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Top-down local management, perceived contribution to people, and actual detriments influence a rampant human–top predator conflict in the Neotropics

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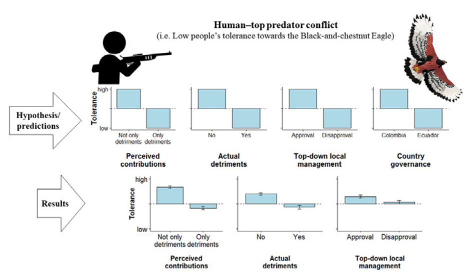
HIGHLIGHTS

- Neotropical governments and their environmental agencies have generally poor governance.
- Poor governance can be influencing human-top predator conflicts in the Neotropics.
- Forty percent of interviewees disapproved the current top-down local management.
- Disapproval of top-down local management influenced human tolerance independently.
- Neotropics need a better balance between bottom-up and top-down governance.

GRAPHICAL ABSTRACT



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ABSTRACT

In most Neotropical countries the proliferation of illegal firearms, limited funding, and low presence of authorities precludes effective application of top-down governance. Despite that, to our knowledge, top-down governance and top predator detriments or benefits to people (perceived and actual) have never been integrated into an empirical study of human–top predator conflict. We hypothesize that people's tolerance towards the black-and-chestnut eagle (*Spizaetus isidori*), a Neotropical top predator, will vary based on the eagle's perceived contributions to people, actual detriments to people, people's support of the top-down local management, and country governance. We tested our hypothesis by carrying out a closed-ended question survey in human communities around 27 eagle nesting sites in two countries (Colombia and Ecuador). People's tolerance towards the eagle showed a negative relationship with perceived detriments, actual detriments, and disapproval of the top-down local management, but there was no influence of country governance. Overall, most people showed high (41.13%) or neutral (35.46%)

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tolerance towards the eagle and less than a quarter (23.41%) showed low tolerance. Forty percent of people disapproved of the top-down local management. We documented human persecution of this top predator in the majority of sampled nests (59%, 16 of 27) and across all the geographical jurisdictions assessed. Our results suggest that poor governance could also negatively affect other human–top predator conflicts in the Neotropics. To be more effective at saving top predators in the Neotropical Region, structural changes such as a better balance between bottom-up and top-down approaches and, thus, co-management among stakeholders are needed.

Introduction

Top predator conservation is nowadays one of the most challenging global conservation issues. Although these species play critical roles in the ecosystem, thus benefiting society (Gilbert et al., 2021), when their behaviour poses a perceived or real threat to people or animal species associated with humans, conflicts arise and predators are usually persecuted (Conover, 2001; Inskip and Zimmermann, 2009; IUCN, 2020). To protect top predators and biodiversity in general, two non-mutually exclusive forms of environmental governance have been mainly used: the bottom-up and the top-down approaches (Bennett and Satterfield, 2018; Redpath et al., 2017; Treves et al., 2017). Historically several human cultures around the world have used the bottom-up approach to restrict or regulate access to natural resources, although in the last half-century a government-managed, top-down approach, has predominated (Koprowski et al., 2019; Rodrigues and Micael, 2021). However, neither approach is a panacea in itself as both can have advantages and disadvantages depending on the geographic scale or the particular context in which they are applied (Koprowski et al., 2019; Western and Wright, 1994). Thus, a co-management among stakeholders (e.g. through a simultaneous application of bottom-up and top-down measures) has been taking force in the last years as the most effective way to manage human–top predator conflicts worldwide (Killion et al., 2021; Redpath et al., 2017; Salvatori et al., 2021, 2020).

The management of human–top predator interactions in developing countries usually poses additional challenges to those occurring in developed countries, such as limited funding, low institutional presence, and poor governance (Fletcher and Toncheva, 2021; Gaynor et al., 2016; Santangeli et al., 2019). Governance is a system composed of institutions, structures, and processes that determine who takes decisions, how and for whom decisions are taken, as well as what actions are taken, by whom, how and to what effect (Bennett and Satterfield, 2018). Poor governance at the country level, for instance, may lead to an increase in illegal use of firearms or poison to control predators or to an uncontrolled extraction of wildlife and other natural resources that could also affect top predators, including large raptors (Santangeli et al., 2019). Although the Global South supports a large diversity of top predators (McClure et al., 2018; Miranda, 2017; Ripple et al., 2014), unfortunately it also includes some of the areas most affected by poor governance (Gaynor et al., 2016). The Neotropical Region is the most biodiverse in the world but it is also the region with the largest number of threatened species (Allan et al., 2019; Gaynor et al., 2016). In this region, systems of environmental governance are more based on the top-down approach (Bennett and Satterfield, 2018; Redpath et al., 2017; Treves et al., 2017) than the bottom-up approach (e.g. Constantino, 2016; Schleicher et al., 2017). As such, access to natural resources by rural people is usually controlled by the government's environmental authorities, sometimes with low social legitimacy, through regulations and top-down imposed laws. These laws, however, are poorly enforced due to a lack of environmental police officers and rangers, and by an inefficient judicial system, and thus are usually not effective in controlling human persecution of legally protected top predators (Barbar et al., 2016; Engel et al., 2016; Giraldo-Amaya et al., 2021; Morcatty et al., 2020; Restrepo-Cardona et al., 2020; Zuluaga et al., 2021).

To effectively manage human–top predator conflicts in the Neotropics in the long-term, we need to consider the additional challenges of environmental systems with poor governance. The particular goal of environmental governance is to manage individual behaviours and collective actions in compliance with public environmental goods and related social outcomes through environmental management (i.e. the resources, plans, and actions that result from the functioning of governance; see Bennett and Satterfield, 2018). Some recent indirect evidence suggests the existence of a negative influence of poor governance at national and local levels on several human–felid, human–raptor, and human–reptile conflicts in the Neotropics (Barbar et al., 2016; Estrada-Pacheco et al., 2020; Giraldo-Amaya et al., 2021; Miranda et al., 2016; Morcatty et al., 2020; Plaza and Lambertucci, 2020; Restrepo-Cardona et al., 2020; Zimmermann et al., 2021). Thus, to ensure persistence of top predator populations in Neotropical countries, we need to have more evidence about how poor governance is influencing human–top predator conflicts across the region. This knowledge could be useful for governments and environmental agencies to improve top predator conservation and environmental governance (e.g. through a co-management with stakeholders; Redpath et al., 2017), and for local non-governmental organizations (NGOs) as well as the private sector (e.g. tourism agencies, productive associations, and others) to help with this process (Carter and Linnell, 2016; Redpath et al., 2013; Santangeli et al., 2019).

