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RESEARCH

Predator-friendly ranching, use of electric fences, and creole cattle in the Colombian savannas

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Abstract
Livestock ranching overlaps extensively with jaguar and puma distribution in the Casanare Department of east-central Colombia. Conservation programs prioritize large carnivores in the region. Ranchers retaliate by killing them in response to economic losses or fear related to their presence. Reducing retaliatory hunting is a top priority in the conservation of feline species. Predation mitigation methods (PMMs) are necessary to reduce depredation and increase tolerance for large felines. In a prospective cohort study, 16 ranches between 2017 and 2019 used electric fences ($n = 14$) and introduced creole cattle ($n = 2$) as PMMs. There was a significant difference in the risk and odds ratios between the control and treatment groups. Livestock depredation was 14.78 times higher outside PMM areas (OR, 14.78; RR, 0.069; $p < 0.001$) than inside such areas. The losses caused by depredation were much higher than the investments made in PMMs.

Keywords Carnivores · Human-wildlife conflict · Predation mitigation methods · Electric fences · Creole cattle

Introduction

Reconciling wildlife conservation with livestock production on rangelands requires a departure from the conventional "either/or" model, where separate competing stakeholders represent conservation and livestock production. Conservation biology focuses on integrating human societies into the biological environment (du-Toit et al. 2017; Mace 2014). Livestock depredation is the primary source of conflict between carnivores and livestock owners. Jaguars (*Panthera onca*) and pumas (*Puma concolor*) in America are examples of such conflicts. It is crucial to protect livestock from the attacks of large carnivores for two reasons: (i) Cattle depredation is the most common reason for carnivore persecution in the field (Sanderson et al. 2002; Zeller 2007), and (ii) retaliatory killing significantly impacts carnivore populations and reduces their range (Castaño-Uribe et al. 2016; Cavalcanti and Gese 2010; de-la-Torre et al. 2021; Garrote et al. 2016; Guerisoli 2017; Llanos et al. 2020; Palmeira et al. 2008; Peña-Mondragon et al. 2017; Polisar et al. 2003; Soto-Shoender and Giuliano 2011; Tortato et al. 2015; Villalva and Palomares 2019 amongst others). Human-wildlife conflicts often go beyond physical conflict and are influenced by social, cultural, and political factors (Madden 2004).

Jaguars favor forested areas and avoid open or disturbed habitats (Morato et al. 2018). They are known for their ability to kill large prey, making them notorious livestock predators. This often leads to conflicts with humans (Inskip and Zimmerman 2009). Additionally, large carnivores have low reproductive rates, low non-human-related mortality rates, and large area requirements, which results in low population densities (Ewer 1973; Hunter 2015). These biological characteristics make them particularly vulnerable to persecution (Purvis et al. 2000).

Livestock depredation rates can vary significantly based on wild prey availability and livestock management. These rates are also dependent on the location and time of the year. Even one instance of depredation can lead to a catastrophic loss of income for livestock owners, especially those not very affluent. (Khorozyan et al. 2015; Zanin et al. 2015). To solve the problem, it is common to eliminate carnivores. Although

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jaguars and pumas are legally protected in Colombia, they still face the threat of illegal hunting due to the remoteness of their habitats and the lack of law enforcement. People often hunt them out of fear, even though jaguars rarely cause harm to humans unless they are being hunted or harassed (Hoogesteijn et al. 2016a). Additionally, there has been a recent surge in the hunting of jaguars for their body parts, which are exported to Asian markets (Morcatty et al. 2020).

Large feline conservation cannot be achieved in the long term with only public protected areas (Verdade et al. 2014); therefore, private lands play a crucial role. Livestock owners experience varying degrees of loss, which could be influenced by factors such as the livestock species, how they are raised, and the behavior of predators (Baker et al. 2008; Peña-Mondragon et al. 2017). This is particularly true in areas where extensive meat production is a significant economic activity (Palmeira et al. 2015; Quigley et al. 2015; Ubiali et al. 2018). It is often assumed that felines are responsible for significant loss of livestock, disregarding other factors such as drought, disease, flooding, and starvation. Research conducted by Cavalcanti and Gese (2010) and Hoogesteijn et al. (1993) suggests that the blame cannot be solely attributed to predators. Additionally, jaguars are known to scavenge domestic animal carcasses that died from other causes, which may contribute to the misconception that they are the primary culprits. Jędrzejewski et al. (2011) provided further evidence to support this claim.

