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Management Tools to Reduce Carnivore-Livestock Conflicts: Current Gap and Future Challenges☆

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ABSTRACT

Predation on domestic animals by carnivores is a persistent problem wherever carnivores and livestock co-occur. A wide range of management tools to reduce predation has been invoked. However, the evidence of their effectiveness is still limited for a broader range of species and conditions. Using a global analysis of domestic animal predation by native carnivores under a "before-after/control-impact" framework, we assessed the effectiveness of management techniques used to reduce domestic animal predation identifying knowledge gaps and research needs. We reviewed 291 predation cases in 149 studies published between 1990 and 2017 involving 47 carnivores. Lethal control is the most common method to reduce predation in comparison with nonlethal techniques. Yet the effectiveness of both approaches remains poorly evaluated (30.1% of study cases) and largely based on producers' perceptions (70% of cases where effectiveness was evaluated). Lethal control and night confinement of domestic animals would have no effect on reducing predation, whereas the use of livestock-guarding dogs, fencing, or herdsmen may significantly reduce domestic animal losses. When the effectiveness of each technique to reduce predation was assessed by large and mesocarnivores, fencing significantly reduced predation of domestic animals by the former. Despite little scientifically published material, our findings indicate lethal control would have no effect in reducing animal predation by native carnivores when compared with nonlethal techniques. Our study also indicates the effectiveness may vary depending on the type of carnivore involved in the conflict with livestock activity. The use of an evidence-based framework to measure and assess the differential effectiveness of nonlethal techniques and the use of complementary tools at different spatial and temporal scales must be research priorities to prevent livestock predation while promoting the conservation of carnivores in production-oriented lands as encouraged by the Convention of Biological Diversity.

Introduction

Carnivore predation upon domestic animals is a matter of conservation concern (Treves and Karanth 2003; Woodroffe et al. 2005). Although the number of domestic animals lost annually to predators tends to be small relative to the number of animals raised (<1–5%; Baker et al. 2008), these losses might be significant in term of livestock biomass (Novaro et al. 2004) or economically sizeable for the local economy and owner's well-being (Knowlton et al. 1999). As a consequence, due to human retaliation, numerous carnivores' populations have declined, some to the extent of being locally extirpated (Thirgood et al. 2005; Dickman 2010).

Effective management of the conflict derived from the predation of domestic animals would benefit from the explicit use of verifiable scientific evidence obtained from both experimental research and the disemination of routinely systematic reviews (Sutherland et al. 2004; Treves et al. 2016). Although the reduction of predation upon domestic animals has traditionally relied on lethal methods (Treves and Karanth 2003), the effectiveness and acceptability of lethal approaches are still controversial (Baker et al. 2008; Treves et al. 2016). For instance, the elimination of "problem" predators at local scale might be buffered by recolonization of individuals migrating from adjacent areas (Novaro et al. 2005) or by the individuals' compensatory reproduction at regional scale in subsequent years (Knowlton et al. 1999). Thus, even though the elimination of animals could reduce the domestic animal losses in the short term (i.e., during lambing season), little or no effect may be achieved in the long term (Blejwas et al. 2002). More importantly, the

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extirpation of native carnivores as a management technique is socially regarded as undesirable on ethical and ecological grounds (Treves and Naughton-Treves 2005; Dickman 2010).

In turn, the effectiveness and efficiency of nonlethal techniques to reduce predation upon domestic animals while conserving carnivores have to be demonstrated in order to replace the reliance on lethal control techniques (Treves and Karanth 2003; Baker et al. 2008; Treves et al. 2016). This is particularly important if conservation of biodiversity is to be achieved in lands devoted to agriculture including livestock raising, as expected under the Aichi Biodiversity Targets (CBD 2010). For instance, presumed nonlethal techniques such as the animals' translocation, requires critical appraisal, as they have turned to trigger higher mortality among translocated individuals, being equivalent to lethal control (Fontúrbel and Simonetti 2011).

