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Short communication

A cost-effective approach to mitigate conflict between ranchers and large predators: A case study with jaguars in the Mayan Forest

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ABSTRACT

Conflicts between humans and large carnivores are exacerbated in poor rural areas where people's livelihood depends on livestock ranching. Here we present a pseudo-experimental and co-participatory approach to test the effectiveness of a program to mitigate conflicts with jaguars (*Panthera onca*) in Mexico's Mayan Forest. We worked with eleven ranchers with a recent history of livestock predation by jaguars to codesign, implement, and evaluate changes in their husbandry practices intended to reduce the risk of predation and to increase livestock productivity. We used four parameters to evaluate the effectiveness of the program and found that (1) the use of electric fences and night enclosures greatly reduced the rate of predation on the livestock; (2) the cost of building such protection infrastructure was financially offset by the lack of losses to predation; (3) the application of more science-based husbandry practices led to an overall increase in livestock productivity; and (4) jaguar presence in at least seven of the eleven ranches, showing that the lack of predation was not due to jaguar absence. Our neat results show that conflict between local communities and large carnivores can be largely mitigated through ranchers' capacity building and applying evidence-based husbandry techniques. This approach leads to win-win situations for both jaguars and the local communities and hence can be scaled up to promote coexistence between people and large carnivores in the Mayan Forest and elsewhere.

1. Introduction

One of the main threats for large carnivores worldwide are their conflicts with people (Inskip and Zimmermann, 2009). Large carnivores often occur in human-occupied landscapes in which they attack livestock and suffer retaliatory killing by people (Woodroffe and Ginsberg, 1998). This situation is aggravated in low income regions where large carnivores' predation upon livestock cause severe economic losses to local communities (Soto-Shoender and Giuliano, 2011). Mitigating these human-wildlife conflicts to acceptable levels largely depends on multisectorial collaborations to develop strategies that reduce the cost of predation, increasing the cost-effectiveness of productive activities in rural communities, and creating suitable landscapes for large carnivores, particularly in areas that surround protected and wilderness areas (Dolrenry et al., 2020; Quigley et al., 2015).

Jaguars (*Panthera onca*) are the largest predators in the Neotropics and require vast areas of relatively well conserved habitat and abundant and diverse prey to persist (Sanderson et al., 2002). Jaguars now occupy just 50% of their historical range, with most of their populations being threatened (de la Torre et al., 2018) by habitat loss and fragmentation, retaliatory killing, and prey depletion. Jaguar mortality is associated with an increase in agriculture and cattle raising and with the construction of infrastructure. The latter allows hunters to deplete jaguars' natural prey, increasing conflicts with livestock and ranchers (Romero-

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Muñoz et al., 2020). Intolerance and persecution of jaguars are frequently motivated by economic losses associated with livestock predation (Marchini et al., 2016). The mitigation of human-jaguar conflict should therefore focus on evidence-based and cost-effective approaches to reduce livestock predation, removing any economic burden to local communities for living next to jaguars.

The Mayan Forest hosts one of the largest and few long-term viable jaguar populations (de la Torre et al., 2018). Previous studies have documented human-jaguar conflicts in this region (Peña-Mondragón et al., 2016; Soto-Shoender and Giuliano, 2011) but, despite the pressing need, no studies have attempted to implement and evaluate the effectiveness of human-jaguar conflicts mitigation strategies. Mexico is the only country in Latin-American that has an economic compensation program for ranchers that have lost animals predated by jaguars and other carnivores through the Livestock Insurance Fund and this is one of the main strategies to conserve the species in this country. Economic compensation, however, is a palliative measure that does not solve the root of the conflict. Effective human-jaguar conflict mitigation strategies should be easy to implement by the local community, financially cost-effective, sustainable, and up-scalable. Here we present the evaluation of a program to mitigate conflicts between jaguars and rural communities in the Mayan Forest. Our specific objectives were to: 1) test the effectiveness of electric fences and night enclosures to reduce livestock predation; 2) asses the cost-effectiveness of improved husbandry practices; and 3) monitor jaguar occurrence in the ranches involved in this program.

