Non-lethal defense of livestock against predators: flashing lights deter puma attacks in Chile

Omar Ohrens[1,2,3,4]*, Cristian Bonacic[3,4], and Adrian Treves[1]

Anthropogenic mortality among populations of large terrestrial carnivores undermines the health of ecosystems globally, and generally increases when people respond lethally to real or perceived threats to property, including livestock. Reducing such threats through the use of non-lethal methods could therefore protect both large predators and human interests. However, the scarcity of information on the effectiveness of methods to prevent livestock predation hinders the formulation of science-based policy. We present the results of a randomized crossover experimental test of a method to prevent predation on livestock, which to our knowledge is the first such test in Latin America. By relying on a so-called "gold-standard" design, we evaluated the effectiveness of using flashing lights to deter predators. We found that light deterrents discouraged pumas (*Puma concolor*) but not Andean foxes (*Lycalopex culpaeus*) from preying on alpacas (*Vicugna pacos*) and llamas (*Lama glama*), and demonstrated that gold-standard experiments are feasible in large natural ecosystems, contradicting assumptions that people will reject placebo controls and that such systems contain too many confounding variables. Functionally effective non-lethal methods can protect wildlife, livestock, and people. Strong inference is needed for the development of sound policy concerning wildlife management, livestock husbandry, environmental conservation, and biodiversity.

Declines in predator populations have resulted in ecosystem degradation and loss of biodiversity and ecosystem services worldwide (Crooks and Soulé 1999; Myers *et al.* 2007; Estes *et al.* 2011). Human-induced mortality is the primary cause of global endangerment of large carnivores (Woodroffe and Ginsberg 1998; Ripple *et al.* 2014). For terrestrial carnivores, much of this mortality results from retaliation against or pre-emptive responses to real or perceived threats to human interests. Sound policy to reduce conflicts between people and predators would balance human needs with environmental protection (Chapron *et al.* 2014; Treves *et al.* 2015); such a balance is mandated by the constitutions of a large majority of the world's nations (Boyd 2011; Treves *et al.* 2018).

Non-lethal methods that protect human property hold the greatest promise for finding a balance between the conservation of predator populations and human needs (Treves *et al.* 2016). Traditionally, threats to domestic animals prompted lethal retaliation against predators. Prior reviews revealed that few methods, whether lethal or non-lethal, have been rigorously evaluated for functional effectiveness: that is, for their effect in preventing future damage, in this case reducing predation on livestock (van Eeden *et al.* 2018). Controlled experiments are

needed to draw strong inference about functional effectiveness and will thereby help to prevent the implementation of ineffective but popular interventions, which often lead to wasted resources and harm to animals, both wild and domestic. Rigorous experiments using random assignments as well as methods that avoid bias in sampling, treatments, measurements, and reporting (hereafter referred to as "gold-standard" experiments) (Platt 1964; Ioannidis 2005) are required, given widespread promotion of methods based on perceived effectiveness, small sample sizes, or flawed research designs (van Eeden *et al.* 2018; Ohrens *et al.* 2019).

Here we evaluate the effectiveness of a non-lethal light deterrent on pumas (*Puma concolor*) and Andean foxes (*Lycalopex culpaeus*) approaching alpacas (*Vicugna pacos*) and llamas (*Lama glama*) in the Andean plateau (hereafter "altiplano") of Chile. To the best of our knowledge, this is the first experiment of its kind conducted on puma deterrence (or for any predator in Latin America), and the first to evaluate the potential for camelid protection (van Eeden *et al.* 2018). Functionally effective non-lethal methods can protect wildlife, livestock, and people, and systematic evidence is needed for the development of effective policies concerning wildlife management, livestock husbandry, environmental conservation, and biodiversity (Sutherland *et al.* 2004).

Previous research in the Chilean altiplano revealed that pumas and Andean foxes were both viewed negatively by the region's indigenous residents, known as the Aymara, who blamed pumas for an average 10% loss per livestock herd annually. In the same survey, local people expressed preference for non-lethal predator deterrents with support from local gov-