Heterogeneous stakeholders require various management approaches that value their diverse interests and investment capacities (not only economic) (Hoogesteijn and Hoogesteijn 2014; Zimmermann et al. 2021). Methods to control livestock depredation by jaguars and pumas are extensively described elsewhere (Castaño-Uribe et al. 2016; Cavalcanti et al. 2012; Hoogesteijn et al. 2016b; Hoogesteijn and Hoogesteijn 2014; Quigley et al. 2015; Valderrama-Vasquez et al. 2017). Several studies (Baker et al. 2008; Krafte-Holland et al. 2018; Van Eeden et al. 2017; Van Eeden et al. 2018; and Wilkinson et al. 2020) have raised concerns over the efficiency and acceptance of methods employed to manage depredation and decrease financial losses, despite some degree of success. These studies analyzed a significant portion of scientific literature written in English. The studies highlighted concerns about a lack of knowledge, insufficient evidence of effective interventions, experimental design, and a poor understanding of ecological theories, among other factors. However, promoting human-carnivore coexistence remains a crucial aspect of carnivore conservation worldwide. The main objectives of this study were twofold: (i) to provide a quantitative evaluation of the effectiveness of five different PMMs across 16 ranches in the Casanare region of Colombia over 2 years. The study recorded the number of cattle depredation incidents by jaguars and pumas, achievements were measured in the number of depredated cattle or not in any given method, and (ii) to determine whether the economic losses caused by predation were higher or lower than the costs of implementing each PMM.

Methods

Study area

The neotropical savannas span over 2.1 million km^2, primarily in Brazil, Colombia, Venezuela, and Bolivia (Cochrane et al. 1985). The Llanos are natural old grassland biomes, strongly influenced by fire, flooding, and herbivory, but able to support large mammal biomass (Lehman and Parr 2016) and cover more than 400,000 km^2 across Colombia and Venezuela. The Colombian Llanos, covering approximately 250,000 km^2, has been heavily impacted by human activities such as oil extraction, deforestation, and illegal crop cultivation (Mora-Fernández and Peñuela-Recio 2013).

The project was developed in the northern Llanos of the Casanare Department, Colombia. The area has an average elevation of 350 m and a human density of 9.4 inhabitants/km^2 (Romero-Duque et al. 2018). The ranches (Fig. 1) were in a hot and humid region (Holdridge 1947). The mean annual temperature was 26 °C and the mean annual precipitation was 1500–2000 mm. The rainy season in Casanare usually lasts from April to October, with March and November being the transition months between the dry and rainy seasons. The region's geomorphology is based on sedimentary parent rock, which supports an alluvial savanna prone to flooding and overflow. The slopes in the study area vary from 0 to 3%. There is also a zone with a slightly more undulating relief where the slope ranges from 3 to 7% (Aguirre 1999). This zone contains flooded savannas, gallery forests, forested hills, and aggregations of moriche palms, with a predominance of *Maquira coriacea* and *Mauritia flexuosa* species (Romero-Duque et al. 2018).

Selection of ranches for the study

Compiling information on economic and property losses due to carnivore depredation is challenging as no centralized database is available. Data were collected from the following sources: (i) the Regional Environmental Authority (Corporinoquia), (ii) the local mayor's office (Alcaldía), and (iii) the local Cattle Ranchers Association. The data mentioned in the text was collected and formatted using the methodology described in the GRECO Field Manual (Valderrama-Vasquez et al. 2017). Depredation losses by jaguars and pumas were reported in 36 ranches. Later, a workshop was held with local ranchers, and 20 participants agreed to a follow-up visit and evaluation. From those 20 ranches, 16 were chosen to implement PMMs to prevent further losses. The selection was