2. Material and methods

2.1. Study area

Our study area is the southern portion of the Mayan Forest region, Mesoamerica's largest tropical rainforest. Specifically, we worked in the Lacandona Rainforest in Mexico's state of Chiapas (de la Torre et al., 2017a), which includes five Natural Protected Areas (Fig. S1). The vegetation is dominated by tropical rainforest with presence of flooded forest, flooded savannas, and wetlands. The ongoing expansion of cattle ranching inside and outside protected areas is causing deforestation, and is one of the main threats to jaguars and their habitats. After more than 40 years of extensive ranching by local communities, livestock has become a common prey for jaguars and other predators.

2.2. Identification of ranchers to join the mitigation program

We conducted several site visits and engagement activities with local authorities, rancher associations, and individuals to identify ranchers who had suffered predation by jaguars in the previous seven years (2012–2018). We identified and interviewed 21 ranchers, whom we subsequently invited to participate in a human-jaguar conflict mitigation program in which we would provide support to reduce the risk of predation and improve the productivity of their husbandry practices. To join the program, ranchers had to commit to: 1) take part in a training workshop, 2) allow us to monitor their husbandry practices, 3) report any new cases of livestock predation, and 4) allow us to monitor jaguar presence in their ranches and adjacent forested areas. Eleven ranchers agreed to partner with us and participate in the program (Table S1).

2.3. Implementation of the mitigation program

The 11 ranchers attended one of three training workshops in which we addressed topics such as carnivore ecology, techniques to avoid livestock predation, practices to improve livestock production, livestock disease and vaccination, pastures carrying capacity and rotation, and low-cost feed blocks as dietary supplement. We then worked individually with each of the ranchers to codesign improved husbandry practices according to their individual circumstances and preferences. We built electric fences and night enclosures to reduce the risk of predation of cattle and sheep, respectively. The electric fences were constructed for cattle maternity pastures (Table S2, Appendix S2). Similar techniques have been previously used with positive results in Costa Rica and Brazil (Cavalcanti et al., 2012; Castaño et al., 2016).

At the program onset we recorded information on each ranch's characteristics and management practices, including the number of livestock heads, water sources, distance to forested areas, and fencing design. For monitoring purposes, we provided a specially designed notebook to each rancher and encouraged them to keep written records of their husbandry practices. The program started in different years for different ranches (Table 1). During the monitoring phase we visited the ranches every two months after the intervention to verify the performance of electric fences and night enclosures, to count the number of livestock heads, and to record new predation cases. Additionally, we deployed one camera trap in eight ranches and conducted terrestrial transects in all ranches during our visits (Table S4) to detect jaguar presence. The program implementation and effectiveness were monitored for an average period of 15.4 months (range: 3 to 34 months) in each ranch.

2.4. Evaluating mitigation effectiveness

We evaluated the effectiveness of the mitigation program using four parameters (Fig. 1): 1) a comparison of the predation rate before and after the program; 2) a benefit/cost ratio of electric fences and night enclosures; 3) changes in livestock productivity associated to the new husbandry practices; and 4) jaguar presence in the ranches.

We analyzed changes in predation rate using a linear mixed model with a negative binomial distribution of the error and with the number of predated livestock heads as response variable, mitigation treatment ('before' vs. 'after' joining the program) as fixed effect, and ranch as random effect. We normalized the response variable as each ranch's average number of livestock heads predated per month. We used a likelihood ratio test to evaluate the statistical significance of differences between the full and a reduced model without the fixed effect.

We estimated the cost of fences and enclosures as the economic investment in materials for their construction (corrected by their expected lifetime) and their economic benefit as the value of non-predated livestock heads, estimated based on each ranch's predation history (Zarco-González and Monroy-Vilchis, 2014). Benefit/cost ratios >1.0 indicate net economic benefit.