The black-and-chestnut eagle (*Spizaetus isidori*) is one of the most endangered top predators in the Neotropical region, requiring urgent conservation actions to mitigate the rampant human–top predator conflict in which it is involved (BirdLife International, 2021; Buechley et al., 2019). A loss of this species would imply the loss of relevant and irreplaceable benefits that this bird of prey provides to the tropical Andean montane ecosystems and ultimately to society (Sekercioglu, 2006). With an estimated population size of less than 1000 mature individuals, this large raptor is globally listed as Endangered and therefore requires urgent conservation actions (BirdLife International, 2021). The species is threatened by habitat loss and particularly by human persecution in retaliation for domestic fowl predation (BirdLife International, 2021; Echeverry-Galvis et al., 2014; Lehmann, 1959; Restrepo-Cardona et al., 2020; Zuluaga et al., 2020a, 2020b). Socio-demographic variables, on their own, do not have an important contribution to explain tolerance towards this top predator (Zuluaga et al., 2021). However, poor governance, likely due to top-down coercive policies, also could be triggering discontent and environmental conflicts among stakeholders (i.e. human–human conflicts) and thus worsening this human–top predator conflict (Zuluaga et al., 2021).

Top predator detriments or benefits to people (perceived or actual) have already been extensively considered as important drivers of human tolerance in the human–top predator conflict-to-coexistence continuum (Bruskotter and Wilson, 2014; Frank et al., 2019; Kansky et al., 2016; Restrepo-Cardona et al., 2020; Zuluaga et al., 2021). Despite that, to our knowledge, perceived top predator detriments or benefits (*hereafter* perceived contributions), actual top predator detriments (*hereafter* actual detriments), the top-down local management, and governance at the country level (*hereafter* country governance) have never been integrated into an empirical study of human–top predator conflict. Here, we aim to understand how black-and-chestnut eagle's perceived contributions, actual detriments, top-down local management and country governance affect the rampant human–top predator conflict with this top predator in the Neotropics, in order to assess opportunities to advance towards top predator conservation. Our hypothesis is that people's tolerance towards the black-and-chestnut eagle will vary with the species' perceived contribution to people, species' actual detriments, people's support of the top-down local management, and the country governance. Based on corresponding earlier works, we tested the following predictions:

1 **Perceived contributions.** Perceived top predator detriments or benefits to people have already been extensively considered as important drivers of human tolerance towards top predators (Kansky et al., 2016; Kansky and Knight, 2014). People perceiving *only detriments* of top predators (e.g. the black-and-chestnut eagle) will be less tolerant towards this top predator than those perceiving only benefits, detriments but also benefits, or neither detriments or benefits (Broekhuis et al., 2020; Struebig et al., 2018).
2 **Actual detriments.** Livestock loss by predation of top predators has been regarded as one of the main drivers of low tolerance in human–top predator conflicts (Inskip and Zimmermann, 2009; Zimmermann et al., 2010). People suffering losses of domestic fowl by the black-and-chestnut eagle will be less tolerant towards this top predator than those not suffering losses.
3 **Top-down local management.** People disapproving of the local management of the government environmental authority (i.e. the functioning of the top-down local governance; Bennett and Satterfield, 2018) are usually more prone to be less tolerant towards top predators (Engel et al., 2016; Redpath et al., 2017; Struebig et al., 2018). While, when people approve of the local management of the government environmental authority, they will be more prone to tolerate top predators.
4 **Country governance**. Human tolerance towards top predators is potentially influenced by country governance (Santangeli et al., 2019). Although Ecuador and Colombia are considered two countries with poor governance, Ecuador is ranked worse than Colombia (Kaufmann and Kraay, 2020). Therefore, we predicted that in Ecuador people will be less tolerant towards the black-and-chestnut eagle than in Colombia.

Material and methods

Study species

The black-and-chestnut eagle is the main avian top predator of the tropical Andean montane forests from Venezuela and Colombia to north-western Argentina (Ferguson-Lees and Christie, 2001). During the reproductive season it is an obligate central place forager centred in the nesting territory (Lehmann, 1959), with a home range estimated at between 50 and 100 km^2 (BirdLife International, 2021), although the core area can be between 3 and 9 km^2 (Authors' unpublished data). Each breeding attempt takes almost ten months including the incubation of one egg for approximately 50 days, and at least eight months of juvenile dependence (i.e. time in which juvenile stays within the vicinity of the nest; Zuluaga et al., 2018). Once juveniles are independent, they begin to hunt on their own. Apart from preying upon native wildlife, they may also hunt small to medium sized domestic animals (mainly poultry). As a result, they may be perceived as prejudicial, and thus are more likely to be killed by humans (Authors' unpublished data). Despite the fact that this species is one of the least known raptors in the world (Buechley et al., 2019), recent data indicate this eagle can attempt to breed each year, although in the long-term it has a productivity of around 0.5 chicks per pair per year (Authors' unpublished data). Although the species seems to tolerate a certain threshold of habitat destruction and fragmentation, in those fragmented habitats they may prey more readily on poultry triggering conflict and facing higher human persecution (Restrepo-Cardona et al., 2020, 2019; Zuluaga et al., 2021).

Study area

The study area is located in the Tropical Andes of Colombia and Ecuador (between 5.8° N and 1.5° S) at an altitudinal range from 2000 to 2800 m above sea level (Fig. 1). The area is a stronghold population for the black-and-chestnut eagle, with 31 known nests (most of them from Ecuador) that have been monitored during the last decade as part of the Black-and-chestnut Eagle Project (https://www.researchgate.net/project/Black-and-chestnut-Eagle-Project-South-America). Colombia and Ecuador, located in the northern part of the Andes of South America, share a similar history, culture, language, topography, weather, biogeography, and economy, but have slight differences in their governance processes, laws, size, and policy. For instance, both countries have governmental environmental authorities which implement national, provincial or municipal policies to control the harvesting of natural resources and protect top predators and biodiversity in general. Environmental governance systems of all these authorities are based historically on a top-down approach (Treves et al., 2017), where responsibility for conserving biodiversity is mainly that of the national state. In Ecuador, provincial agencies depend on the central government (see Ley 37/1999 of Ecuador), although strong actions have been taken in recent years to decentralize environmental governance. While in Colombia they are a bit more autonomous, and the central government is only one among several other stakeholders (i.e. representatives of each municipality, departmental government, NGOs, private sector, among others; see Ley 99/1993 of Colombia). Despite that, and considering the nature of the top-down approach, the current governance system in both countries is not participatory enough and there is a historic gap in encouraging local people to actively work in community-based conservation strategies to engage and empower them with wildlife conservation.