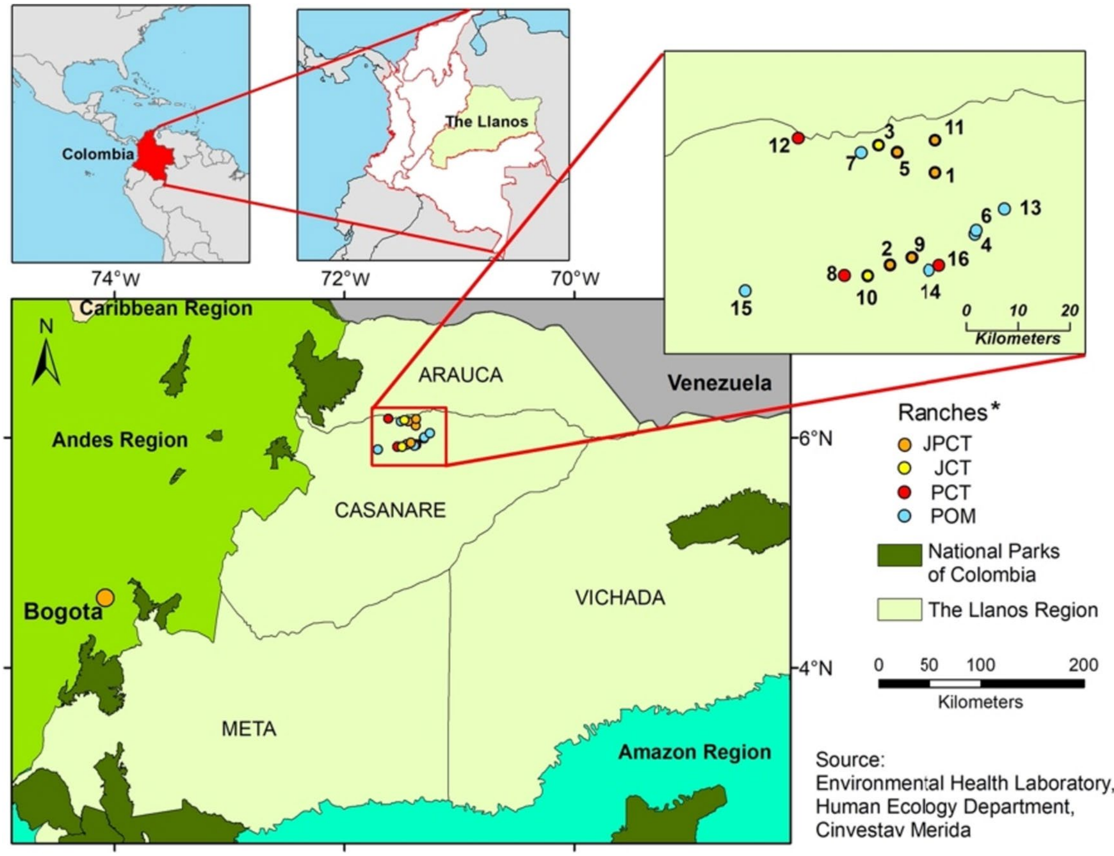

Fig. 1 Ranches where predation mitigation methods were implemented in the Casanare Department of the Orinoquia basin in Colombia. Orange, yellow, and red dots indicate felines detected through camera traps, jaguars and pumas, only jaguars, and only pumas, respectively. Blue dots indicate detected pumas by other means (see the "Confirming carnivore presence" section)

based on the following criteria: (i) the ranches had suffered from depredation attacks by felines in the previous 6 months; (ii) the owners were willing and interested in implementing PMMs; (iii) there was a confirmed evidence of a large feline presence (as explained in the "Confirming carnivore presence" section); (iv) the ranch had motor vehicle access almost all year round; and (v) the ranch was located near a jaguar priority conservation area (as identified by Bernal et al. 2012 and Díaz-Pulido et al. 2015).

Ranch characteristics

A ranch was defined as any land use associated with a herd managed as a single unit, including domestic animals of different species, where less than 10% of the total production value came from non-livestock activities (Aguirre 1999). Ranches were characterized, and data was collected using a semi-structured questionnaire during the first visit. The information that was gathered included the fundamental traits of the ranch (e.g., size, ownership, production system, production goal, number of fixed workers, pastures, topography, etc.) as well as management practices that could facilitate predator attacks (e.g., protection measures, herd size, herd species composition, the age distribution of livestock, animal health, breeding practices, herd location within the ranch, water sources, mortality data if available, etc.). During subsequent visits to the ranch, we updated the database with recent instances of depredation. We recorded all follow-up visits, which included a series of related questions to test the reliability of answers. These questions covered the same aspects and were open-ended.

The primary source of livestock feed was the native grasses found in the rangeland pastures. Forage quality varied, and nutrient-efficient grass crops were utilized by moving cattle seasonally during dry and rainy seasons (transhumance). Seasonal fluctuations in food supply can cause weight loss in livestock, which limits productivity during severe droughts or floods. Sometimes, pasture improvement was employed (mainly through introducing *Brachiaria* spp.). Twelve ranches utilized year-round salt supplementation. The predominant breed of cattle found in all ranches was mostly of the zebu type (commercial Brahman). Meat production in the Llanos region of Colombia is primarily intended for the domestic market. Calves that have been weaned and steers up to 2 years old are sold and finished for slaughter in other systems. The production goal for all ranches in the area can be defined as a cow-weaned calf operation.

Confirming carnivore presence

Jaguars and pumas historically inhabited the Llanos, with jaguar densities ranging from 1.12 to 2.19 adults per 100 km^2 (Boron et al. 2016). The study did not aim to assess species composition, density, distribution, or any operationalization related to their population dynamics. The data regarding the presence of jaguars and pumas were collected from captures in camera-traps and by detecting signs during visits (Eisenberg et al. 1970; Borges and Tomas, 2004).

To confirm the presence of carnivores and their prey, 57 camera traps were set across the 20 ranches visited (including the 16 ranches selected for this study). As informed by respondents and confirmed upon inspection, the camera stations were installed on existing footpaths in the nearest forested area where repeated depredation events occurred. Due to logistical restrictions, cameras were only installed at specific locations and adjusted to the survey design accordingly. During the study, camera traps were operated continuously, replacing batteries and memories every 60 days. The photographs taken at each camera trap site were used to confirm the presence or absence of the target species (Fig. 1, orange, yellow, and red dots). Some of the pumas present in the area were not captured in photographs. Still, they were detected through other means, such as track patterns, scats, claw marks, sprayed trees, and the inspection of vegetal material-covered carcasses (only for pumas) and depredated livestock carcasses (Fig. 1, blue dots). On the other hand, there were also cases where jaguars and pumas were not photographed and could not be detected by any means; such ranches were not included in the study ($n = 4$).

The locations where jaguars and pumas attacked were recorded using a global positioning system (Garmin; GPSMAP 64, Garmin International, INC. Olathe, KS). The data gathered included information on when the attacks occurred, which livestock species were attacked, and their age. Ranches participating in the project were visited regularly every 2 to 4 months, for a minimum of four times a year.