In response to the increasing rate of conflicts between carnivores and livestock, recent review studies have documented the relative effectiveness of conflict-mitigation strategies on a global scale (Miller et al. 2016; Van Eeden et al. 2017; Eklund et al. 2017). Although the evidence provided by research suggests that nonlethal strategies may reduce domestic animal predation, the focus on large carnivores-livestock conflicts, as well as the use of predation cases reporting statistic metrics, limit our understanding above the success of nonlethal techniques under a wider range of species and conditions. Consequently, from a conflict management perspective, important insights can be gained by assessing if the effectiveness of each technique varies between carnivore species and environmental conditions. Furthermore, to demonstrate this effectiveness, confident and accurate methods to quantify domestic animal predation should also be considered in order to avoid the overestimates/underestimations of animals' losses under different management strategies. This is particularly important if replacement animals or financial payments schemes are used by public agencies to compensate those losses (Baker et al. 2008).

If the utilization of nonlethal techniques is not only perceived but also demonstrated to effectively decrease predation, then the willingness to use these methods by producers is expected to increase, enhancing the survival of native carnivores in production-oriented lands (Redpath et al. 2013). The success of techniques has been mostly evaluated individually (e.g., Andelt 1992; Woodroffe et al. 2007; see examples in Eklund et al. 2017), and little evidence is known about the additive or synergic effects of combined strategies (Espuno et al. 2004; Garrote et al. 2015). Here, we examined the effectiveness of lethal and nonlethal management techniques in reducing predation upon a wide range of domestic animals and carnivores. As a new aspect of this research, we have disaggregated the predation by carnivores with different body sizes in an attempt to identify patterns of used techniques that might facilitate more informed selection by potential users. To do so, we reviewed published cases of predation of domestic animals that quantified effectiveness of a given management technique as the change in domestic animal losses (as reported by different sources) after/with the applied technique.

Methods

We searched the Web of Science (Science Citation Index Expanded) for papers using the following search terms: carnivore-livestock conflict* OR human-carnivore interaction* OR predation risk*. We reviewed peer-reviewed literature dealing with predation of a wide range of domestic animals (from poultry to cattle) by a wide range of terrestrial native carnivores and excluded studies that did not explicitly mention management techniques to prevent domestic animal losses. We also excluded avian carnivores from our search since the carnivores-livestock conflict has been primarily related to carnivore taxon occurring in production-oriented lands (Baker et al. 2008).

In order to characterize the diversity of published studies in terms of management approaches, we considered those techniques mentioned in recent studies (Miller et al. 2016; Van Eeden et al. 2017; Eklund et al. 2017): lethal control, livestock-guardian dogs, night confinement, livestock fencing, the presence of herdsman, carnivores' translocation, and aversive devices. We also included the use of decision support tools such as predictive spatial models since they can be used as a complementary approach to reduce domestic animals' predation, operating to larger spatial scales, and their results can be validated (Treves et al. 2011; Treves and Rabenhorst 2017). We classified the studies as 1) those where the specific method was used or mentioned but not tested for its impact to reduce animal losses (e.g., across methods or discussion sections) and 2) those aimed explicitly at evaluating the success of the technique used. Of the later set of studies, we identified the source used to assess or quantify the effectiveness of each technique.

On the basis of those publications that presented quantitative information regarding predation, we used a "before-after/control-impact" (BACI) framework to test if the technique used indeed reduced predation (Treves et al. 2016). To do that, we compared the response ratio (postmeasurement predation/baseline predation or with technique implemented/without technique implemented) and standardized it by using ln in order to avoid overdispersion (Simonetti et al. 2013). If the technique does reduce predation, the response ratio will be negative, with lower frequencies after implementing that method compared with the baseline frequency. A Student's *t*-test (Zar 1974) was performed to determine if the average of the response ratio for each used technique was different from 0 (i.e., no change in predation before-and-after technique implementation). We performed the analyses in two steps. First, we assessed the effectiveness of different techniques by accounting for the whole diversity of carnivores included in the study cases that presented quantitative information regarding predation. We then disaggregated the predation cases involving mesocarnivores and large carnivores. To separate between these two groups of species, we used the median of body sizes of involved predators (20.9 kg) obtained from (Jones et al. 2009). Those cases for which it was not possible to separate the predation by mesocarnivores or large carnivores were included in the first analysis only.