To carry out the interviews, we defined a radius of 2 km (i.e. area of 12.6 km^2) around each eagle's known nest. This distance was the midpoint of the shortest known distance between two occupied nests in our study area (i.e. ~4 km; Authors unpublished data). This allowed us to include people that live within the eagle's territory and thus, people that could be similarly influenced by the eagles in all sampled locations in both countries (e.g. interviewees definitively live within the potential foraging range of the eagles). We interviewed as many respondents as possible around 27 eagle nesting sites covering an area of 340.2 km^2. The interviews were conducted around six nests in the central and western Andes of Colombia (mean number of households: 24, range 11–42) and around 21 nests in the northern and central Andes of Ecuador (mean number of households: 16, range 2–72). Of the initial 31 known black-and-chestnut eagle nests in both countries we did not conduct interviews around two nest sites in Colombia and two in Ecuador. One nest in Ecuador was in a private reserve without local people living in its vicinity and the other three nests were located in remote areas with difficult access. In Colombia, the sampled nests were located in the departments of Antioquia (n = 3), Huila (n = 2), and Tolima (n = 1), while in Ecuador they were located in the provinces of Carchi (n = 1), Imbabura (n = 5), Napo (n = 4), Pichincha (n = 3), and Tungurahua (n = 8). The governmen-

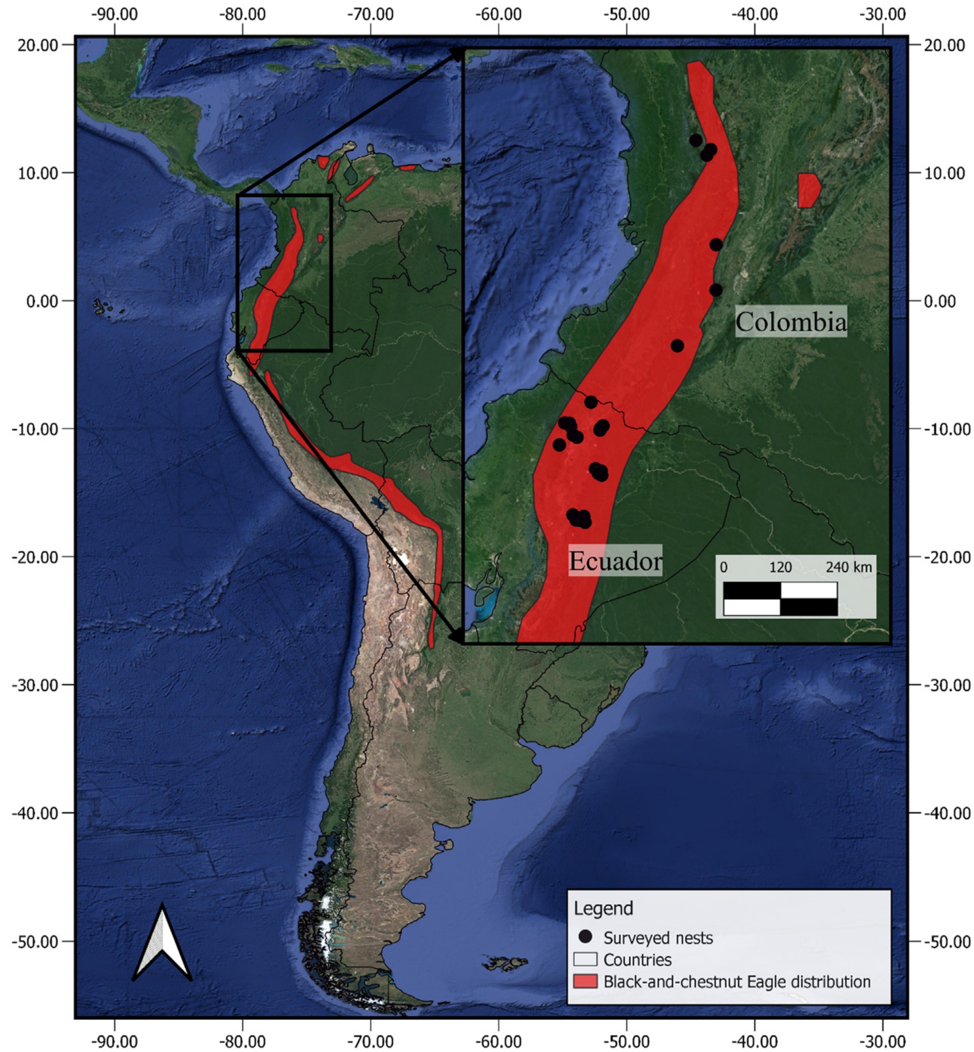

Fig. 1. Study area within the black-and-chestnut eagle (*Spizaetus isidori*) distribution range (http://www.birdlife.org) in the Neotropics. Surveyed nests were located in the central and western Andes of Colombia (n = 6) and in the northern and central Andes of Ecuador (n = 21).

tal environmental authorities (*autoridades ambientales* in Spanish) in these states (i.e. departments or provinces) are: CORANTIOQUIA (http://www.corantioquia.gov.co), CAM (www.cam.gov.co), CORTOLIMA (www.cortolima.gov.co), Ministerio del Ambiente y Agua (MAAE, www.ambiente.gob.ec) Carchi, MAAE Imbabura, MAAE Napo, MAAE Pichincha, and MAAE Tungurahua, respectively.

Data collection

The first author and three trained field assistants conducted interviews between 30 November 2019 and 28 February 2020. Interviewees were contacted in their homes and only one person older than 18 years of age was interviewed from each household. To ensure that the interviewees knew the black-and-chestnut eagle, we first asked them to name the wildlife species in the area they were familiar with. We then asked them to identify the black-and-chestnut eagle from a photo (i.e. we showed photos of an adult black-and-chestnut eagle, another of a juvenile, and a third of both birds together) (Zuluaga et al., 2021; Zuluaga and Echeverry-galvis, 2016). Of 359 interviewees, 282 people recognized or had heard of the species, and 77 could not identify it and were unfamiliar with the species (76 in Ecuador and one in Colombia; Table 1). Our sample reached 60% of the households living in a 2 km radius around these 27 eagle nests. In all cases, ethical standards of social surveys were met by informing respondents that their participation was voluntary and that we would ensure their anonymity.