Study design

A prospective cohort study was conducted from November 2017 to November 2019 in 16 ranches. Since the ranches were privately owned, all research activities were conducted with the owner's involvement and consent. After discussing with the ranch owner and field hands, analyzing the main depredation complaint, and inspecting the sites with repeated depredation problems, PMMs were proposed from a portfolio of available strategies (Hoogesteijn and Hoogesteijn 2014; Valderrama-Vasquez et al. 2017). Owners choose a PMM based on their desired approach and willingness to follow procedures. Livestock mortality caused by large felines was monitored and recorded during each visit. Two PMMs were implemented: four variations of electric fences and the introduction of Sanmartinero creole cattle.

A no-hunting policy was convened for all predators and prey species on all ranches as part of the active cooperation. All livestock on each farm was enrolled and recorded independently of species or production status. At the start of the study, a livestock census was conducted, and any domestic animal killed by a jaguar or puma was recorded as a "loss." The livestock were either kept within a PMM area (treatment) or outside of it (control). We considered all livestock (cattle, horses, pigs, goats, and sheep) in the PMM as "treatment"; animals outside the PMM were considered the control group for each ranch. To provide an idea of the size of the PMMs (fences), a percentage was calculated based on the total size of the ranch (Table 3).

Technical information on fences

Fourteen ranches opted to use anti-predator solar-powered electric fences. However, these fences were used with different variations in husbandry. Six (6) ranches used protective maternity paddocks to safeguard newborn calves with their mothers. Four (4) of the ranches used night enclosures to protect vulnerable animals during the hours of highest predator activity. Two (2) of the ranches used weaning paddocks to protect recently weaned livestock. The other two (2) used forest barriers to prevent cattle from moving into forested riverine areas and to keep predators out of cattle pastures.

To construct fences, two options were used. (i) Conventional barbed wire fences at 20 cm, 60 cm, and 120 cm height above the ground. These fences were complemented with two additional electrified wires at 40 cm and 80 cm above the ground to complete the perimeter of pastures. (ii) A new electric fence with four electrified wires at 40 cm, 60 cm, 80 cm, and 120 cm above the ground and a barbed wire at 20 cm. The closest wire to the ground was not electrified to ensure that reptiles (mostly *Chelonoidis carbonaria*) were protected from electrocution.

The fencing used for the ranch was powered by solar energy, providing a voltage output consistently above 5000 V. The voltage range for the fencing was between 5000 and 10,000 V. Per the agreement, the ranch hands checked the fences weekly to ensure no energy loss due to ground contact by vegetation or other issues. Cleaning was necessary only during the rainy season, when weeds were manually removed, and a narrow herbicide line was sprayed beneath the wires.

Electric fence costs were calculated by measuring the perimeter of the enclosures in kilometers. The study found that a kilometer of electric fence to deter predators costs USD 1058.

Livestock values were rounded up to simplify calculations, without considering age, production capacity, breed, and market values. In this study, we are analyzing the fencing cost to determine if it is a more viable investment than the losses incurred due to depredation episodes in areas outside the PMM.

Introduction of Sanmartinero cattle

Spanish and Portuguese introduced European cattle, which went feral in America and adapted over 500 years to become the creole cattle of today. Creole cattle breeds such as Sanmartinero and Pantaneiro retain anti-predation behaviors. Males confront predators aggressively, while females form a protective circle around calves and young (Hoogesteijn and Hoogesteijn 2014; Hoogesteijn et al. 2016c; Valderrama-Vasquez et al. 2017). Sanmartinero cattle were introduced to ranches 1 and 9. Ranch 1 received one bull and two cows at a purchase and transportation cost of USD 2257. Ranch 9 received four bulls and five cows at a purchase and transportation cost of USD 7147.

Sanmartinero cattle were purchased from breeders in the Meta and Casanare Departments. The treatment group consisted of bulls and breeding cows mixed with zebu cows. They were separated from the main herds (control group) using conventional barbed wire fences. We compared the total investment in these animals to the losses incurred due to depredation episodes in areas outside the PMM area.

Statistical analysis

To determine the impact of each PMM, such as electric fence maternity, electric fence night enclosure, electric fence barrier, electric fence weaning paddock, and creole cattle, a relative risk or risk ratio (RR) was calculated, similar to what is done in a cohort study. Relative risk is the ratio of the probability of depredation occurring in livestock in the PMM area to the probability of depredation occurring in the control area. The odds ratio measures the strength of association between a depredation event in control areas. It is defined as a ratio of the odds of an event occurring in an exposed group to the odds of the event occurring in a non-exposed group (Andrade 2015).

All cases were classified by strategy using a 2 × 2 contingency table (Table 1). The risk ratio (RR) 95% confidence interval was calculated according to Altman (1991).

A relative risk (RR) value of 1 indicates no difference in the risk of carnivore depredation between the treatment group (PMM) and the control group. If the RR is greater than 1, it suggests that livestock in the PMM are at a higher risk of depredation than livestock in the control group.