Results

A total of 255 papers were retrieved, of which 149 studies published between 1990 and 2017 fulfilled our inclusion criteria completing a total of 291 study cases involving 47 carnivore species (Appendix 1). We considered a study case as an event of predation on individuals of domestic animal species by a particular carnivore. Lethal control was the method most frequently mentioned across the study cases (19.2%) compared with nonlethal techniques: livestock fencing (15.8%), livestock-guarding dogs (15.4%), reliance on predation risk models (15.0%), night confinement (13.7%), the presence of herdsman (12.8%), carnivores' translocation (5.1%), and the use of aversive devices (3.0%) (Fig. 1). The effectiveness of different management techniques was explicitly assessed only in 30.1% of study cases. Whereas the success of livestock fencing and livestock-guarding dogs appeared most frequently evaluated (8.1% and 7.6 of total study cases; see Fig. 1), studies dealing with the effectiveness of carnivores' translocation and predation risk models to reduce predation were scarce (<1% of studied cases; see Fig. 1). When examining the effectiveness within each technique (i.e., considering as the total of study cases those available for each technique), the use of aversive devices has been mostly evaluated (60% of studied cases for this technique; see Fig. 1), whereas predation risk models appear poorly tested (4.3% of studied cases for this technique; see Fig. 1). The effectiveness of techniques used to reduce animal losses was largely evaluated through producers' perceptions conducting surveys (70% of total cases where evaluation was conducted), whereas the use of diet analyses, reports of claims provided by local agencies, and the use of direct observations of preyed animals were rarely used (1.1%, 14.4%, and 14.5%, respectively; Fig. 2).

Thirty-eight publications (25.5% of studies published) reported 87 study cases (30.1% of total study cases considered) with quantitative

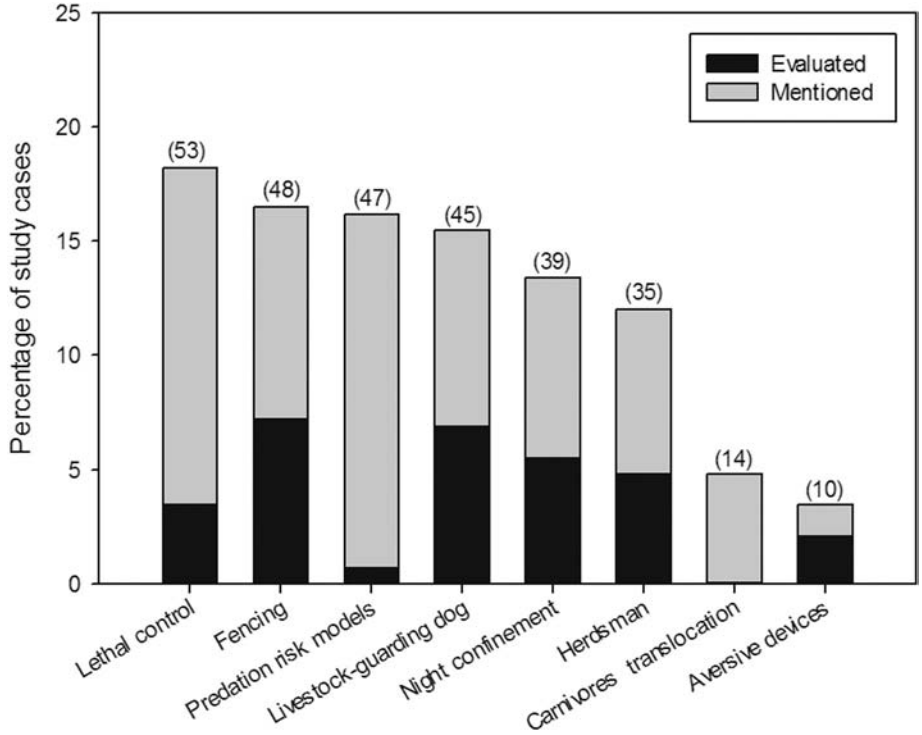

Figure 1. Management techniques mentioned (gray section of the bar) and evaluated (black section of the bar) to reduce domestic animal predation by native carnivores ($N = 291$ study cases in 149 publications). The number of study cases considered for each technique is shown in parentheses.

measurement of domestic animal predation by 20 carnivores species (10 large carnivores and 10 mesocarnivores) under a BACI design for a particular management technique. Lethal control and night confinement did not reduce predation rates ($-1.78 < t < -0.34$, $P > 0.05$; see Fig. 3), whereas animal losses were on average eight, 60, and 13 times lower in cases where livestock-guardian dogs, fencing, and the use of herdsmen were applied ($t = -3.21$, $P < 0.01$; t = -5.21, p < 0.01 and t = -3.12, p < 0.01, respectively; Fig. 3). Even though aversive devices appeared to reduce domestic animal losses, statistical inference was not possible due to small sample size (N = 2). The disaggregated analysis by carnivores group showed the predation of domestic animals by large and mesocarnivores decreased when lethal control, livestock-