Questionnaire

Variables defined *a priori* from literature on socio-ecological research of human–wildlife interactions were included in a questionnaire (e.g. Ceauşu et al., 2019; Dressel et al., 2018; Kansky et al., 2016; Lischka et al., 2018; Struebig et al., 2018; Zuluaga et al., 2021). We conducted a closed-ended question survey asking about tolerance towards the black-and-chestnut eagle, perceived contribution (i.e. benefits or detriments), actual detriments (i.e. livestock losses by the black-and-chestnut eagle), local people's support of the top-down local management, socio-demographics (e.g. country, gender, age, years of education, number of domestic fowl they own, and percentage of income from farming production), historical or current records of poached eagles, the number of environmental workshops in which people have participated, among others (see Appendix A). Socio-demographics were obtained in order to know some characteristics of the sample. The main conservation strategy of the local top-down governance to persuade people to coexist with top predators is through environmental laws and

Table 1
Interviews conducted with rural people around six nests in Colombia (C01-C06) and twenty-one nests in Ecuador (E01-E21). State refers to departments in Colombia and provinces in Ecuador. Population size (*N*) was estimated based on the number of households (around 2 km from the nest, i.e. 12.6 km^2), sample size (*n*) is the number of individuals interviewed around each nest, and final sample size (*n'*) is the final dataset considering only people who knew the black-and-chestnut eagle (*Spizaetus isidori*).

Nest ID	State	*N*	*n*	*n'*
C01	Huila	41	31	31
C02	Huila	15	11	10
C03	Tolima	10	5	5
C04	Antioquia	25	20	20
C05	Antioquia	11	9	9
C06	Antioquia	42	36	34
E01	Tungurahua	72	51	30
E02	Tungurahua	3	3	2
E03	Tungurahua	7	4	4
E04	Tungurahua	2	2	1
E05	Tungurahua	16	11	6
E06	Tungurahua	10	8	5
E07	Tungurahua	15	11	8
E08	Carchi	38	26	22
E09	Imbabura	14	13	8
E10	Pichincha	8	7	5
E11	Imbabura	7	5	5
E12	Imbabura	8	6	5
E13	Imbabura	11	10	9
E14	Imbabura	20	16	9
E15	Pichincha	33	24	12
E16	Napo	15	14	14
E17	Napo	8	5	4
E18	Napo	5	3	1
E19	Napo	12	8	8
E20	Pichincha	13	11	6
E21	Tungurahua	10	9	9
Total		471	359	282

See Material and methods.

workshops. The historical or current records of poached eagles and the number of environmental workshops in which people participated were obtained to contextualize and support our results in respect to tolerance and the effectiveness of the top-down local management.

Tolerance towards the black-and-chestnut eagle was selected as the response variable and was measured as public support for one of three possible species population trends. That is, people were asked if they would like the black-and-chestnut eagle population to be: *reduced* (i.e. low tolerance), *kept the same* (i.e. neutral) or *increased* (i.e. high tolerance). Perceived contributions were measured by asking respondents whether they perceived the eagle as detrimental or beneficial to them (possible answer: *benefits*, *detriments*, *both* or *none*). Actual detriments were measured by asking respondents whether they had lost livestock (i.e. domestic fowl) to black-and-chestnut eagle predation in the past (possible answer: *yes* or *no*). To assess people's support of the top-down local management, local people were asked if they *approve* or *disapprove* of the management of the government's environmental authority in each geographical jurisdiction. When they expressed lack of awareness about the management of the government's environmental authority, and thus how the top-down governance works, their response was marked as: *did not have an opinion.* Country governance was measured by the country where people were interviewed (i.e. *Ecuador* or *Colombia*). The historical or current records of poached eagles were assessed based on self-reported behaviour and triangulation among interviewees (i.e. asking people to inform about whether their neighbours had killed any black-and-chestnut eagles). That information was used to estimate the prevalence of nest territories with poached eagles. Age, education level, number of domestic fowl they own, percentage of income from farming production, and the number of environmental workshops in which people have participated were considered as continuous variables.

Statistical analyses

We first made a plot of our hypotheses to know the mean and standard error of the tolerance according to each of the predictor variables (Fig. 2). To obtain this, we re-codified tolerance as a discrete variable (see Struebig et al., 2018), as follows: −1 = *reduced*, 0 = *kept the same*, and 1 = *increased*. Descriptive statistics were used for presenting results on socio-demographics and the number of environmental workshops in which people participated. Some missing socio-demographic data were imputed using the iterative Factorial Analysis for Mixed Data (FAMD) algorithm of the package *missMDA* in R (Josse and Husson, 2016). A x^2 test was run for testing the independence among perceived contributions and actual detriments by the black-and-chestnut eagle between countries. Welch *t*-test was used for testing the influence of the country on the number of environmental workshops in which people participated. A generalized linear models (GLM) framework was used to test our hypothesis considering tolerance as our multinomial response variable (Ripley and Venables, 2021; Zuur et al., 2009). Prior to the GLM analysis, we re-codified two of the predictors as binomial variables: perceived contribution (as *only detriments* = detriments and *not only detriments* = benefits, both, and none) and top-down local management (as *approval* = approval and *disapproval* = disapproval or did not have an opinion of the top-down local management). Our hypotheses were translated into a hypothetical mathematical model (HM), as follows:

Tolerance ∼ perceived contributions + actual detriments + top-down local management + country governance

In order to determine if our HM was the best for explaining the human–top predator conflict, we compared it with simpler alternative models (AM) which included all the combinations of three of the four variables in the HM (e.g. a model including *perceived detriments + actual detriments + top-down local management*; another model including *perceived detriments + top-down local management + country governance*, and so on), two of the four variables, and afterwards only one variable. In addition, to discard interactive relationships among variables, particularly of the *top-down local management* with *perceived detriments* and *actual detriments*, we compared our HM with an alternative model including interactions and independent effects among these (e.g. AMI: *Tolerance ∼ perceived detriments + actual detriments + top-down local management + perceived detriments : top-down local management + actual detriments : top-down local management + country governance*) and simpler models derived from this (Table 2).