To assess the program's effect on livestock productivity, we compared the actual number of livestock heads at the end of the program with the expected numbers based on each ranch's predation rate before the program. In the case of cattle, we focused only on calf numbers because adults are rarely predated, and the sale of calves constitutes the main income for cattle ranches. In the case of sheep, we used the total headcount because jaguars predate on them regardless of age.

The detection of jaguars in the study ranches and adjacent forests was considered indicative of effectiveness of intervention actions and potential tolerance of ranchers to jaguar presence in their lands. See Appendix A for more details on the effectiveness evaluation.

3. Results

3.1. Husbandry practices and characteristics of human-jaguar conflict

All the 11 ranchers were smallholders ($<$150 animal heads per ranch) for whom livestock rearing was the main source of income. Seven ranchers specialized in cattle (with 27 to 150 heads each) and four in sheep (20 to 68 heads); although one cattle rancher and one sheep rancher also owned six heads of sheep and cattle, respectively. The mean extension of their pastures was 19.5 ha (range: 3 to 41) and most (72%) of ranchers maintained forest patches within their land. In all cases,

Table 1
Number of predation cases cost of the intervention, estimated productivity saved by the intervention and cost-benefit of the intervention in the eleven ranches intervened to avoid predation of jaguars upon livestock.

Ranch ID	Locality	Number of cattle losses	Predator	Years of depredation incidents before the intervention	Year of intervention	Total cost of the intervention (USD)	Estimated % in the productivity of the intervention	Cost-benefit ratio
FLO - 02	Flor de Marques	9 calves	Jaguar	2014, 2018	2018	$1362	18.2	5.9
FRONT - 01	Frontera Corozal	4 calves	Jaguar	2015	2018	$1096	15.4	6.6
FRONT - 02	Frontera Corozal	4 calves, 4 sheep	Jaguar, Coyote	2015	2018	$1259	12.5	11.4
FRONT - 04	Frontera Corozal	10 calves	Jaguar	2016	2018	$1015	11.8	26.6
QUIRI - 01	Quiringüicharo	3 calves	Jaguar	2016	2018	$528	13.6	15.3
CHA - 01	Boca de Chajul	4 calves	Jaguar	2017	2019	$1023	25.0	10.6
LOP - 01	Adolfo Lopez Mateos	17 calves	Jaguar	2016, 2017, 2018	2019	$1187	2.0	19.3
QUIRI - 02	Quiringüicharo	4 sheep	Jaguar	2017	2018	$580	17.9	2.7
FLO - 01	Flor de Marques	9 sheep	Jaguar	2012	2016	$1810	3.3	1.5
PLAY - 01	Playón de la Gloria	4 sheep	Jaguar	2012	2016	$998	4.8	1.2
MIRA - 01	San Felipe de Jatate	8 sheep	Jaguar	2019	2019	$656	14.0	4.8