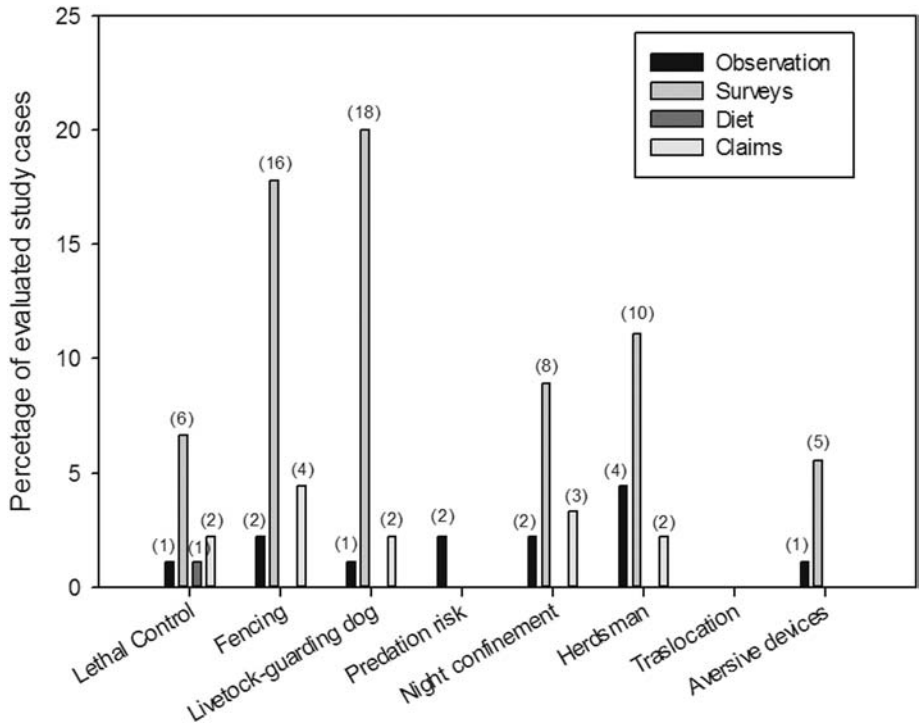

Figure 2. Methods used to assess the effectiveness of different management techniques. Direct observations of preyed animals (observations), producers' perceptions (surveys), diet analyses (diet), and report of claims provided by local agencies (claims). The number of study cases considered for each technique is shown in parentheses.