[1]*Nelson Institute for Environmental Studies, University of Wisconsin–Madison, Madison, WI *(ohrens@wisc.edu); [2]Center for Local Development, Pontifícia Universidad Católica de Chile–Campus Villarrica, Villarrica, Chile; [3]Center for Intercultural and Indigenous Research, Faculty of Social Sciences, Institute of Sociology, Pontifícia Universidad Católica de Chile, Santiago, Chile; [4]Fauna Australis Wildlife Laboratory, Department of Ecosystems and the Environment, Pontifícia Universidad Católica de Chile, Santiago, Chile*
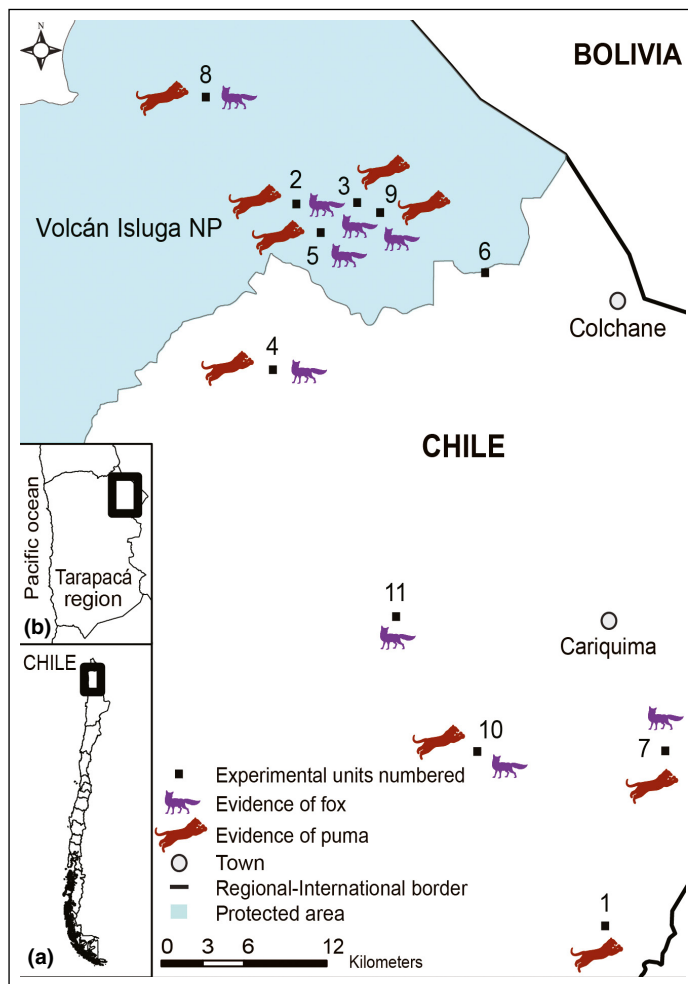
Figure 1. Study area with experimental units and evidence of carnivores. Inset maps show (a) the Tarapacá region within Chile and (b) the study area within the Tarapacá region. Experimental units follow the same numbering scheme as that presented in Table 1. Free public-domain vector clipart of both carnivores was obtained from www.clker.com.

ernment agencies to reduce predation on livestock (Ohrens *et al.* 2016). We built on this study by conducting a participatory intervention planning workshop (Treves *et al.* 2009) and a randomized experiment to evaluate methods preferred by livestock owners.

Methods

Method approval

We received approval from the Institutional Review Board at the University of Wisconsin–Madison and the Ethical Committee at the Pontificia Universidad Católica de Chile for human subject research. The study was performed in accordance with ethical guidelines from the Belmont Report, and written informed consent was obtained from all subjects. The animal protocol followed in this research was reviewed and approved by the University of Wisconsin–Madison Institutional Animal Care and Use Committee.

Study area

The study area covered one district (Colchane) of the Tarapacá region in the altiplano of Chile, at an altitude of 3500–5000 m (Figure 1) (19°23' S; 68°44' W). Here, the indigenous Aymara grow crops, raise livestock, and co-occur with both pumas and Andean foxes (WebPanel 1; Ohrens *et al.* 2016).

Participant enrollment and workshop design

We adopted a participatory approach because our previous baseline data and human dimensions fieldwork revealed (as mentioned above) that the Aymara people favored the adoption of non-lethal predator deterrents (Ohrens *et al.* 2016), and because participatory intervention planning is recognized as an effective approach in resolving conflicts and promoting the implementation and use of interventions (Treves *et al.* 2006, 2009; Reed 2008). In May 2016, a total of 54 affected and interested parties (livestock owners and government agencies) were recruited to help evaluate and select feasible interventions (WebPanel 1). We divided participatory workshops into five sections (following Treves *et al.* 2006, 2009; Newing *et al.* 2011): (1) introduction to the subject and aim of the workshop; (2) presentation of a wide range of possible interventions for reducing predation on livestock; (3) small-group discussions about interventions ("buzz groups" with 5–6 participants per group) assisted by facilitators; (4) presentation of ideal examples of interventions selected by the whole group; and finally (5) discussion about the selected intervention. During the workshops, we encouraged participants to choose feasible and cost-efficient methods to reduce predation on livestock for which there was at least some correlative evidence of effectiveness from previous research. Because all native carnivores are under legal protection in Chile, we provided a list of non-lethal options (eg barriers, guards, deterrents), and used audio-visual presentations (eg PowerPoint, videos) about these interventions, to help participants visualize how they work in the field. Participants were given the opportunity to share their personal knowledge about and experiences with carnivores, livestock, and carnivore–livestock interactions. Disagreements were moderated by the lead author, who also facilitated the process of considering scientific evidence with local, practical decisions about cost-efficiency and acceptability of an intervention. After consideration of the potential deterrents, participants selected a solar-powered light device known as Foxlights® (Bexley North, Australia); we then explained the crossover design of the experiment and described the trial procedures in full detail. Participants did not place any conditions on our experiment.

Farmers that agreed to implement light deterrents, the crossover experimental design, and monitoring by our team members also had to present pre-established sleeping areas for livestock prior to the random assignment. In this step, six units were first randomly assigned to a treatment–control sequence,

Table 1. Number of attacks on livestock by puma and Andean fox, sorted by experimental unit and period

| | | | Attacks on livestock | | | |
| | | | By puma | | By Andean fox | |
Treatment sequence	Experimental unit	Livestock herd size	Period 1	Period 2	Period 1	Period 2
Light–control	1	100	0	1	0	0
Light–control	2	380	0	4*	5	1
Light–control	3	60	0	0	8	1
Light–control	5	38	0	1*	0	1
Light–control	7	22	0	0	0	0
Light–control	11	69	0	0	0	0
Control–light	4	160	0	0	0	0
Control–light	6	80	0	0	0	0
Control–light	8	180	0	0	4	0
Control–light	9	280	0	0	8	12
Control–light	10	46	1	0	0	0

Notes: *Predation events verified by a trained officer. In experimental unit 2, only one of the four predation events was verified by a trained verifier.

and an additional six units were then randomly assigned to the converse control–treatment sequence. One unit was excluded from the analysis, as the farmer could not be re-contacted, leaving us with 11 units in total (*n* = 22 replicates).

