors and attitudes towards wildlife are not necessarily based on evidence (Marchini & Macdonald 2012). The stronger research effort into mitigating conflict in North America, a pattern also observed by Can et al. (2014) for research on bear management, may be partly due to public pressure that led to US President Richard Nixon's ban on poison baiting in the United States in 1972 (Flores 2016: 164). Around this time, there was an increase in research overall, with a particular focus on innovative 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 ethically inappropriate. On the other hand, in Australia, where poison baiting is still the dominant management method, public knowledge of lethal dingo control is complicated by labeling of the dingo as a "wild dog". Portraying the dingo as a domestic dog that has gone feral

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 as 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 (Naughton-Treves et al. 2003; Marchini & Macdonald 2012).

There is no silver bullet for managing human-large carnivore conflict, and management strategies 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 can 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 money (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 employs traditional conflict mitigation techniques and builds tolerance for lions by incorporating Maasai community cultural values and belief systems (Hazzah et al. 2014). Considering biological contexts, innovative techniques are used such as mimicry to deter predators. In a similar style to the masks worn on the back of forest workers' heads to deter tiger attacks in the Sundarbans (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 that are tailored to local contexts.

Limitations

While our review aimed to be as comprehensive as possible, it is important to recognize biases that could affect the results. Publication bias was observed in that studies only presented significant results, and it is possible that non-significant research was entirely omitted from publication. We searched only in English, which may cause bias towards English-speaking countries. Furthermore, comparable and consistent data are required for a meta-analysis, and while 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 reveals 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 or geographic locations. Such information is needed to inform context-specific management. Variation in

effect sizes within groups is partly contributed to by 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 study provides 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, while also minimizing negative effects to carnivore populations) in a range of contexts. Thus, nonlethal methods are beneficial both to livestock production and to reducing pressure on carnivore species by allowing coexistence. Indeed, our meta-analysis suggests that in spite of limited data, we have evidence that challenges the assumption that lethal control reduces livestock loss more effectively than nonlethal methods (not considering financial cost effectiveness). If we are to conserve carnivores, we need to build a stronger evidence base 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 the evidence for nonlethal management presented here.

We recommend that future research strives to measure the success of mitigation methods using standardized, experimental, and appropriate response variables under different contexts. Many studies were excluded 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, affecting both human livelihoods and the conservation of large carnivores.

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(a)

Figure. 1 (a) Number of publications per mitigation method per continent. Total N = 235.

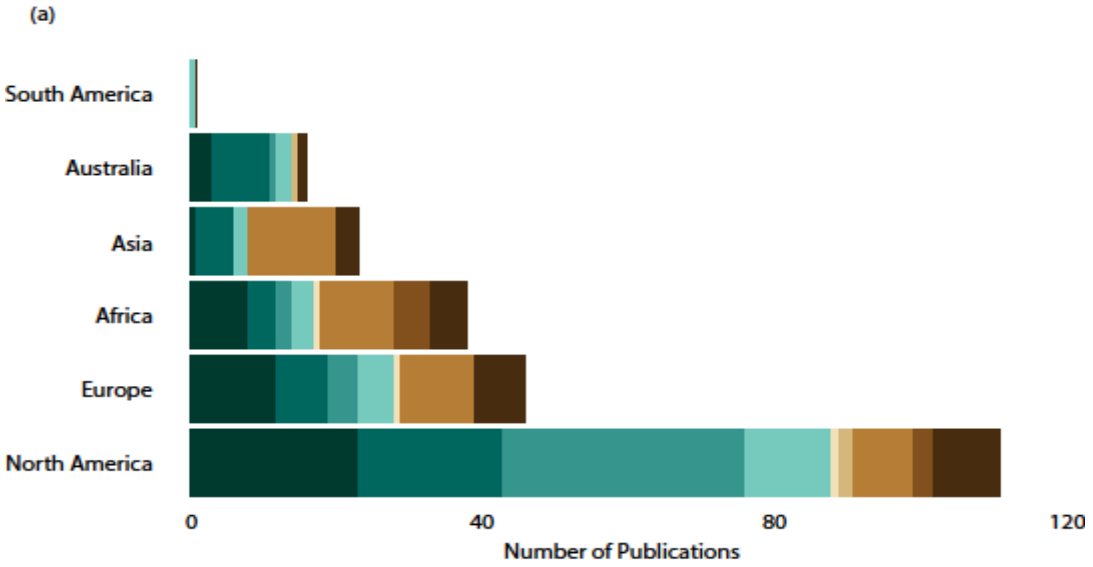

Figure. 1 (b) Number of publications per mitigation method over the last seven decades since published research on mitigation conflict with large carnivores began.