Before analysis, multicollinearity was assessed for all models by calculating the variance inflation factors (VIF) using the package *car*. The VIFs obtained for all predictors used were ∼1, well below the common threshold value and thus we are confident of the absence of multicollinearity among variables (see O'Brien, 2007). Through an information-theoretic approach, using Akaike's information criterion (AIC) and Akaike weights (ωi), we determined the parsimony of our HM describing the data respect to the AMs (Richards et al., 2011). Models were ranked according to the Akaike Information Criterion corrected for small sample sizes (AICc). Akaike weights (ωi) estimate the probability of a model to be the best model. The model with lower AICc value and higher Akaike weights was the model that best fitted our data. We considered models in which the difference in AIC relative to the best model is <2 as alternatively well-supported models (Burnham and Anderson, 2004, 2002). Through the packages *nnet* and *lme4* we fitted the multinomial models and compared them to each other, respectively (Bates

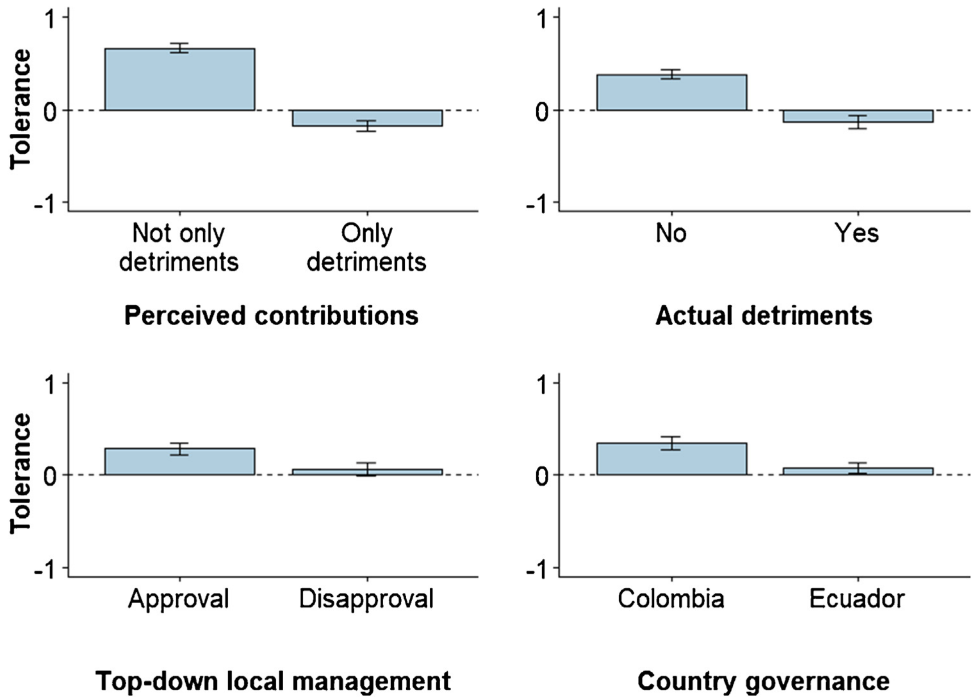

Fig. 2. Mean and standard error of tolerance according to each of the predictor variables included in our hipotheses based on 282 interviews conducted around 27 black-and-chestnut eagle (*Spizaetus isidori*) nests in Colombia and Ecuador.

Table 2
Comparison of our hypothetical model of tolerance (HM) with a set of simpler alternative models (AM) and alternative models considering interactions (AMI). * = consider the interactions and the independent effect of the variables.

Model	Variables include
HM1	**Tolerance ~ Perceived contributions + actual detriments + top-down local management + country governance**
AM1	Tolerance ~ Perceived contributions + actual detriments + top-down local management
AM2	Tolerance ~ Perceived contributions + top-down local management + country governance
AM3	Tolerance ~ Perceived contributions + actual detriments + country governance
AM4	Tolerance ~ Actual detriments + top-down local management + country governance
AM5	Tolerance ~ Perceived contributions + top-down local management
AM6	Tolerance ~ Perceived contributions + actual detriments
AM7	Tolerance ~ Perceived contributions + country governance
AM8	Tolerance ~ Actual detriments + top-down local management
AM9	Tolerance ~ Top-down local management + country governance
AM10	Tolerance ~ Actual detriments + country governance
AM11	Tolerance ~ Perceived contributions
AM12	Tolerance ~ Top-down local management
AM13	Tolerance ~ Actual detriments
AM14	Tolerance ~ Country governance
AMI1	Tolerance ~ Perceived detriments*top-down local management + actual detriments*top-down local management + country governance
AMI2	Tolerance ~ Perceived detriments*top-down local management + actual detriments*top-down local management
AMI3	Tolerance ~ Actual detriments + perceived detriments*top-down local management + country governance
AMI4	Tolerance ~ Perceived detriments + actual detriments*top-down local management + country governance
AMI5	Tolerance ~ Perceived detriments*top-down local management + country governance
AMI6	Tolerance ~ Actual detriments*top-down local management + country governance
AMI7	Tolerance ~ Perceived detriments*top-down local management
AMI8	Tolerance ~ Actual detriments*top-down local management

See Material and methods.

et al., 2015; Ripley and Venables, 2021). In all cases, we used R language in R version 3.6.3 (R Development Core Team, 2014).

Results

Socio-demographic characteristics of sample

Of all interviewed respondents (n = 282), 62% were men and 38% were women. The mean age of interviewees was 48.2 (SD = 16.3) years, and the mean number of years of formal education was 6.6 (SD = 4.3). The percentage of income obtained from farming production was 64.9% (SD = 44.7) and the mean number of domestic fowl owned was 18.1 (SD = 65.4). The mean number of homes around a 2 km radius of a black-and-chestnut eagle nest was 19.9 (SD = 15.5; range: 2–72), with a mean of 2.3 people per home (i.e. ~1088 people; n = 27 nests). The mean number of environmental education workshops in which people had participated was 5.5 (SD = 23.1). We found a marginal country-level difference in the number of environmental workshops in which people had participated ($t = -1.566$, $p = 0.11$), with a higher number of environmental workshops in Colombia (mean = 8.84, SD = 35.40) than in Ecuador (mean = 3.33, SD = 8.72).

Human–top predator conflict model

Near one quarter (23.41%, 66 of 282) of interviewees showed low tolerance towards the eagle, 35.46% were neutral (100 of 282), and 41.13% showed high tolerance (116 of 282). The model that best adjusted to the data to explain tolerance towards the black-and-chestnut eagle was an alternative model including: *perceived detriments*, *actual detriments*, and *top-down local management* as additive terms (Table 3). It showed a negative relationship between people's tolerance towards the black-and-chestnut eagle and perceived detriments, actual detriments, and disapproval of the top-down local management ($R^2 = 0.205$, $\omega_i = 0.775$; Table 4). Our proposed model, which included the country as one of the predictive variables, did not show the best performance with the data. Models including interactions among variables were also unsupported.