Experimental design

We evaluated the effectiveness of the light deterrents, using a randomized 2×2 crossover design in which each experimental unit (an established sleeping area ranging from 30 to 180 m in diameter used by a camelid livestock herd) received a light deterrent treatment (two lights and two camera traps) and a placebo control (two camera traps only) for 2 months through random assignment. In other words, the order of the experimental sequence would be determined by chance: a 2-month treatment period followed by 2-month control period (treatment then control) or a 2-month control period followed by 2-month treatment period (control then treatment). Each experimental unit (*n* = 11 herds) was managed by a different livestock owner, but owners were aware of whether their herds were treatment or control subjects because the lights were too obvious to conceal. However, our design reduced the likelihood that pre-existing differences and chance events during a trial would confound any treatment effects (Jones and Kenward 1989; Quinn and Keough 2002). The influence of confounding effects that did not vary in exactly the same sequence as the treatments is reduced because each experimental unit serves as its own control, and therefore comparisons between treatments are made within subjects, thereby increasing the statistical power to detect direct treatment effects. The procedure removes from the treatment comparison (light and control) any component that is related to the difference between units. Moreover, the fact that our experimental units were distributed over
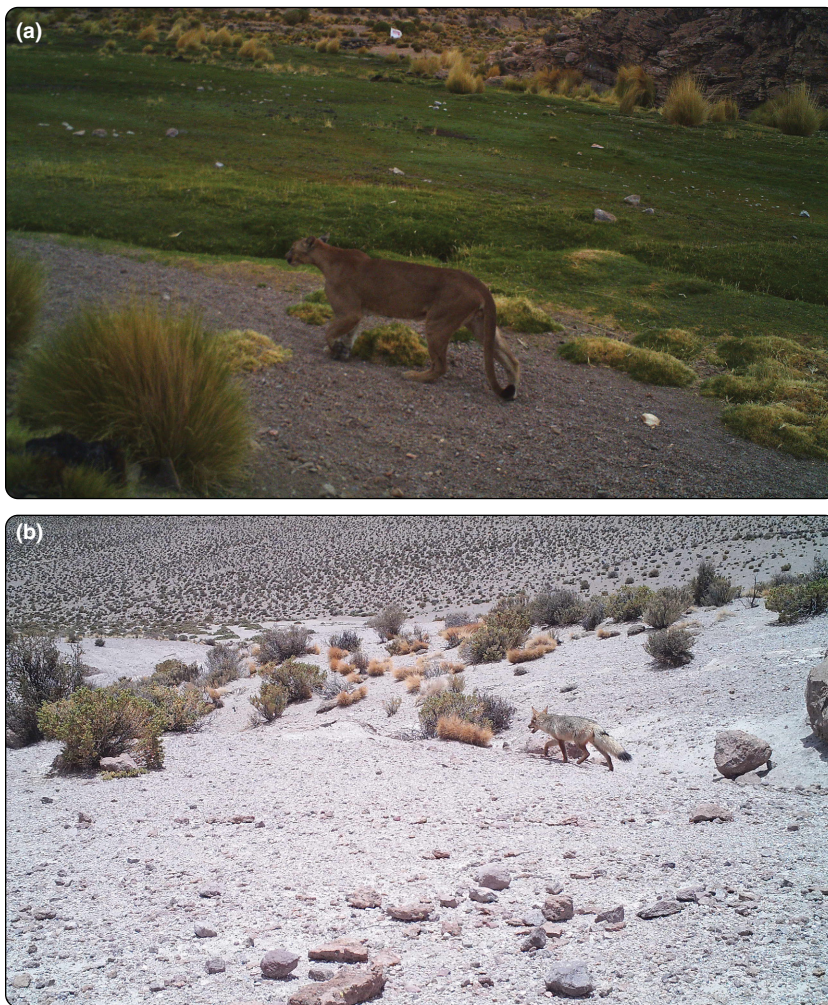
long distances (ie many kilometers; Figure 1) greatly reduced the likelihood of one event or local variable affecting all units in one treatment or during one period. The trial overlapped the 4-month calving season (November 2016–March 2017), a time when livestock are more vulnerable to predation by both pumas and foxes, as the latter appear to be capable of preying on only newborn calves and not on adult camelids.

Treatments

Participants and the lead author installed two light deterrents on either end of an imaginary ellipse surrounding a sleeping area, separated by approximately 50–200 m (depending on the size of the sleeping area) and high enough to be seen by predators (depending on vegetation and topography) (Figure 2; WebPanel 1). These devices continuously emit randomly varying, flashing lights in three colors, which are

Figure 2. Example of one of the Foxlights® deployed by farmers and researchers next to a sleeping site.

