Biological Conservation 251 (2020) 108795

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Landscapes of coexistence: generating predictive risk models to mitigate human-raptor conflicts in forest socio-ecosystems

Rocío Almuna[a,b,c], J. Manuel Cruz[a], F. Hernán Vargas[b], José Tomás Ibarra[a,d,*]

[a] ECOS (Ecosystem-Complexity-Society) Laboratory, Center for Local Development (CEDEL), Center for Intercultural and Indigenous Research (CIIR), Villarrica Campus, Pontificia Universidad Católica de Chile, Bernardo O'Higgins 501, Villarrica 4930000, Chile

[b] The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709, USA

[c] Bristol Veterinary School, University of Bristol, Langford House, Langford, Bristol, BS40 5DU, United Kingdom

[d] Millennium Nucleus Center for the Socioeconomic Impact of Environmental Policies (CESIEP), Center for Applied Ecology and Sustainability (CAPES), Pontificia Universidad Católica de Chile, Av. Libertador Bernardo O'Higgins 340, Santiago 8331150, Chile

ARTICLE INFO

Keywords:
Southern Chile
Diurnal raptors
Predictive modelling
Predation
Conflict management
Temperate forests
Coexistence

ABSTRACT

Human persecution is a worldwide threat to raptors, contributing to the decline of many species. Perceived or real predation of domestic animals is the main driver of persecution and a barrier to the success of conservation initiatives. Predictive risk models are used to identify hazards in order to target effective prevention actions, and they have been successfully applied to conflicts with top predators. The Andean temperate region of Chile is a Global Biodiversity Hotspot where diurnal raptors co-inhabit with humans in rural areas. Here, complaints from farmers on raptor attacks on poultry have steadily increased; however, there is no empirical information about the conflict. This study aims to build a predictive social-ecological risk model to identify husbandry practices and landscape attributes associated with poultry predation by diurnal raptors in Chile. We applied 100 questionnaires to local farmers about their poultry husbandry practices and raptor predation patterns. We used data from questionnaires and landscape attributes to generate risk models of poultry predation. We show that farmers maintaining an enclosure to keep the chickens, a guard dog and a high proportion of forest in their properties can reduce the risk of raptor predation. These findings can be used to prevent raptor attacks on poultry by facilitating the implementation of these management measures in southern Chile. Our results indicate that predictive models can help in identifying effective coexistence measures for human-raptor conflicts benefiting human livelihoods as well as conservation of wild predators.

1. Introduction

Anthropogenic expansion and encroachment in rural areas have increased human-wildlife competition for space and food resources, producing serious threats to wildlife conservation worldwide (Marshall et al., 2007; Treves et al., 2009). A common case of competition is when wildlife with carnivorous feeding habits prey upon domestic animals in rural socio-ecosystems. Diurnal raptors can have a broad trophic niche as they consume a wide variety of prey species (Navarro-López and Fargallo, 2015) by developing dietary and behavioural shifts (Margalida et al., 2014). On occasions, raptors feed on small livestock (e.g. poultry), and thus farmers consider them a factor increasing economic loss. Chickens (*Gallus gallus domesticus*), turkeys (*Meleagris gallopavo*) and domestic ducks (*Anas platyrhynchos domesticus*), for example, are vulnerable to raptor attacks because they are conspicuous, unwary and they frequently stay in groups (Washburn, 2016). Due to these losses, many local communities act against raptor conservation initiatives and use lethal control measures against raptors (Redpath et al., 2004).

Although exploring these human-raptor interactions from an ecological perspective is necessary, it is not sufficient for acquiring a broad understanding of coupled social-ecological systems, especially in rural socio-ecosystems (Marshall et al., 2007; Naughton-Treves and Treves, 2005). Predictive risk models are a multidimensional approach that simultaneously explores both social and ecological aspects of human-wildlife competition (Holmern and Røskaft, 2014; Restrepo-Cardona et al., 2019). To build a predictive risk model, information on kill sites and sites without livestock or poultry loss is needed, along with measurements of spatial, ecological and livestock husbandry practices (Miller, 2015). Predictive risk models, including spatial risk

* Corresponding author at: ECOS (Ecosystem-Complexity-Society) Laboratory, Center for Local Development (CEDEL), Center for Intercultural and Indigenous Research (CIIR), Villarrica Campus, Pontificia Universidad Católica de Chile, Bernardo O'Higgins 501, Villarrica 4930000, Chile.

E-mail address: jtibarra@uc.cl (J.T. Ibarra).

https://doi.org/10.1016/j.biocon.2020.108795
Received 26 March 2020; Received in revised form 6 September 2020; Accepted 17 September 2020

Table 1
Husbandry and landscape covariates used to evaluate their associations with predation by diurnal raptors on poultry in the Andean temperate forests of southern Chile.