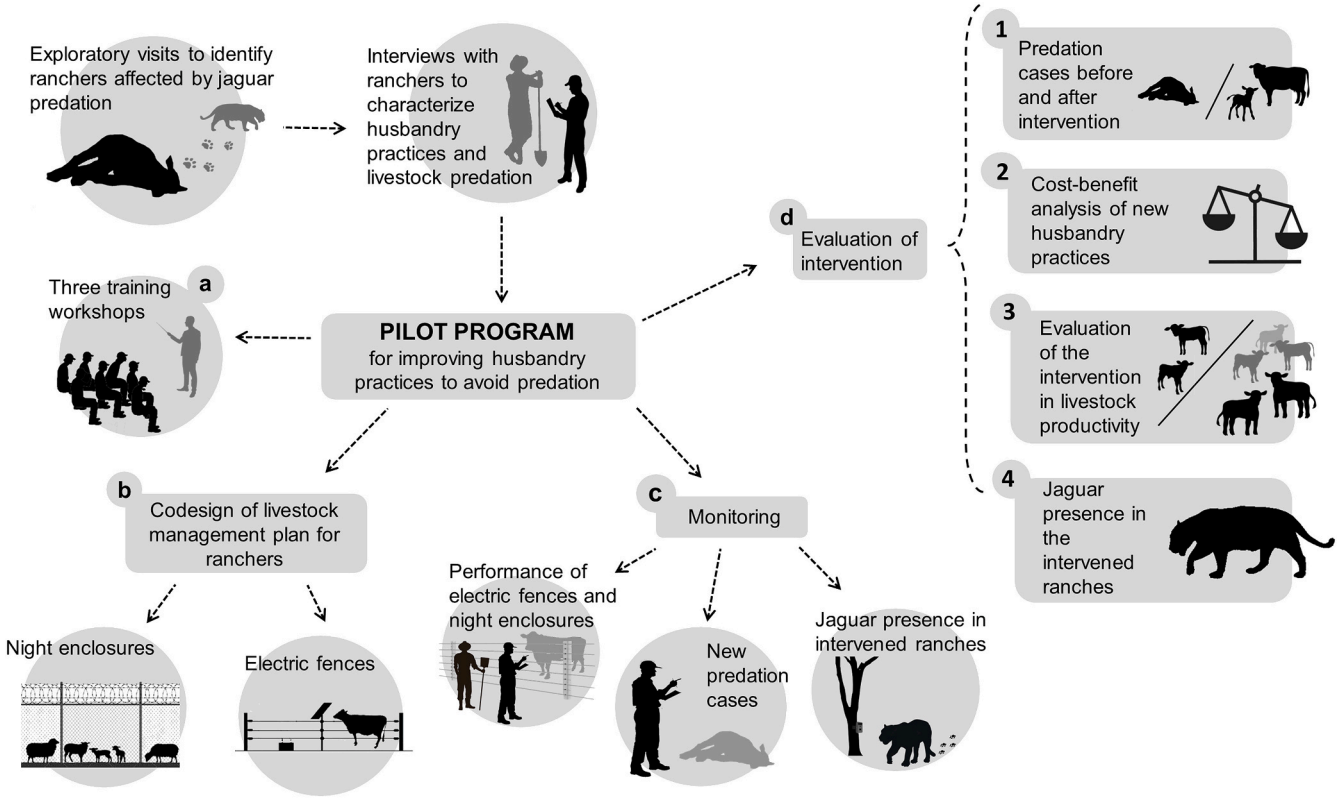

Fig. 1. Flow chart of the methodology followed in this study which include the four stages a) capacity building, b) codesign of management plan for ranchers, c) monitoring and d) evaluation. Evaluation was based on four aspects: 1) predation cases before and after the intervention; 2) cost-benefits of the intervention; 3) effect on productivity; 4) jaguar presence in the intervened ranches.

pastures were located near forest areas and far, 0.25 to 47 km, from the ranchers' homes. Accordingly, the ranchers reported not being able to look after their animals every day or during the night (Table S1).

We documented a total of 51 cattle and 29 sheep predated by jaguars and other carnivores (coyote, *Canis latrans*) before joining the program (Table 1). The losses per rancher ranged from three to 17 cattle heads and from four to nine sheep in the five years prior to joining the program (Table 1). Several ranchers lost animals in multiple predation events and in different years. Only one of the 51 predated cattle was older than six months (i.e. 98% of the cattle lost were calves). Considering USD540 as the average price per cattle and USD78.75 per sheep (rate USD dollar per Mexican Pesos $ 20.00), we estimated an aggregated economic loss of USD29,823, with average losses per rancher per year of USD1,408 (range: USD810–2700) for cattle owners, and USD300 (range: USD79 to

630) for sheep owners.

3.2. Effectiveness of the human-jaguar conflict mitigation

Predation rate was significantly lower after the implementation of the program ($X^2 = 24.09$, $P < 0.0001$). During the whole monitoring period (167 ranch-months, Table S3), we only recorded one predation incident, which happened when a sheep rancher did not enclose his herd for one night and four sheep were killed by a jaguar. This indicates a high level of effectiveness of electric fences and night enclosures to prevent attacks by jaguars and other predators.