Figure 3. Images of predators captured by camera traps deployed around the experimental units. (a) Adult male puma (*Puma concolor*) and (b) Andean fox (*Lycalopex culpaeus*).

from farmers to complement the direct measurement of predation events by independent verifiers (see below). We installed two cameras (Bushnell Trophy Cam, Bushnell, Overland Park, KS) at each sleeping area, one of which was situated <50 m from each sleeping area and the second placed approximately 1 km away; both cameras were positioned on the edges of ravines, hills, or where carnivore tracks or feces were found (Figure 3). To complement the cameras, we walked circular transects 100 m out from the perimeter around each sleeping area to search for carnivore tracks and feces. Finally, we asked participants and neighboring land owners about observations of carnivores during the trial period.

Verifying predation

We trained park rangers and wildlife officers from three government agencies to conduct field investigations of predation complaints. We supplemented two verifiers' reports with farmers' self-reported losses at the end of both periods (two verified losses versus 45 self-reported losses; Table 1). We provided no incentives for data or for any outcomes. Previous work had built trust and all participants spoke Spanish (Ohrens *et al.* 2016), the lead author's native tongue. Long distances between villages and limited phone coverage are the main problems that farmers encounter when reporting predation events to government verifiers (V Malinarich pers comm; Ohrens *et al.* 2016). Self-reporting might represent a source of bias (non-random error) if farmers hoped that the light devices would deter pumas and intentionally blamed foxes for puma-associated losses in treated herds. However, several sources of evidence gave us confidence that measurement error was random, if it existed at all (WebPanel 1).

Data analysis

We adopted a conservative approach by employing multiple statistical tests of effectiveness. Shapiro–Wilk and analysis of variance (ANOVA) tests were used to assess non-normality and the distribution of residuals. Data for predator presence and treatment effect were determined to be non-normal, and thus a non-parametric test was used. For predator presence, we relied on a Wilcoxon rank sum test to compare differences between treatments and between periods. To test for the effect of light deterrents, we used three approaches: (1) a non-parametric approach for factorial design ANOVA-type-statistics based on ranks (Brunner *et al.* 2002; Noguchi *et al.* 2012); (2) a split-plot ANOVA with treatment (light and control), block (each unit or subject), and period as explanatory variables (Díaz-Uriarte 2002); and (3) the Hills–Armitage

directed upward and outward; the devices are activated at dusk by declining light levels and are deactivated at dawn in response to increasing light levels.

Each farmer attended the treated sleeping site for about an hour for a maximum of three dusks, to detect whether the lights disturbed the livestock. No livestock were reported to have departed from sleeping sites after dark during the course of the 4-month trial.

Funding was available for only 12 light devices, which were installed on the 12 sleeping sites based on the experimental sequence; one of the 12 lights ceased working during the second period in the "control then treatment" sequence, but we were unable to replace it. However, the remaining light at that unit continued working; because no predation was reported for this unit in either period, we retained that unit for analysis.

Detecting predator presence

To confirm that predators were present in the vicinities of all units (treated and non-treated) during the experimental period, we deployed camera traps, conducted transect searches for carnivore tracks and feces, and collected field observations

procedure (Jones and Kenward 1989; Díaz-Uriarte 2002). In the Hills–Armitage procedure, we first calculated the difference in predation between the first and the second period for each subject (sleeping site [unit]), and later used a Wilcoxon rank sum test to compare the values between the two sequences. We tested for both period effects and inequality of carryover effects to evaluate whether the results for the treatment effect were not biased by the treatment in the preceding period (Jones and Kenward 1989; Díaz-Uriarte 2002). We adopted a one-tailed test for the Hills–Armitage procedure because the a priori hypothesis was that the light devices are deterrents and not attractants (Ruxton and Neuhäuser 2010). Finally, we calculated the proper effect size following Nakagawa and Cuthill (2007) and Fritz et al. (2012) by quantifying the size of the treatment effect or the difference between groups ($r > 0.5$: strong effect; $0.5 > r > 0.3$: moderate effect; $0.3 > r > 0.1$: weak effect) (WebPanel 1).

Results

Predator presence

We confirmed the presence of both species of carnivores within the study area repeatedly using camera traps (independent events involving four puma visits and eight fox visits; Figure 3), circular transects searched for tracks (four puma, zero fox), and direct and indirect field observations reported by farmers (12 puma, three fox) – thus establishing that risk persisted for all sleeping sites (units) during the trial (Bomford and O'Brien 1990). The presence of predators analyzed separately and together did not vary between all units (Wilcoxon two-tailed, $P > 0.05$) or periods (Wilcoxon two-tailed, $P > 0.05$). We detected pumas and foxes relatively near all units, and therefore concluded that the treatments did not drive predators far from the sleeping sites (Figure 1).

Effect of treatment

Treated herds experienced zero losses to pumas as compared to seven losses in control herds (ANOVA-type statistic degrees of freedom [df] = 1, $F = 5.49$, $P = 0.0019$; split-plot ANOVA df = 1, $F = 5.21$, $P = 0.045$; Wilcoxon one-tailed, $P = 0.075$, effect size $r = 0.57$; WebFigure 1). Treated and control herds both experienced fox predation, but the observed difference in predation between these herds was insignificant (25 versus 15 total attacks on treated and control herds, respectively; ANOVA-type statistic df = 1, $F = 0.47$, $P = 0.49$; split-plot ANOVA df = 1, $F = 0.48$, $P = 0.5$; Wilcoxon one-tailed, $P = 0.79$, effect size $r = 0.18$; WebFigure 1). We did not detect period or carryover effects (Wilcoxon two-tailed, $P > 0.05$; Table 1). All predation was reported to occur in sleeping areas, or within the periphery in cases where predators chased individuals from the actual sleeping areas.