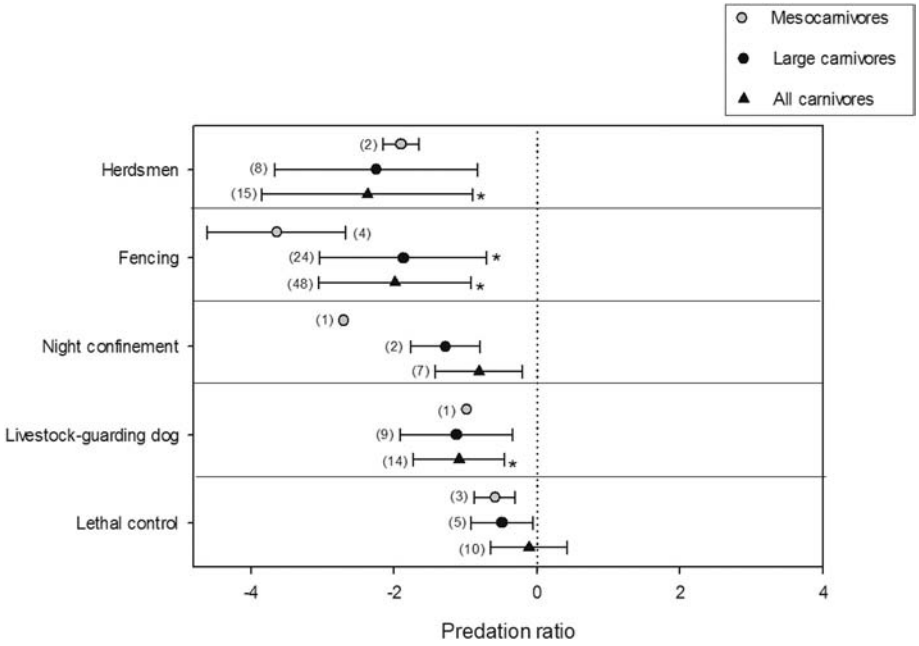

Figure 3. Predation of domestic animal by carnivores in presence of different management techniques. Values are the ln ratio (postmeasurement predation/baseline predation) (mean and SE). Positive and negative values represent increment and reduction of domestic animals losses. Gray and black circles represent predation by mesocarnivores and large carnivores, respectively, whereas black triangles represent predation by total carnivores analyzed. The number of study cases considered for each technique is shown in parentheses. *Indicates significant effect at $P < 0.05$.

guardian dogs, night confinement, and herdsmen were used, but no differences from zero (no change) were found (all cases $P < 0.05$; Fig. 3). On the other hand, fencing also reduced the predation of domestic animals but this decrease was only significant for large carnivores when compared to mesopredators ($t = -3.92$, $P < 0.01$ and $t = -2.93$, $P > 0.05$, respectively; see Fig. 3).

Discussion

Predation on domestic animals by carnivores is a persistent problem wherever carnivores and livestock co-occur. As such, this predation is a triggering factor of human-wildlife conflicts in livestock-raising lands worldwide (Woodroffe et al. 2005). Consequences of this conflict are not only circumscribed to the negative effects on economy or food production of local and regional communities. The elimination of predators is also one of the underlying factors affecting the long-term persistence of many carnivore populations across the globe (Gittleman et al. 2001). Moreover, the implementation of predator control often lacks rigor regarding its effectiveness (Treves et al. 2016). This is particularly noticeable when lethal methods of control are used, which are regarded effective to reduce animal losses despite only 10 study cases (19% of total study cases for that technique) do effectively evaluated their success. Although eradication programs on wolves, coyotes, and red foxes conducted in North America and Europe have shown to drastically reduce domestic animals losses (Treves and Naughton-Treves 2005), their use can have unpredictable consequences on prey population, conflict rates, and ecosystem services (Ripple et al. 2014) and receive low public acceptance (Treves and Naughton-Treves 2005).

Our appraisal pinpoints that lethal control seems to have no long-term effect in reducing animal predation by native carnivores when compared to nonlethal techniques such as livestock-guarding dogs, fencing, and the use of herdsman. These results are in the line of recent reviews published (e.g., Eklund et al. 2017; Miller et al. 2016), albeit using a different literature search method, analytical approach, and species target. Therefore, our data reinforce the notion that these techniques seem to be consistently effective to reduce predation by broader range conditions. Moreover, regardless of the very little scientifically published material on the topic, our study provides novel insights showing that some nonlethal techniques such as fencing may not be equally effective to reduce domestic animal predation by the wide spectrum of carnivores. For instance, depending on how this technique is implemented and maintained in livestock-raising areas, it may be unuseful to prevent the predation by medium-size predators. Large gaps between the lowest wire and the ground, particularly in zones where fencing crosses a ditch or other terrain features may facilitate mesopredators to enter domestic animal enclosures (Frank and Eklund 2017). Similarly, the use of weak and porous enclosures made from thorny bushes and other native vegetation as those used in African villages have been showed to have low success in keeping some predators from entering (e.g., Tumenta et al. 2013). On the other hand, livestock-guarding dogs may act as top predators in productive landscapes where native apex predators have been extirped, having a strong effect on reducing predation by small and mesocarnivores (e.g., Van Bommel & Johnson 2014).

The extirpation of carnivores from human-dominated landscapes is clearly in conflict with ethical concerns and the efforts to achieve land sharing as a conservation approach (CBD 2010). Alternative nonlethal approaches are needed to prevent domestic animal losses while at the same time promoting the conservation of carnivores in production-oriented lands (Breitenmoser et al. 2005). Yet quantitative evaluation must be undertaken to identify the relative effectiveness of management practices aimed at reducing domestic animal losses. This validation will ultimately be an essential part of demonstrating the success of these management techniques as tools for informed conservation decision making (Larrosa et al. 2016). Even in novel spatial approaches as predation risk models, field validation is needed to build a bridge between theory and practice.