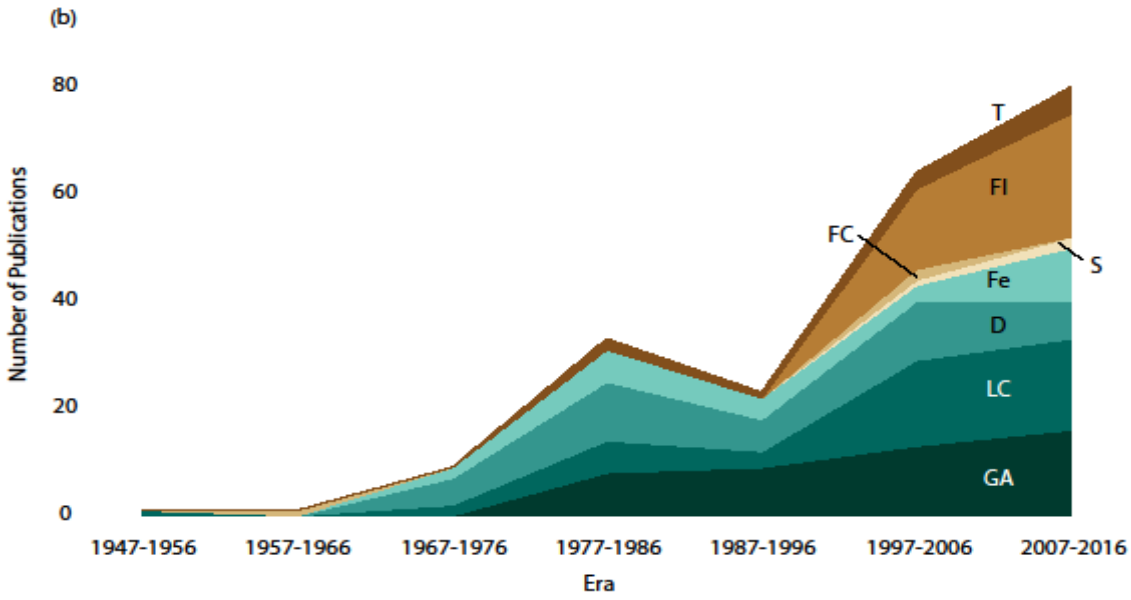

Figure. 2 Mean effect size (Hedges' *d*) and percentile bootstrap confidence intervals per mitigation method (with number of studies included in the meta-analysis). * indicates pooled variance was less than or equal to zero so data were analysed using a fixed effects model rather than random effects model.

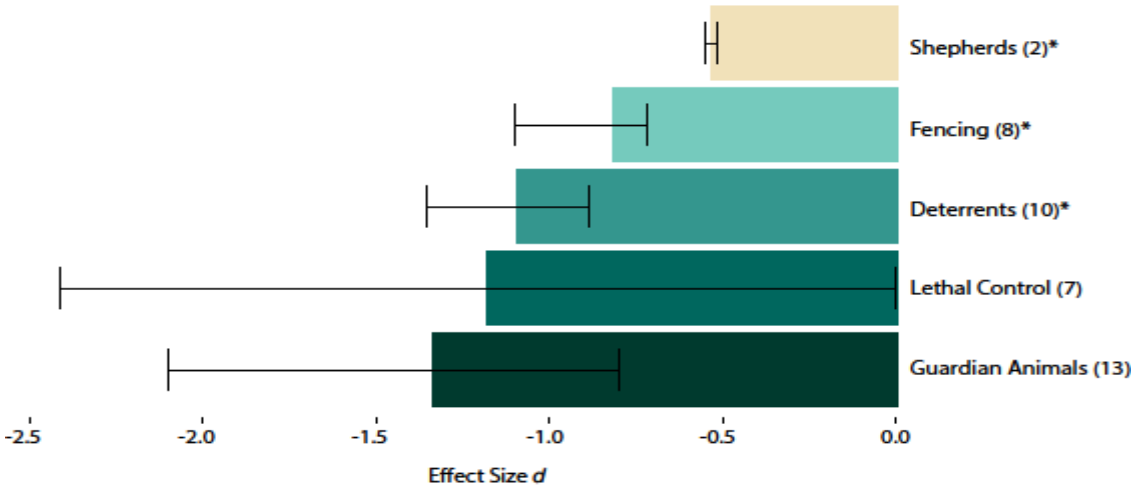

Figure. 3 Adaptive and context-specific management to facilitate coexistence with large carnivores, allowing their provision of ecosystem services across landscapes to benefit biodiversity and rural livelihoods.