Discussion

This is, to the best of our knowledge, the largest randomized experiment without bias ever conducted on livestock predation, and the first in Latin America (Treves et al. 2016; van Eeden et al. 2018). Moreover, this is the first known random-assignment experiment testing the functional effectiveness of light devices in deterring puma predation. We found that the devices deterred predation by puma on camelid livestock (alpacas and llamas) but had no significant effect on predation by Andean foxes. Given the higher (but non-significant) effect of greater losses to foxes among treated herds, we recommend further testing with a larger sample size to evaluate if the light devices attracted foxes instead of deterring them, or possibly that the deterrence of pumas created opportunities for foxes.

Progress in predator management has been hampered by two widespread assumptions. First, it is assumed that gold-standard experiments are not feasible for studying livestock and predators under typical field conditions. For instance, the many potentially confounding variables in natural ecosystems and on working livestock farms do indeed hamper experimental control, but our work demonstrates that such challenges can be overcome by adopting crossover (reverse-treatment) and moderate control over recruiting participants (see also Quinn and Keough 2002; Donnelly and Woodroffe 2012; Treves et al. 2016). Second, some authorities (ie government agencies) assume that livestock owners will refuse the placebo control, and that such refusals might lead to the introduction of selection and response biases (Groves 2006; Creswell 2009). However, this was not a problem among our 11 participant farmers, probably due to the long-term prior engagement process, the lack of other sources of external support to farmers, and the crossover design, which gave all owners the opportunity to try the light devices.

However, we wish to highlight two issues concerning our research design. First, it was impossible to ensure that the participant livestock owners were unaware of which treatment they were assigned due to the conspicuousness of the nighttime lights, which could introduce at least some degree of confirmation bias if the owners believed the deterrents would be effective. We partially countered this potential measurement bias by recruiting independent verifiers from the government agency in charge of livestock protection; the verifiers did not ultimately visit all incident sites but owners did not know this ahead of time. It is not clear why verifiers or owners would have intentionally or unintentionally skewed results toward effectiveness against pumas but not foxes, especially given the product name of the light devices (Foxlights®). Regardless, we call for future experimenters to engage independent verifiers or to train owners and verify their reports (McManus et al. 2015). Second, we could not evaluate the duration of effectiveness of the lights or whether

one or both of the predators would eventually habituate to the light devices after 4 months. However, providing protection to camelid young even just for a 4-month period might be enough for them to reach market size or grow to a large enough size that their vulnerability to predation is reduced by innate defenses.

Conceivably, the effectiveness of light deterrents might merely reflect the case of a single puma that was interested in preying on livestock but was afraid of the light; however, if we assume that there was a single livestock-killing puma in the area, then that puma had to have been responsible for all the camelids lost to puma predation. This might be possible, as pumas can travel very long distances, but we would have expected a switch in behavior of this hypothetical puma in response to switches in treatment; instead, control herds within reach of the hypothetical puma remained unaffected (Table 1). Moreover, the large expanse covered by the entire experiment – almost 2000 km^2 – would substantially reduce the likelihood that a single puma accounted for all predation. Using the widest home ranges described in the literature for pumas (Logan and Sweanor 2010), ~2000 km^2 in 4 months would require at least two individuals. We believe that there were almost certainly two pumas at a minimum and more likely several others, for the following reasons: the areal extent of our experiment could support 2–3 resident male pumas and 5–6 resident female pumas, as well as transients of either sex, which would suggest a minimum of 6–8 individual pumas. In addition, a camera trap study previously performed in roughly the same area (Leichtle 2013) estimated puma density at 0.5 pumas per 100 km^2, which translates to ~10 individuals in our study area of ~2000 km^2. On the basis of our own camera trap data, we confirmed the presence of three pumas (Figure 3; WebFigure 2). Tracks of two different pumas were also observed at one site in the northern part of our study area, indicating that there were at least two individuals in the vicinity of the northern sleeping sites used in our experiment (Figure 1). Given the distance from the location of these tracks to our southernmost experimental units (~65 km), it would seem that a minimum of three pumas is the most reasonable inference. Finally, if the light deterrents have an effect on even just a few livestock-killing pumas, then the results would have even greater relevance for predator–livestock coexistence and conflict mitigation, because "problem individuals" have long been recognized as the primary cause of most livestock deaths (Linnell *et al.* 1999). Furthermore, pumas and other carnivores are known to specialize on prey, such as livestock, even within a multi-prey landscape (Elbroch and Wittmer 2013), and so our findings suggest owners might be able to use lights to interfere with livestock selection before it occurs.

Scarcity of evidence and weak inferences regarding effectiveness have important consequences for all parties. For instance, implementation of ineffective methods might aggravate social conflicts over biodiversity by increasing the suffering of domestic animals and wildlife, as well as by increasing economic costs. When faced with social conflicts, people might revert to traditional lethal controls regardless of their effectiveness (Treves and Bruskotter 2014; Woodroffe and Redpath 2015). Moreover, when governments promote methods that show no evidence of being effective or, worse yet, invest in disseminating untested methods, trust in the government or confidence in its recommendations might be eroded. We expect that our experimental approach will help to inform evidence-based policy not only for wildlife and livestock, but also for environmental conservation and biodiversity, and help lead to the development of sound policies that promote the coexistence of humans and wild animals.