The average investment per ranch was USD1067 (range: USD528 to 1362) to build electric fences and USD1,011 (range: USD580 to 1810) for night enclosures (Table S2). Considering pre-intervention predation rates, cattle ranchers ($n = 7$) saved an average of USD1,407 (range: 720 to 2700) per year as result of the electric fences; and sheep ranchers saved USD300 (range: 78.8 to 630) as result of the night enclosures. The mean benefit/cost ratio was very positive in all cases, being 13.7 (range: 5 to 26) for electric fences and 2.5 (range: 1.5 to 4.8) for night enclosures (Table S3).

More than half (63.6%) of the ranchers adopted the written record-keeping in the notebook we provided. Among the newly implemented practices, the most common and persistent were the enclosing of their most vulnerable animals (100%), pasture rotation (100%), and regular cleaning of the pasture near electric fences to ensure their well-functioning (57.1% of cattle ranchers; Table S2).

At the start of the program, cattle ranchers had an average of 65 (range: 27 to 150) animals, and sheep ranchers 35 (range: 20 to 68; Table 1). After the program, considering the previous predation record in each ranch, productivity increased an average of 14.1% (range: 2 to 25%) for cattle ranchers and 10.0% (range: 3.3 to 17.9%) for sheep ranchers as results of the animals no predated (Table S3).

During the monitoring period, we recorded jaguar presence in seven of the 11 ranches (Table S4), indicating that the reduced predation rate was not due to the absence of jaguars in the area.

4. Discussion

Despite much emphasis on conflicts between humans and large carnivores and the need to promote mechanisms for coexistence, few studies have actually attempted to implement and evaluate the effectiveness of conflict mitigation interventions. Here we show that cattle and sheep predation by jaguars and other carnivores can be substantially reduced by improving ranchers' husbandry practices, particularly enhancing livestock protection strategies. The use of electric fences (for cattle) and night enclosures (for sheep) led to a significant reduction in the predation rate, which, together with other improved husbandry practices, resulted in a net economic benefit for the ranchers involved in this mitigation program. All this while jaguars were still detected in most of the ranches. Large-scale implementation of this kind of mitigation program would benefit both ranchers and jaguars, improving their coexistence throughout the species range.

Allocating resources to protect livestock should be a priority to ensure jaguars' long-term persistence. The extensive and relatively hands-off traditional ranching practiced in our study area and often throughout the species range makes the protection of livestock against predators less effective and can lead to increased conflicts with jaguars (Peña-Mondragón et al., 2016). This, in turn, has negative effects on the jaguar population because lethal control was commonly practiced by local ranchers, at least until the onset of our program (de la Torre, unpublished data). Jaguars in the Mayan Forest use large home ranges (range: 180 to 540 km^2; de la Torre et al., 2017a), usually moving across a matrix of forests and human modified areas for cattle pastures or crops (de la Torre et al., 2017b). If the local human-jaguar conflict is not alleviated, the forest patches near pastures may act as ecological traps for jaguars and compromise the population viability and connectivity (Romero-Muñoz et al., 2019).

Economic compensation through the Livestock Insurance Fund is currently one of the main strategies to address human-jaguar conflicts in Mexico (Chávez et al., 2016). Compensation programs, however, do not work in all circumstances to mitigate human-wildlife conflicts (Ravenelle and Nyhus, 2017). In the Mayan Forest, the compensation program might end up costing more than implementing predation prevention measures such as the electric fences and night enclosures tested by us. In 2019, the Livestock Insurance Fund paid $250 USD per cattle calf and USD125 per sheep lost to predators. At these rates, the cost of building an electric fence or a night enclosure would be equivalent to the compensation of four to five cattle calves or six to eight sheep, respectively. These numbers are similar to the mean cattle or sheep lost per rancher in approximately one or two years (Table 1).