Perceived and actual detriments

Percentage of people perceiving *only detriments* (58.15%, 164 of 282) was higher than those who had actual detriments (40.43%, 114 of 282) associated with the species ($\chi^2 = 5.599$, $p = 0.018$). More people perceived *only detriments* from the black-and-chestnut eagle in Ecuador (66%, 114 of 173) than in Colombia (46%, 50 of 109) ($x^2 = 7.340$, $p = 0.007$). Also, in Ecuador more people (46%, 80 of 173) suffered livestock predation by the black-and-chestnut eagle (i.e. actual detriments) than in Colombia (31%, 34 of 109) ($x^2 = 4.161$, $p = 0.041$).

Top-down local management

The approval of the top-down local management was quite divided. Slightly more than half of interviewees (52.1%, 147 of 282) approved of it, 40.4% (114 of 282) disapproved, and 7.5% (21 of 282) did not have an opinion. People's tolerance towards the black-and-chestnut eagle differed between those approving and disapproving of the top-down local management ($x^2 = 7.866$, $p = 0.0196$, $n = 261$). Of the people that approved of the top-down local management, 48% (70 of 147) had high tolerance, 33% (49 of 147) were neutral, and 19% had low tolerance (28 of 147). While of the people disapproving of the top-down local management, 37% (42 of 114) had high tolerance, the same proportion (i.e. 37%, 42 of 114) had low tolerance, and 26% (30 of 114) were neutral. Of the people that did not have an opinion of the top-down local management, 19% (4 of 21) had high tolerance, 38% (8 of 21) were neutral, and 43% (9 of 21) had low tolerance.

Regarding the specific top-down local management of the government environmental authorities, in Colombia, 30.2% of interviewees (19 of 63) disapproved of CORANTIOQUIA's management, 29.3% (12 of 41) disapproved of CAM's management, and all (5 of 5) disapproved of CORTOLIMA's management. In Ecuador, 36.4% of the interviewees (8 of 22) disapproved of MAAE Carchi's management, 52.8% (19 of 36) disapproved of MAAE Imbabura's management, 59.3% (16 of 27) disapproved of MAAE Napo's management, 30.4% (7 of 23) disapproved of MAAE Pichincha's management, and 43.1% (28 of 65) disapproved of MAAE Tungurahua's management.

Prevalence of nest territories with poached eagles

We obtained evidence of black-and-chestnut eagle poaching in 59% of the sampled nests (4 of 6 nests in Colombia and 12 of 21 in Ecuador) and across all the eight geographical jurisdictions of government authorities. The proportion of nests with evidence of poaching (nests with evidence of poaching/sampled nests) by state (i.e. department or province) were: 0.7 (2/3) in Antioquia, 0.5 (1/2) in Huila, 1(1/1) in Tolima, 1(1/1) in Carchi, 0.6 (3/5) in Imbabura, 0.75 (3/4) in Napo, 0.7 (2/3) in Pichincha, and 0.4 (3/8) in Tungurahua. For all but two of these records, the poachers self-reported the poaching incident.

Discussion

People's tolerance towards the black-and-chestnut eagle was lower when they perceived the species as detrimental, received detriments, and when they disapproved of the top-down local management, however, each variable influenced human tolerance independently of each other as reflected by the additive structure of the best supported model. The best model consistently informed the people's tolerance towards the species. More than a half of the people approved of the top-down local management, 7.5% did not have an opinion, and the rest disapproved of it. We recorded eagle poaching in most sampled nests, and across all the eight geographical jurisdictions of government authorities. Both the percentage of people perceiving *only detriments* and *actual detriments* generated by the black-and-chestnut eagle were higher in Ecuador than in Colombia.

Country governance was not retained in the best model (according to the model selection) although people in both countries had slight differences in their mean tolerance (Fig. 2). This lack of clear differences may be explained by the fact that both countries have poor governance with minimal distinctions between them (see Kaufmann and Kraay, 2020). They both also have similar disapproval of the top-down management at the local level, namely the environmental authorities with which farmers have to deal directly. Therefore, disapproval of predominant top-down local management may be influencing people's low tolerance towards eagles and, consequently, affecting in the same way the high human persecution of this top predator in both countries. In fact, at least 30% of the local people in both countries disapproved of the top-down local management across all the governmental environmental authorities in which we conducted interviews. Furthermore, in one region in Ecuador the disapproval rate increased to 59% while in one in Colombia it increased to 100%. Because higher disapproval of top-down local management also means lower tolerance towards eagles and thus persecution, it is not surprising that black-and-chestnut eagles were extensively hunted in all the geographical jurisdictions studied in both countries.

Recent emerging evidence on human–top predator conflicts suggests cautionary insights about generalisations of results and conservation measures (Dickman, 2010; Frank et al., 2019; IUCN, 2020). For instance, a recent study on the socio-economic drivers of human–jaguar conflict across the Neotropics showed that each conflict case is probably unique and thus each requires particular solutions (Zimmermann et al., 2021). However, our study was not aimed at only considering socio-economic predictors (like Zimmermann et al., 2021) but also at evaluating the effect of broader policies shaping human–top predator interactions (i.e. top-down local management and national governance; see Bennett and Satterfield, 2018; Lischka et al., 2018). Therefore, here we provide evidence about how the influence of perceived contributions, actual detriments, and disapproval of top-down local management on human–top predator conflicts can be generalized at least to the studied populations of black-and-chestnut eagle of Colombia and Ecuador. We think, though, that each local socio-ecological context of the human–black-and-chestnut eagle conflicts should be considered, to inform specific technical and cognitive conservation measures (e.g. Zuluaga et al., 2021).

As shown in several studies, in large areas of its northern distribution, the black-and-chestnut eagle suffers widespread persecution requiring urgent conservation and conflict mitigation actions (BirdLife International, 2021; Restrepo-Cardona et al., 2020;

Table 3
Comparison of our hypothetical model (HM) performance with respect to other alternative models (AM) and alternative models considering interactions (AMI). Models are ranked according to the Akaike Information Criterion corrected for small sample sizes (AICc). Besides AICc, ΔAICc, Akaike weights (ωi), and the number of parameters (k) are provided. * = consider the interactions and the independent effect of the variables.