▪ Acknowledgements

▪ References

Bomford M and O'Brien PH. 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. *Wildlife Soc B* **18**: 411–22.

Boyd DR. 2011. The implicit constitutional right to live in a healthy environment. *Rev Europ Commun Intern Environ Law* **20**: 171–79.

Brunner E, Domhof S, and Langer F. 2002. Nonparametric analysis of longitudinal data in factorial experiments. New York, NY: John Wiley & Sons.

Chapron G, Kaczensky P, Linnell JDC, *et al.* 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science* **346**: 1517–19.

Creswell JW. 2009. Research design: qualitative, quantitative, and mixed methods approaches. Los Angeles, CA: SAGE Publications.

Crooks KR and Soulé ME. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature* **400**: 563–66.

Díaz-Uriarte R. 2002. Incorrect analysis of crossover trials in animal behaviour research. *Anim Behav* **63**: 815–22.

Donnelly C and Woodroffe R. 2012. Reduce uncertainty in UK badger culling. *Nature* **485**: 582.

Elbroch M and Wittmer H. 2013. The effects of puma prey selection and specialization on less abundant prey in Patagonia. *J Mammal* **94**: 259–68.

Estes JA, Terborgh J, Brashares JS, *et al.* 2011. Trophic downgrading of planet Earth. *Science* **333**: 301–07.

Fritz CO, Morris PE, and Richler JJ. 2012. Effect size estimates: current use, calculations, and interpretation. *J Exp Psychol* **141**: 2–18.

Groves RM. 2006. Nonresponse rates and nonresponse bias in household surveys. *Public Opin Quart* **70**: 646–75.

Ioannidis JPA. 2005. Why most published research findings are false. *PLoS Med* **2**: 696–701.

Jones B and Kenward MG. 1989. Design and analysis of cross-over trials. London, UK: Chapman and Hall.

Leichtle J. 2013. Oferta de presas, dieta y densidad de pumas (*Puma concolor*) en el altiplano de la region de Tarapacá, Chile (MS thesis). Santiago, Chile: Pontificia Universidad Católica de Chile.

Linnell JDC, Odden J, Smith ME, *et al*. 1999. Large carnivores that kill livestock: do "problem individuals" really exist? *Wildlife Soc B* **27**: 698–705.

Logan K and Sweanor L. 2010. Behavior and social organization of a solitary carnivore. In: Hornocker M and Negri S (Eds). Cougar ecology & conservation. Chicago, IL: University of Chicago Press.

McManus JS, Dickman AJ, Gaynor D, *et al*. 2015. Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. *Oryx* **49**: 687–95.

Myers RA, Baum JK, Shepherd TD, *et al*. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science* **315**: 1846–50.

Nakagawa S and Cuthill IC. 2007. Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biol Rev* **82**: 591–605.

Newing H, Eagle CM, Puri RK, and Watson CW. 2011. Conducting research in conservation: social science methods and practice. London, UK: Routledge.

Noguchi K, Gel YR, Brunner E, and Konietschke F. 2012. nparLD: an R software package for the nonparametric analysis of longitudinal data in factorial experiments. *J Stat Softw* **50**: 1–23.

Ohrens O, Treves A, and Bonacic C. 2016. Relationship between rural depopulation and puma–human conflict in the high Andes of Chile. *Environ Conserv* **43**: 24–33.

Ohrens O, Santiago-Ávila F, and Treves A. 2019. The twin challenges of preventing real and perceived threats to human interests. In: Frank B, Glikman JA, and Marchini S (Eds). Human–wildlife interactions: turning conflict into coexistence. Cambridge, UK: Cambridge University Press.

Platt JR. 1964. Strong inference. *Science* **146**: 347–53.

Quinn GP and Keough MJ. 2002. Experimental design and data analysis for biologists. New York, NY: Cambridge University Press.

Reed MS. 2008. Stakeholder participation for environmental management: a literature review. *Biol Conserv* **141**: 2417–31.

Ripple WJ, Estes JA, Beschta RL, *et al*. 2014. Status and ecological effects of the world's largest carnivores. *Science* **343**: 151–62.

Ruxton GD and Neuhäuser M. 2010. When should we use one-tailed hypothesis testing? *Methods Ecol Evol* **1**: 114–17.

Sutherland WJ, Pullin AS, Dolman PM, *et al*. 2004. The need for evidence-based conservation. *Trends Ecol Evol* **19**: 305–08.

Treves A and Bruskotter J. 2014. Tolerance for predatory wildlife. *Science* **344**: 476–77.

Treves A, Andriamampianina L, Didier K, *et al*. 2006. A simple, cost-effective method for involving stakeholders in spatial assessments of threats to biodiversity. *Hum Dimens Wildl* **11**: 43–54.

Treves A, Artelle KA, Darimont CT, *et al*. 2018. Intergenerational equity can help to prevent climate change and extinction. *Nature Ecol Evol* **2**: 204–07.

Treves A, Chapron G, López-Bao JV, *et al*. 2015. Predators and the public trust. *Biol Rev* **92**: 248–70.

Treves A, Krofel M, and McManus J. 2016. Predator control should not be a shot in the dark. *Front Ecol Environ* **14**: 380–88.