Local people frequently feel that their knowledge and perspectives regarding human-wildlife conflicts are ignored, which creates mistrust to support programs like the Livestock Insurance Fund (Lecuyer et al., 2019). Local ranchers' involvement was central to our mitigation program: they codesigned, implemented, and contributed to the monitoring and evaluation of the new husbandry practices. This approach empowers the local community, provides economic benefits, and can create a sense of shared responsibility – with government and NGOs – towards jaguar conservation (Lecuyer et al., 2019).

The presence of jaguars in the ranches involved in this program confirmed that the reduction in predation rate was not due to the absence of predators, suggesting that human-jaguar coexistence is possible in the Mayan Forest and other parts of the species range. Although our program was effective in reducing livestock losses by jaguars, these mitigation measures do not necessarily change negative perceptions of local people towards jaguars (Marchini et al., 2016). Promoting positive attitudes and behaviours towards jaguars, as well as communicating their ecological, cultural, and economic value is essential to reduce the jaguars-human conflict (Zimmermann et al., 2005).

Two important strengths and novelties of our study are (1) the co-participation of ranchers in the design and implementation of realistic and adapted interventions to reduce livestock losses by large carnivores; and (2) the use of a pseudo-experimental design, which is a rigorous approach to evaluate the effectiveness of interventions (van Eeden et al., 2018). One relevant caveat, however, was the lack of control ranches in our sample (case control design), to diminish possible biases as the result of confounding factors not considered in our study (van Eeden et al., 2018).

Despite the great amount of resources invested to protect livestock from jaguars throughout the species range, only six studies have tested the effectiveness of such interventions (e.g. Cavalcanti et al., 2012; Castaño et al., 2016; Quigley et al., 2015), let alone reported positive results. We demonstrated that improved husbandry practices can mitigate the impact of jaguar predation. Our results highlight the need and potential benefits for NGOs and government to invest in capacity building among ranchers and local communities, involving ranchers in the codesign of the mitigation, and creating economic incentives to motivate ranchers' participation in such programs (Peña-Mondragón et al., 2016).

The application of evidence-based husbandry practices to reduce the risk of predation and increase livestock productivity may allow an upgrade from traditional extensive ranching to more efficient and sustainable practices that benefit not only local livelihoods but also jaguar conservation. Furthermore, our approach is compatible with the ongoing economic compensation scheme and can be linked to new sustainable supply chain schemes, such as certification of wildlife-friendly beef, or other types of sustainable markets that bring benefits to farmers coexisting with jaguars (Romero-Muñoz et al., 2020). Payment for Ecosystem Services, which has been used successfully in Southern Mexico to protect critical jaguar habitats and corridors (de la Torre et al., 2017b) could also be implemented in the Mayan Forest.

Such combined actions, effective livestock protection, enhanced

productivity, and additional economic incentives, may be effective in mitigating the conflict between jaguars and local people by promoting a scenario of greater tolerance towards jaguars (Dolrenry et al., 2020), which will help ensure the long-term conservation of the largest jaguar population in Mesoamerica.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

This manuscript is original work of the authors enlisted below and we warrant that it has not previously been published. We also state here that this manuscript it is not submitted to any other journal at this time. We declared here that all sources of funding are acknowledged in the manuscript. We stated that all interviews implemented for this study were conducted under the ethical standards established by the Social Research Association.

All authors listed made substantial contributions to the manuscript and qualify for authorship, and no authors have been omitted. J. Antonio de la Torre designed the study, conducted the research, compiled the data, drafted the manuscript, and directed the revisions. Gamaliel Camacho-Hernandez, Paulina Arroyo-Gerala, Ivonne Cassaigne and Marina Rivero compiled data in field and analyzed the information. Ahimsa Campos-Arceiz reviewed the data and reviewed the manuscript critically. We warrant that the six authors have agreed to this submission and that none of the authors has any conflict of interest in regard this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2021.109066.

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