Table 1 Conventional layout for a 2 × 2 contingency table for binary predictor or screening test and binary outcome or event

Outcome/event	Predictor/test		
	Predation mitigation method (treatment)	Control (no treatment)	Outcome totals
Dead	a	b	$a+b$
Alive	c	d	$c+d$
Predictor totals	$a+c$	$b+d$	$a+b+c+d$

Relative risk (RR) = a/a + b / c/c + d

Odds ratio (OR) = c/d / a/b

Conversely, if the RR is less than 1, it indicates a lower risk of depredation in the treatment group than in the control group. The RR compares the risk among the treatment and control groups for each strategy. However, it does not explain the actual risk of livestock predation in the Casanare region. Rather, it represents a value that indicates how effective the treatment is compared to doing business as usual without any PMM intervention. We also calculated the odds ratio (OR) to conclude if the odds of a particular event or outcome (death by depredation) were the same for the two experimental groups in each strategy. The OR indicates the increased likelihood of an event occurring in one group over the other. If the OR is greater than 1, it indicates that the control group, which was exposed to carnivores, is X times more likely to be preyed upon than the livestock in the treatment group protected by PMM. Statistical tests were performed using Minitab (v.16) and MedCalc Software, RR and OR calculator (https://www.medcalc.org/calc/odds_ratio.php (version 20.011; accessed September 10, 2021).

Results

Out of the 16 selected ranches, camera traps confirmed that jaguars and pumas were present in 10, accounting for 63% of the total ranches; these ranches are indicated by yellow, orange, and red dots in Fig. 1. Puma presence was established in the remaining six ranches through other signs such as track patterns, scats, clawed and sprayed trees, vegetal material-covered carcasses (pumas only), and depredated livestock carcass inspection. These ranches are represented by blue dots in Fig. 1.

The ranchers had different reasons for participating in the project, ranging from reducing economic losses to contributing to the conservation of felines. All ranches maintained records of animal deaths in the control and PMM areas. The percentage of animal deaths caused by pumas and jaguars varied significantly between ranches (with mean, 5.8%; median, 2.25%; minimum, 0.18%; maximum, 49%; standard deviation, 11.33; $n = 16$) as outlined in Table 2.

Livestock lost due to depredation in the PMM areas can be described as follows: Ranch 9 introduced creole cattle to a paddock near a forested area heavily affected by depredation. Although introducing creole cattle decreased the attacks, two calves were lost to felines. In ranch 10, one weaned calf was lost during a power outage. The lower strand of the fence was submerged due to severe flooding caused by a heavy rainstorm. In ranch 11, one cow was lost due to a rotten fence post interrupting the electrical circuit. In ranch 15, a puma attacked a small goat through the fence but released it after receiving electric shocks. In ranch 16, one calf was left outside the PMM (maternity paddock) and was attacked by a jaguar (Table 2).

The investments in the PMMs (electric fences and purchase of Creole cattle) were considerably lower than the losses experienced due to depredation (Table 3).

All interventions had a lower RR and OR for animals inside the PMMs than those outside. For instance, there was a 99.93% higher risk of predation outside the maternity paddocks than inside (RR, 0.07; $p = 0.009$). When expressed as an OR, the odds of livestock predation were nearly 14 times greater outside the maternity paddock protected by an electric fence (OR, 13.88; $p = 0.009$). A merged OR was calculated due to homogeneity. Livestock outside of protection had odds of depredation nearly 15 times higher (OR, 14.78; RR, 0.069; $p < 0.001$) (Table 4).

Discussion

When predators and livestock share resources, depredation is inevitable; however, sustainable levels of risk can be achieved (Castaño-Uribe et al. 2016; Hoogesteijn and Hoogesteijn 2014; Valderrama-Vasquez et al. 2017). Our research indicates that PMMs are highly effective in controlling feline depredation, regardless of the size, number, and type of livestock and/or husbandry systems, while remaining low-cost (Tables 2, 3, and 4).

Our data has proven that utilizing electric fences and creole cattle effectively reduces livestock losses across small, medium, and large ranches. This method is irrespective of the production goals (calves, weaners, yearlings, or home consumption) or the protected species (cattle, horses, pigs, sheep, or goats). These methods are a practical and cost-effective way to manage jaguar and puma depredation. We have confidence that using PMMs can increase ranchers' tolerance for large carnivores and decrease retaliatory killing. This could lead to coexistence and support for conservation efforts that reduce cattle losses and increase production efficiency. These PMMs designed for Latin American countries could be used in other regions with similar ecological and husbandry conditions. The model aims to support ranchers affected by depredation by providing advice on better husbandry practices.