Treves A, Wallace RB, and White S. 2009. Participatory planning of interventions to mitigate human–wildlife conflicts. *Conserv Biol* **23**: 1577–87.

van Eeden LM, Eklund A, Miller JRB, *et al*. 2018. Carnivore conservation needs evidence-based livestock protection. *PLoS Biol* **16**: e2005577.

Woodroffe R and Ginsberg JR. 1998. Edge effects and the extinction of populations inside protected areas. *Science* **280**: 2126–28.

Woodroffe R and Redpath SM. 2015. When the hunter becomes the hunted. *Science* **348**: 1312–14.

◼ Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1952/suppinfo
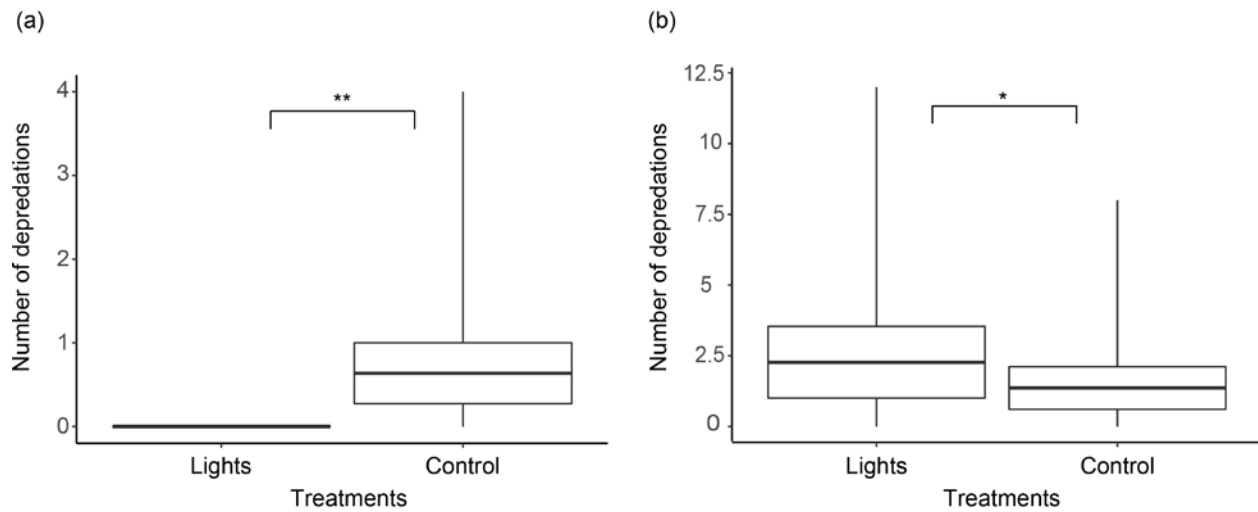
WebFigure 1. Predator attacks on livestock by treatment or placebo control. Means ± standard error (SE; boxes, *n* = 11), bars span the range of each, and statistical significance are presented for each plot. (a) Plot of puma (*Puma concolor*) attacks, (**significant). (b) Plot of Andean fox (*Lycalopex culpaeus*) attacks, (*not significant).

(a)

(b)

WebFigure 2. Individual pumas identified within the study area over the course of the 4-month trial. Identification was performed independently by the lead author and an external colleague, based on patterns (eg marks, scars, shape of tail, spots) observed on puma individuals. (a) Female puma and (b) juvenile puma.

WebPanel 1. Methods

Study area

The altiplano of Tarapacá is characterized by a cold, arid climate, with temperatures ranging from –10°C to 12°C and an annual average rainfall of 50–250 mm, which is largely concentrated between December and March. Human population densities within the study area are extremely low, from 0.01 to 0.4 individuals per square kilometer. The topography of this region is rugged, and characterized by large expanses of sandy and stony flats interspersed with ridges, moderate slopes, and boulder-strewn cliffs. With low primary productivity, the altiplano is predominantly covered by montane grasslands and shrublands, as well as Andean meadows or wetlands (*bofedales*). Most biodiversity is found in areas that are capable of supporting relatively higher productivity, such as the Andean meadows or *bofedales*. Wildlife such as the native vicuña (*Vicugna vicugna*), species of vizcacha (Chinchillidae), Andean mountain cat (*Leopardus jacobita*), Andean condor (*Vultur gryphus*), and introduced feral mammals (eg hare, donkey) are common in the study area (Ohrens *et al*. 2016).

From September to March (the rainy season), herds of llamas (*Lama glama*) and alpacas (*Vicugna pacos*) normally graze in *bofedales* and the surrounding montane grasslands and shrublands. Livestock grazing rules applicable to the local Aymara people do not differ between protected and non-protected areas.

Participant enrollment and workshop design

The Chilean government convened meetings between livestock farmers, National Forest Service (CONAF) park rangers, and agricultural officers of the National Agricultural Development Institute (INDAP) working in both the Indigenous Territorial Development Program (PDTI) and the Local Development Program (PRODESAL) in the Tarapacá region (Figure 1). We presented outlines of our research at three such meetings in May 2016 (during which we were explicit about our independence from the Chilean government, and that we were university representatives and funded by the US Fish & Wildlife Service, because livestock owners had expressed explicit discontent with the Chilean government in previous work; Ohrens *et al*. 2016). Farmers that agreed to the crossover design and presented pre-established sleeping areas for livestock then progressed to the randomization step. We started with 12 experimental units, but one unit was excluded from the analysis, as the farmer could not be re-contacted, leaving us with 11 units in total.