Use of nonlethal techniques appears to be an avenue to reduce carnivore-livestock conflicts. Nevertheless, producers' perceptions on their success is ultimately crucial in adopting these strategies (Treves and Karanth 2003; Marker et al. 2005; Naughton-Treves and Treves 2005; Dickman 2010). Techniques applied individually such as livestock-guarding dogs, fencing, and herdsmen have been shown to diminish predation (see examples in Eklund et al. 2017 and this study). However, the simultaneous use of them would enhance the effectiveness of reducing livestock predation, as suggested by our preliminary

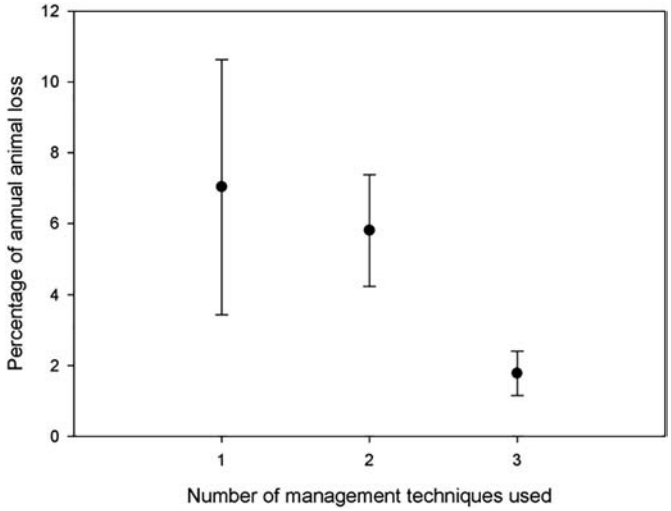

Figure 4. Relationship between perceived annual predation (mean percentage of sheep and SE) and the number of nonlethal techniques used by local ranchers to reduce animal loss in Magallanes Region, Chilean Patagonia ($N = 18$).

study conducted in Patagonia. Perceived predation was up to four times lower among sheep ranches using more techniques (including those commonly used such as livestock-guarding dogs and nocturnal confinement) than those relying on just one (Fig. 4). Interestingly, it was not only the average losses that decreased but also the variability, suggesting that the use of more techniques tends to reduce more predictably losses (Levene test 3.2, df = 2, $P = 0.08$, see Fig. 4). Although local, our exploratory study offers general insights about how the combination of different nonlethal techniques, which can be implemented at different spatial and/or temporal scales, may reduce domestic animal losses to an acceptable level.

Furthermore, real predation by carnivores may have little connection with perceived domestic animal loss. Although costly and/or logistically difficult to implement, estimates of predation reduction should then consider producers' perceptions but also be strengthened with more empirical records including field validation of preyed animals and diet analysis. This may be particularly relevant in rural areas where domestic dogs also cause animals' deaths (Echegaray and Vilà 2010). If losses due to native carnivores occur despite the use of nonlethal techniques, public agencies should consider compensating ranchers for those losses, which is equivalent to investing in the conservation of involved carnivores (Fontúrbel and Simonetti 2011). In this way, the coexistence of carnivores and livestock will be based on approaches technically robust and socially accepted in human-dominated landscapes.

Management Implications

Sustainable livestock production is expected to reduce domestic animal loss while reducing pressure on biodiversity occurring on these production-oriented lands. Despite limited data, current evidence suggests that nonlethal methods such as fencing, livestock-guarding dogs, and herdsmen allow the coexistence between native carnivores and livestock activity, but their effectiveness may vary depending on the carnivore species involved in the conflict.

On the basis of the evidence provided by this study and other recently published articles (Miller et al. 2016; Treves et al. 2016; Eklund et al. 2017; van Eeden et al. 2017), we recommend wildlife managers and producers do the following: 1) assess the differential effectiveness of nonlethal techniques to reduce the predation of domestic animals in multipredator landscapes; 2) promote the complementary use of nonlethal techniques at different spatial and temporal scales; 3) develop a standardized protocol to record animal losses and measure the success of different strategies; and 4) promote the creation of a global committee that evaluates and conducts science-based assessment of interventions to reduce carnivore-livestock conflicts under different ecological and management conditions.

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Appendix A. Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rama.2018.02.005.

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