Table 2 Livestock tallies in the control and PMMs area (fences, creole cattle) from November 2017 to November 2019 in 16 ranches in the Casanare Llanos Colombia

ID	Ranch size	Livestock inventory control group[a]					Predation losses					Depredation strategy	Paddock size	Livestock inventory in PMM area[a]					Predation losses	
	(Ha)	C	H	P	G	S	C	H	P	G	S		Ha	C	H	P	G	S	C	G
1	1380	869	5	0	0	2	48	5	0	0	2	Creole cattle	70	79	0	0	0	0	0	0
2	760	399	40	0	0	0	2	9	0	0	0	EF[b] weaning paddock	53	72	40	0	0	0	0	0
3	600	660	10	60	0	40	6	0	0	0	0	EF maternity	40	240	2	0	0	40	0	0
4	180	37	0	20	0	0	3	1	14	0	0	EF maternity	4	4	0	20	0	0	0	0
5	3500	2000	75	100	0	51	3	1	0	0	0	EF maternity	136	600	20	0	0	51	0	0
6	44	39	3	40	0	0	0	0	2	0	0	EF night enclosure	2	39	3	38	0	0	0	0
7	1000	540	43	0	0	0	3	0	0	0	0	EF maternity	58	80	42	0	0	0	0	0
8	879	570	12	45	0	15	8	1	0	0	0	EF maternity	6	240	0	0	0	15	0	0
9	13,832	5500	400	100	0	0	127	100	0	0	0	Creole cattle	492	358	0	0	0	0	2	0
10	643	333	16	0	0	0	2	4	0	0	0	EF weaning paddock	32	100	0	0	0	0	1	0
11	1150	1200	74	3	0	0	19	7	0	0	0	EF barrier	5 (km lineal)	600	38	0	0	0	1	0
12	350	55	31	6	0	4	0	1	0	0	2	EF night enclosure	4	27	00	0	0	4	0	0
13	1000	1440	40	60	0	0	6	3	0	0	0	EF barrier	2 (km lineal)	320	15	0	0	0	0	0
14	200	195	9	0	0	48	2	0	0	0	7	EF night enclosure	8	76	4	0	0	48	0	0
15	185	135	2	0	13	0	4	0	0	9	0	EF night enclosure	11	0	0	0	13	0	0	1
16	1800	980	100	100	0	0	2	3	1	0	0	EF maternity	58	180	100	0	0	0	1	0

[a] *C* cows, *H* horses, *P* pigs, *G* goats, *S* sheep

[b] *EF* electric fence

Table 3 Livestock predation losses, electric fence, and cattle costs for 16 ranches of the Casanare Llanos of Colombia between November 2017 and November 2019

Ranch	Paddock function	Ranch size	Paddocksize	Paddock size/ranch size	Fence costs Cattle costs	Losses to predation control areas	Losses to predation in PMM areas
		ha	ha	%	USD	USD	USD
1	Creole cattle	1380	70	0.5	2257[b]	26 080	0
2	EF[a] weaning	760	53	6.9	1728	4600	0
3	EF maternity	600	40	6.6	1328	3000	0
4	EF maternity	180	4	2.2	133	2838	0
5	EF maternity	3500	136	6.10	4518	1900	0
6	EF night enclosure	44	2	4.5	67	134	0
7	EF maternity	1000	58	5.8	1927	1500	0
8	EF maternity	879	6	0.68	199	4400	0
9	Creole cattle	13 832	492	3.5	7147[b]	103 500	1000
10	EF weaning	643	32	4.9	1063	2600	500
11	EF barrier	1150	5 km (lineal)	-	5290	12 300	500
12	EF night enclosure	350	4	1.1	133	480	0
13	EF barrier	1000	2 km (lineal)	-	2116	4200	0
14	EF night enclosure	200	8	4	266	1280	0
15	EF night enclosure	185	11	5.9	366	2360	40
16	EF maternity	1800	58	3.2	3854	2267	500
Total costs					**32 392**	**173 439**	**2540**

Cattle ≅ USD 500, horse ≅ USD 400, pig ≅ USD 67, goat ≅ USD 40, sheep ≅ USD 40

Exchange rate for 2018, 1 USD = 2992 Colombian pesos

[a] *EF* electric fence; electric fence prize, USD 1058/km

[b] Costs of creole cattle (cattle prize: bulls USD 1003, cows USD 627)

Table 4 Summary statistics of the relative risk relating number of dead livestock per applied strategy (treatment) and control group. We present relative risk (RR), 95% confidence interval (95% CI), odds ratio (OR), 95% CI and the significant effect $p < 0.05$

Strategy	N Ranches	Predation mitigation method	Livestock killed	Livestock n per group	RR	95% CI	OR	95% CI	*p* value
EF maternity	6	Yes	1	1634	0.07	0.01–0.52	13.88	1.91–100.7	0.009
		No	46	5412					
EF night enclosure	4	Yes	1	251	0.08	0.01–0.62	12.25	1.65–90.69	0.014
		No	27	553					
EF barrier	2	Yes	1	972	0.08	0.01–0.59	12.40	1.69–90.68	0.013
		No	35	2742					
EF weaning	2	Yes	1	211	0.21	0.02–1.63	4.65	0.61–35.16	0.13
		No	17	771					
Creole cattle	2	Yes	2	435	0.11	0.02–0.44	9.30	2.30–37.50	0.001
		No	282	6594					
Merged ratios	**16**				**0.069**	**0.03–0.15**	**14.78**	**6.59–33.13**	**< 0.001**

Based on our past interventions and experience, livestock depredation rates exceeding 4% are considered high. For the set of ranches we analyzed, the mean value of depredation losses was 5.8%, indicating a need to further explore the prey base, hunting activities, traditions, ecology, and livestock management.