Model	Variables include	k	AIC_c	ΔAIC_c	ω_i
AM1	**Tolerance ~ Perceived contributions + actual detriments + top-down local management**	**8**	**498.93**	**0**	**0.775**
HM1	Tolerance ~ Perceived contributions + actual detriments + top-down local management + country governance	10	502.74	3.82	0.115
AMI3	Tolerance ~ Perceived contributions*top-down local management + actual detriments + country governance	12	505.30	6.38	0.032
AMI2	Tolerance ~ Perceived contributions*top-down local management + actual detriments*top-down local management	12	505.37	6.45	0.031
AM6	Tolerance ~ Perceived contributions + actual detriments	6	506.04	7.12	0.022
AMI4	Tolerance ~ Perceived contributions + actual detriments*top-down local management + country governance	12	506.73	7.80	0.016
AMI1	Tolerance ~ Perceived contributions*top-down local management + actual detriments*top-down local management + country governance	14	509.20	10.27	0.005
AM3	Tolerance ~ Perceived contributions + actual detriments + country governance	8	509.37	10.45	0.004
AM5	Tolerance ~ Perceived contributions + top-down local management	6	516.51	17.58	0
AMI7	Tolerance ~ Perceived contributions*top-down local management	8	519.81	20.89	0
AM2	Tolerance ~ Perceived contributions + top-down local management + country governance	8	519.82	20.89	0
AM11	Tolerance ~ Perceived contributions	4	522.42	23.49	0
AMI5	Tolerance ~ Perceived contributions*top-down local management + country governance	10	523.13	24.20	0
AM7	Tolerance ~ Perceived contributions + country governance	6	524.79	25.86	0
AM8	Tolerance ~ Actual detriments + top-down local management	6	579.30	80.38	0
AM4	Tolerance ~ Actual detriments + top-down local management + country governance	8	580.73	81.81	0
AM10	Tolerance ~ Actual detriments + country governance	6	581.37	82.45	0
AM13	Tolerance ~ Actual detriments	4	581.68	82.75	0
AMI8	Tolerance ~ Actual detriments*top-down local management	8	583.18	84.25	0
AMI6	Tolerance ~ Actual detriments*top-down local management + country governance	10	584.74	85.82	0
AM14	Tolerance ~ Country	4	605.37	106.45	0
AM9	Tolerance ~ Top-down local management + country governance	6	605.65	106.72	0
AM12	Tolerance ~ Top-down local management	4	607.23	108.30	0

Table 4
Multinomial logistic regression of the best-fitted model (AM1: Tolerance ~ Perceived contributions + actual detriments + top-down local management) describing predictors of people's tolerance towards black-and-chestnut eagle (*Spizaetus isidori*) in Colombia and Ecuador.

AM1	β	SE	z value	P value
Increase vs. reduce				
Intercept	3.323	0.583	5.704	0
Perceived contributions: only detriments	−3.813	0.587	−6.500	0
Actual detriments: yes	−1.760	0.402	−4.379	0
Top-down local management: approval	1.282	0.400	3.208	0.001
Increase vs. keep same				
Intercept	0.803	0.273	2.945	0.003
Perceived contributions: only detriments	−1.800	0.311	−5.784	0
Actual detriments: yes	−0.520	0.321	−1.619	0.106
Top-down local management: approval	0.712	0.310	2.300	0.021

See Material and methods.

Zuluaga et al., 2021). People's perceptions about the black-and-chestnut eagle as a potential poultry predator were higher than the actual harm the eagle caused through predation, suggesting that some underlying issues related to a human–top predator conflict are present (i.e. perceived behavioural control, perceived risks, social norms; Dickman, 2010; Lischka et al., 2020; Thondhlana et al., 2020). As frequently suggested in recent times, it is clear that the use of tools from social and human behavioural sciences (e.g. conservation psychology and conservation marketing; Grande et al., 2018; Zuluaga et al., 2020b, 2020a) will be needed to change this disproportionate perception of predatory risk (Bruskotter and Wilson, 2014; Dickman, 2010). In addition, to tackling the conflict by working to analyse and discuss the gap between perceived and actual detriments, specific measures to reduce predation of poultry (actual detriments) will be needed. Among those, some suggested options include measures to increase poultry protection in the vicinity of rural houses such as through the construction of pens, fences or natural refuges that could facilitate the escape or refuge of poultry from flying predators, as well as the promotion of agroecological production (e.g. shade coffee, blackberry, sweet granadilla, fruit trees, alternative crops, etc.) that could diversify resources for farmers as well as to facilitate the escape or refuge of poultry (Restrepo-Cardona et al., 2020, 2019; Zuluaga et al., 2021). However, changing the species' current situation should not only depend on local technical or cognitive interventions to mitigate the human–eagle conflict (see Baynham-Herd et al., 2018) as has been suggested before (Restrepo-Cardona et al., 2020, 2019; Zuluaga et al., 2021). Our results indicate that we also need structural interventions to change the context to make the current governance systems more collaborative and inclusive (Baynham-Herd et al., 2018; Redpath et al., 2017). This structural intervention could be reached by changing conservation policy and practices towards more participative governance (i.e. bottom-up and co-management) where the application of measures from bottom-up and top-down can be better integrated depending on the local socio-ecological context (Redpath et al., 2017; Salvatori et al., 2021, 2020). This strategy has already proven effective in preventing deforestation and overhunting in the Neotropics (Constantino, 2016; Schleicher et al., 2017) and could also be useful in addressing the conservation of top predators in the region.

Under the current context of top-down local governance, the government-based conservation strategies attempting to persuade people to coexist with wildlife including top predators (i.e. environmental laws and workshops) are not sufficiently effective (see Barbar et al., 2016; Giraldo-Amaya et al., 2021; Morcatty et al., 2020; Restrepo-Cardona et al., 2020; Zuluaga et al., 2021). A strategy with bottom-up conservation and co-management would likely achieve better results. For instance, people in both countries had participated in a similar number of environmental workshops, however, our results indicate that participation in workshops does not affect the tolerance towards top predators or at least does not change the context of widespread hunting of top predators. Probably because these workshops are not effective in addressing all the factors that, independently, drive human–top predator conflict. Therefore, by shifting the current context towards a governance system with more community-based conservation strategies (e.g. citizen science, participative conservation, wildlife friendly products, ecotourism), a better balance between the top-down and bottom-up local governance could be achieved, and environmental workshops could emphasize cooperation, negotiation, and dialogue (e.g. through knowledge dialogue, knowledge co-production, participative planning, among others). In this way, we could improve the trust and communication among stakeholders, and thus influence the local governance system to make it more effective in fostering human communities to coexist with top predators (e.g. Killion et al., 2021; Koprowski et al., 2019; Martin, 2020; Young et al., 2021). An important step in this direction is the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (i.e. the Escazú Agreement), however, despite entering into force on 22 April 2021 at least a half of the countries have not ratified it (CEPAL, 2021).