Experimental design

We defined the experimental unit as an established sleeping area (ranging from 30 to 180 m in diameter) used by a livestock herd owned by a participant. Although the camelid livestock ranged freely across the landscape during the day, they aggregated in specific sleeping areas every night, when supervision of livestock by people is less frequent (Ohrens *et al*. 2016).

Alpacas and llamas are the main traditional livestock breeds used by the Aymara people of northern Chile (Gundermann 1984; Ohrens *et al*. 2016). Herd sizes used in our trials varied from 22 to 380 animals (Table 1).

Treatments

We used solar-powered Foxlights® attached to wooden poles buried in the ground. The manufacturer recommended placement at a height visible to the predator species of interest; the height of the lights was therefore adjusted depending on the density and height of surrounding vegetation (eg shrubs can achieve 1.5 m in height), and any topographical feature that could affect light visibility by pumas (*Puma concolor*) and Andean foxes (*Lycalopex culpaeus*). Lights were generally situated between 1.5–2 m above the ground. Total cost per deterrent light was US$60, funding for which was provided by the local government agencies PRODESAL and PDTI.

Verifying predation

We found no discrepancies between verifiers' reports and farmers' self-reports. All 11 participant livestock owners reported to have experienced puma predation of their livestock in the past and claimed to be able to recognize and discriminate a puma predation event by tracks and feces. Six experimental units were exposed to puma presence during the 4-month trial periods, as shown by our independent tracking and camera data. Two participants (from a total of four that experienced puma attacks during the trial) reported prey dragging as evidence of a puma attack, which is unambiguous visually; however, even if this was simply a case of pumas scavenging the carcasses of livestock that had died from other causes, the observed deterrent effect against puma scavenging around sleeping sites would be relevant to the effectiveness of lights. Deterring predators from scavenging should also reduce the risk of predation of livestock, as has been demonstrated in several recent meta-analyses in which a lower number of carnivore incursions into pastures was characterized as evidence of the effectiveness of a given deterrent (Treves *et al*. 2016; Eklund *et al*. 2017).

Given that puma predation has been the focus of attention of the Chilean government and the primary concern of farmers (Ohrens *et al*. 2016), it would be odd if concerns about puma predation diminished and concerns about fox predation rose. Indeed, fox predation was reported to be almost six times higher than puma predation and, despite the name of the lights, foxes were apparently undeterred by the light devices. It therefore seems unlikely that farmers would contradict their own prior complaints and concerns about pumas. Research in another region of Chile is presently underway using only independent verifiers, to test our assumption that self-reporting introduces random error. Some of our confidence also comes from the design of workshops before the trial began.

Data analysis

We used a non-parametric ANOVA-type-statistic based on ranks, and an F1-LD-F1 model (ie an experimental design with one whole-plot factor and one sub-plot factor) in which treatment

sequence was set as the whole-plot factor and treatment was the sub-plot factor (Brunner *et al*. 2002; Noguchi *et al*. 2012). For the split-plot ANOVA, we rank-transformed our dependent variable (counts of puma and fox predation events) before conducting the analysis (Conover and Iman 1981; Quinn and Keough 2002), and adjusted for the effects of period by incorporating period into the model prior to testing for direct treatment effects (eg predation = subjects + periods + treatments). For the Hills–Armitage procedure, we evaluated a discrete response variable (counts of puma and fox predation events) and several categorical independent variables (treatments, experimental units as blocks, and period), considering period effects while testing for treatment differences (Jones and Kenward 1989; Díaz-Uriarte 2002). All data were analyzed with Rstudio (v1.0.143) software.

WebReferences
Brunner E, Domhof S, and Langer F. 2002. Nonparametric analysis of longitudinal data in factorial experiments. New York, NY: John Wiley & Sons.
Conover WJ and Iman RL. 1981. Rank transformations as a bridge between parametric and nonparametric statistics. *Am Stat* **35**: 124–29.
Díaz-Uriarte R. 2002. Incorrect analysis of crossover trials in animal behaviour research. *Anim Behav* **63**: 815–22.
Eklund A, López-Bao JV, Tourani M, *et al*. 2017. Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. *Sci Rep-UK* **7**: 2097.
Gundermann H. 1984. Ganadería aymara, ecología y forrajes. *Chungara* **12**: 99–124.
Jones B and Kenward MG. 1989. Design and analysis of cross-over trials. London, UK: Chapman and Hall.
Noguchi K, Gel YR, Brunner E, and Konietschke F. 2012. nparLD: an R software package for the nonparametric analysis of longitudinal data in factorial experiments. *J Stat Softw* **50**: 1–23.
Ohrens O, Treves A, and Bonacic C. 2016. Relationship between rural depopulation and puma–human conflict in the high Andes of Chile. *Environ Conserv* **43**: 24–33.
Quinn GP and Keough MJ. 2002. Experimental design and data analysis for biologists. New York, NY: Cambridge University Press.
Treves A, Krofel M, and McManus J. 2016. Predator control should not be a shot in the dark. *Front Ecol Environ* **14**: 380–88.

O Ohrens *et al*. – Supporting Information

WebPanel 2. Acknowledgements