Ranchers were motivated to participate in jaguar conservation efforts due to economic losses caused by livestock depredation and their desire to contribute to the conservation of the species. Ranchers also observed that lethal control methods did not lead to a sustained decrease in depredation by large felines (Murray-Berger 2004; Treves et al. 2016). However, all depredation events should be acknowledged and addressed because losing even one domestic animal can devastate a smallholder's economy.

The ranchers' interest in a permanent solution with minimal work or investment led to the selection of electric fences (Fig. 2) (14 ranches) and Sanmartinero cattle (2 ranches). Ranchers had become acquainted with electric fences through advertisements and by visiting other ranches. Electric fences have added value since they improved livestock management, monitoring, and better use of pastures by creating paddocks. Electric fence material and construction labor are cheaper than conventional fences, and ranchers were interested in trying them out, with the economic support of SENA and WebConserva. This essay facilitates possible future repeats using their funds. Sanmartinero cattle are originally from the region, and ranchers remembered conversations with elders and other ranchers about the fierceness of this breed against predators; this previous exposure facilitated the introduction of creole cattle.

Husbandry practices in the floodplains of South America and other continent areas can be quite basic. Some ranchers still use husbandry techniques over 300 years old, inherited from the Spanish culture (Hoogesteijn et al. 2019). These ranchers are often reluctant to make any improvements or changes. However, even in these basic conditions, the study shows that minimizing the interface between predator and prey can significantly reduce the risk of depredation by pumas or jaguars. This experience is replicated in other situations (see Castaño-Uribe et al. 2016), where ranchers adopt more efficient animal husbandry techniques and keep up-to-date with the latest advances in tropical animal science. Ranches with more intensive management find it easier to implement methods to mitigate predation (Castaño-Uribe et al. 2016; Hoogesteijn and Chapman 1997; Quigley et al. 2015). Electric fences can be highly effective in various settings (Hoogesteijn et al. 2016b). Their versatility relies on recognizing each ranch's unique needs and ecological variables (Zimmermann et al. 2021) and establishing mutual agreement with stakeholders to determine objectives and expected results.

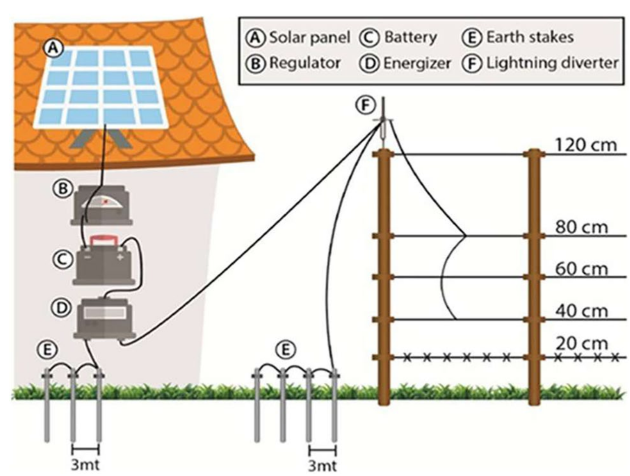

Fig. 2 Electric fence schematics include an energizer, insulator wires fixed on posts, and a ground system emitting a pulsed, high-voltage shock

All the ranches were subjected to a treatment (PMMs) — control design using independent herds. However, the assignment of PMMs could not be done randomly as it required the agreement with ranchers and field hands on which PMM to use and which ranch area to fence (Tables 2, 3).

Our analyses were hindered by the unequal distribution of data on depredation rates among the various PMMs. The use of a simple 2 × 2 contingency table (Table 1) was an excellent analysis tool for dichotomous (binary) outcomes (Hoogesteijn and Hoogesteijn 2008; Parshall 2013). This method represents the risks and odds of depredation in a "control–treatment" situation.

The study showed that the PMMs were effective in protecting livestock. The predation risk was almost 100% higher outside the PMMs than inside the PMMs. The odds of livestock being depredated outside a PMM were nearly 15 (14.78) times higher than the odds of being depredated inside a PMM. All RR were smaller than 1, indicating that the PMMs were functional (merged $p < 0.001$). The study's results demonstrate the importance of PMMs in reducing the risk of livestock predation.

Electrically fenced maternity paddocks, night enclosures, and forest barriers showed good results. The percentage of paddocks compared to the size of ranches did not exceed 6.9% in all 14 ranches (Table 3). Changes in husbandry (e.g., the introduction of synchronized births) could maximize the use of resources. The few losses happened mainly because of human error, such as faulty examination of the fences (rotten fence post) and leaving a calf outside the fence. Constant surveillance can prevent power shortages, especially during the rainy season.