Surveying and modelling illegal human behaviors such as poaching of top predators is a challenging task due to the multiple factors involved (see Milner-Gulland et al., 2020; Nilsson et al., 2020). When dealing with interviews, there is always the risk that some interviewees will not answer truthfully, especially when talking about sensitive issues such as illegal killing of predators. We obtained evidence of black-and-chestnut eagle poaching in 59% of the sampled nests and in all the geographical jurisdictions assessed, both directly from poachers and indirectly (by triangulation among interviewees). However, we believe that this did not undermine our results because before to the interview we informed respondents that we would ensure their anonymity. Therefore, even if our data could underrepresent the true poaching pressure, our results are sufficiently worrysome (see above) to consider taking urgent actions in the study areas. Nevertheless, our data on the prevalence of poaching are limited to small areas around nesting sites on a long temporal scale (i.e. historical and current records of poached eagles), thus, comparisons with data obtained by other methods, on shorter temporal scales and/or on broader geographical scales must be made with caution (e.g. Zuluaga et al., 2021). On the other hand, in order to improve modelling reliability, we compared our mathematical hypothetical model with simpler models and more complex models considering interactions among variables. This allowed us to understand that the predictive variables consistently influence tolerance, and most likely poaching, independently of each other.

Low tolerance towards the black-and-chestnut eagle and high prevalence of human persecution will most likely happen when people perceive the eagle as detrimental, experience detriments caused by the eagle, and disapprove of the top-down local management, although these variables influence tolerance independently of each other. Thus, the widespread human persecution of this top predator in the context of disapproval of top-down local management, independently of the detriments perceived or received by rural settlers, suggests that negative effects of poor governance at the local and national level could also affect other human–top predator conflicts in the region. Most Neotropical countries have similar poor governance with minimal differences among them (see Kaufmann and Kraay, 2020). In general, these countries have conservation strategies based on laws limiting the use of natural resources and protecting wildlife (including top predators), that are imposed by the government from a top-down approach (Dickman, 2010; Redpath et al., 2017) with poor or no contribution from the people actually living in close proximity to wildlife (i.e. with few or no contribution from bottom-up governance; but see Constantino, 2016; Schleicher et al., 2017). However, in most countries the proliferation of illegal firearms, poor presence of the authorities, and corruption precludes the effective application of top-down governance (Santangeli et al., 2019). Therefore, widespread human persecution to other Neotropical top predators such as the jaguar (*Panthera onca*), the cougar (*Puma concolor*), and the harpy eagle (*Harpia harpyja*), and scavengers like the Andean condor (*Vultur gryphus*) is also probably influenced by poor governance on the local, national, and regional scales independently of the perceived contributions of these species to people and the actual detriments received from them (e.g. Engel et al., 2016; Estrada-Pacheco et al., 2020; Giraldo-Amaya et al., 2021; Knox et al., 2019; Morcatty et al., 2020; Plaza and Lambertucci, 2020; Zimmermann et al., 2021; Zuluaga et al., 2021).

Poor governance and widespread hunting of top predators in the Neotropics will be difficult to change if all stakeholders are not willing to actively and collaboratively participate in wildlife conservation and implementation of effective management of conservation conflicts (Carter and Linnell, 2016). Thus, all stakeholders, at the local and national levels, need to work together to achieve long-term conservation goals of top predators in the Neotropics (e.g. Martin, 2020). For instance, environmental management agencies should encourage stakeholders to actively participate in community-based conservation across bottom-up collaborative initiatives (e.g. citizen science, participative conservation, wildlife friendly brands, ecotourism; Amit and Jacobson, 2018; Broekhuis et al., 2020; Huang et al., 2018; Koprowski et al., 2019; Ostermann-Miyashita et al., 2021; Panopio et al., 2021; Zuluaga and Echeverry-galvis, 2016). Additionally, NGOs must become catalysers of stakeholders' active participation and promote changes towards more bottom-up collaborative governance structures to improve top predator conservation (see Redpath et al., 2017). Following this line of thought, the private sector can contribute with the introduction of tourism programs and innovative productive systems (e.g. agroecological farming and wildlife friendly brands; Crespin and Simonetti, 2021; Koprowski et al., 2019) which could diversify income sources, reducing the economic dependence on livestock (Fletcher and Toncheva, 2021). Scientific research institutes should conduct research and collect field data along with local people with the aim of catalysing participatory conservation planning (Panopio et al., 2021). These recommendations could make a significant structural change in the environmental governance systems and at the same time reduce detriments to people and improve people's perception of benefits received from predators, thus, helping to more effectively conserve top predators in the vast wilderness landscapes of the Neotropics.

Conclusion

This study allowed us to understand how perceived contributions, actual detriments, and disapproval of top-down local management negatively affect a rampant human–top predator conflict across two countries in the Neotropics. While social and human behavioural sciences will be needed to implement technical or cognitive interventions to change the disproportionate perception of predatory risk on livestock by top predators, structural changes in the governance systems (i.e. making it more participatory, reliable and transparent) will also be needed for improving the current context for top predator conservation in Neotropical countries. Our study is the first to provide direct evidence of the need for structural changes in the governance systems of the Neotropical Region, particularly at the local and country levels, to effectively save top predators. Given the similar poor governance among countries in the Neotropics, it is also likely that poor governance throughout the region is negatively affecting other human–top predator conflicts independently of perceived or real detriments to humans. Several human–top predator conflicts in the Neotropics are driving some species to the brink of extinction. Therefore, actions to save top predators in the Neotropics will be more effective if governance systems could be improved with a better balance between bottom-up (e.g. citizen science, knowledge dialogue, participative conservation, ecotourism) and the top-down (e.g. institutional presence, laws, control, sanctions) approaches. Otherwise, the direct persecution influenced by the widespread low tolerance of rural settlers towards top predators such as the black-and-chestnut eagle may wipe out top predators from vast extensions.

Conflict of interest

The authors have no financial or non-financial competing interests to declare.

CRediT authorship contribution statement

Santiago Zuluaga: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **F. Hernán Vargas:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition. **Sebastián Kohn:** Conceptualization, Investigation, Writing – review & editing, Project administration, Funding acquisition. **Juan M. Grande:** Conceptualization, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

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