The trial with weaning paddocks yielded mixed results. While the p-value was higher than 0.05, indicating that the intervention was unsuccessful, RR and OR show that it effectively controlled depredation. Specifically, the RR was 0.21, and the OR was 4.65, with a p-value of 0.13 (Table 4). In this intervention, a weaned calf was lost during a power outage caused by flooding. The lower segment of the electrical fence was submerged, rendering it ineffective during the flooding period. This event highlights the importance of proper planning and reconnaissance of the terrain, considering seasonal changes to determine the best location for paddock and corral construction, and the need for constant maintenance and vigilance of the electric fences. This is the primary disadvantage of utilizing electric fences to safeguard livestock in large-scale systems.

Electric fence construction is a more cost-effective option than conventional barbed wire fences. However, it requires higher and more intensive maintenance than traditional barbed wire fences. The absence of electricity lines and the need for solar panels could discourage ranchers from using this method. To address this issue, the study proposes working under a contract with a private company that can supply the necessary materials and technical assistance during installing and maintaining the electric fence. We have estimated the cost and maintenance expenses of installing a 1 km electric fence to prevent predator attacks at USD 1058/km. However, it is important to note that these costs may vary based on the country-region and country. For instance, in Brazil's Pantanal area, conventional fence (barbed wire) costs are higher than in Colombia, up to USD 3000/km. Similarly, an electric fence to contain livestock can cost up to USD 1500/km, whereas an electric fence to deter large felines can cost USD 1700/km. The prices may also differ based on the construction materials availability, such as the ranch's wooden posts.

All fence costs were lower than the losses due to depredation in the control area (Table 3). The difference was quite significant in some cases, such as ranch 11. These findings indicate that investing in livestock protection measures could be a substantial cost, but its benefits justify it. One effective way to lower the costs is to upgrade traditional barbwire fences to deter predators. This can be done using existing posts and wires and adding two electrified wires (as explained in the "Technical information on fences" section).

Electric fences have been proven effective in other parts of the world (Cavalcanti et al. 2012; Hoogesteijn et al. 2016b; Ubiali et al. 2018). Recent experiences with film and camera-trapping in Brazil's northern Pantanal by Panthera Brasil have shown how jaguars receive a shock when approaching an electric fence (video available at: https://www.youtube.com/watch?v=LrPq2czwDuc). After receiving a shock, cats leave the area for several weeks and become cautious around electric fences.

The use of electric fences had an additional benefit for small, low-income families in ranches 4 and 6; the introduction of solar panels and a battery protected their animals and allowed the use of light bulbs. The ability to spare fuel for lamps boosted the familiar economy and well-being, as well as the quality of the light, without fumes.

Since the introduction by European settlers' creole cattle (*Bos taurus*) constituted the primary livestock resources in tropical Latin America. During the last 70 years, zebu cattle (*Bos indicus*) were imported and crossbred with creole cattle, almost driving the latter to near extinction. One consequence of this crossbreeding was the loss of the anti-predator behavior. Considering the small number of creole cattle and paddock size, they fared well. The zebu to creole cattle ratio in ranch 1 was 10 times higher in a 77-ha paddock. In ranch 9, the ratio was even more extreme, with an 18 times higher ratio in a 492-ha enclosure surrounded by forest. Nevertheless, losses due to depredation were very low, with no losses in ranch 1 and only two calves in ranch 9. In comparison, the control group experienced 55 and 227 losses for each ranch in the same area. Creole cattle represented a significant and advantageous investment from an economic perspective. Ranch 1 saw losses 11 times higher than the investment in creole cattle, while ranch 9 saw losses 18 times higher (Table 3).

Additional research is needed to determine the optimal ratio of zebu to creole cattle and the most suitable paddock size. Introducing creole cattle to commercial zebu herds is a viable alternative when electric fences cannot be used. This is especially true in areas where creole cattle are available, and cattle are extensively managed. If ranchers are concerned about creole cattle breeding with commercially or genetically valuable cattle, they can subject the creole bulls to a teaser surgery. This procedure would prevent the bulls from impregnating cows while maintaining their defensive behavior (Gill 1995).

Our data suggest that using electric fences and introducing creole cattle to reduce livestock losses is effective, regardless of production objectives or domestic species involved. These techniques provide a realistic and financially viable approach to managing felid predation. Using PMMs can increase ranchers' tolerance for large carnivores, promoting coexistence and supporting conservation efforts. Ranchers' participation in the project shows their willingness to coexist with wildlife and preserve their land.

As the concern of some authors about the ineffectual performance of PMM (Baker et al. 2008; Krafte-Holland et al. 2018; Van Eeden et al. 2017, 2018; Wilkinson et al. 2020), we hope this study motivates ranchers and conservationists worldwide. PMM's ineffectiveness stems from flawed operationalization, not biology. Then again, Amano and collaborators (2021) demonstrated the importance of synthesizing non-English language research to fill the gap in context-dependent evidence and promote global evidence-based conservation. We believe that the findings of this study can contribute to reducing this information gap.

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Declarations

Ethics approval The authors confirm that the ethical policies of the journal, as noted in the journal's author guidelines page, have been adhered to.

Conflict of interests The authors declare they have no competing interests.

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