Variable	Type of data	Description	Source	Abbreviation
Poultry husbandry practices Animal load	Continuous	Number of chickens in the production system	Questionnaire	a_load
Enclosure	Binary	Use of overhead netting, criss-crossed strings or wires to protect the pen. It can be total or partial.	Questionnaire	exc
Supervision	Binary	Birds managed under controlled and supervised conditions.	Questionnaire	sup
Deterrent	Binary	Use of light reflecting objects (mirrors, CDs, glass bottles) or scaring devices (flags, scarecrows, human presence).	Questionnaire	det
Guard dog	Binary	Presence of dogs that protects the avian stock.	Questionnaire	g_dog
Landscape attributes Forest proportion (r = 50 m/r = 1115 m)	Continuous	Proportion of area covered by dense and semi-dense forest (native, mixed and plantation) and arborescent scrubland (%).	Field observation / INE[a]	for_50 for_1115
Number of houses (r = 1115 m)	Continuous	Number of houses inside the buffer zone	INE	n_hous
Road density (r = 1115 m)	Continuous	Length of road per hectare (m^2/ha)	INE	road_d

[a] Statistic National Institute (Instituto Nacional de Estadística).

assessments, have been successfully used to propose guidelines to prevent carnivore attacks on livestock in high risk areas (Kissling et al., 2009; Treves et al., 2011), via advising policymakers and farmers about management of both their land and domestic animals (Miller, 2015).

Human-predator conflicts occur worldwide and different methodologies have been used to identify the most effective husbandry and landscape management measures. A suite of studies has reported that landscape attributes, such as vegetation cover, topography and proximity variables, as well as animal husbandry practices are the most influential predictors in predation risk models (Margalida et al., 2014; Parrott, 2015). For instance, Kissling et al. (2009) studied the risk predation of puma (*Puma concolor*) upon livestock among different management scenarios in Patagonia and found that livestock rotation may help to reduce the probability of exposure to pumas. Likewise, Holmern and Røskaft (2014) concluded that large poultry flock sizes and increasing distance to protected areas increased the probability of claiming losses to predators, including raptors, in Tanzania.

Domestic dogs (*Canis lupus familiaris*) are mentioned in a number of studies as effective livestock guardians (Gehring et al., 2010; Rodriguez et al., 2019). When dogs are properly trained, they can protect domestic animals against a variety of predators (González et al., 2012). Even though they do not eliminate all predation losses, dogs can significantly reduce them and are economically effective (Andelt and Hopper, 2000). For example, Nyirenda et al. (2017) mention that dogs are used by farmers in Zambia to protect poultry from raptors with positive results. The effectiveness of guard dogs has been reported for terrestrial predator attacks, but it is necessary to assess whether they are effective against raptor predation of domestic animals. Other husbandry managements such as keeping poultry in a protected enclosure with overhead netting (Kenward, 1999), human supervision and use of deterrents (e.g. scary devices, chemical, auditory) can also serve as preventive actions for predatory attacks (Margalida et al., 2014; Parrott, 2015). From a landscape management perspective, increasing forest cover has been associated with an absence of chicken predation because a higher presence of trees around the premises can reduce the visibility of chicken by predatory birds (Restrepo-Cardona et al., 2019; Nyirenda et al., 2017).

Andean temperate forests are part of the South-Central Chile Biodiversity Hotspot based on criteria of high species endemism and degree of threat (Myers et al., 2000). This area is facing high rates of deforestation associated with intensive agriculture, replacement of native stands by exotic-tree plantations, urban development and resource exploitation (Echeverría et al., 2006). These processes have affected wild prey availability for raptors, and predation of poultry by raptors has been associated with low abundance of wild prey and land-use change (Palma et al., 2006). Ten of the twenty species of diurnal raptors present in Chile inhabit this biodiversity hotspot (Trejo et al., 2006). The Chilean Hawk (*Accipiter chilensis*), White-throated Hawk (*Buteo albigula*) and Rufous-tailed Hawk (*Buteo ventralis*) are in the maximum priority conservation category (Pincheira-Ulbrich et al., 2008) because, as forest specialist (i.e. species that depend on forests to breed and feed), they are severely affected by deforestation (Trejo et al., 2006). Conversely, Chimango Caracara (*Milvago chimango*) and Harris's Hawk (*Parabuteo unicinctus*) are suspected to be benefited from humanized landscapes because they are able to adapt to different prey and habitats, remaining stable and numerous (Jaksic et al., 2001), even though the Harris's Hawk is presumably persecuted by farmers due to poultry predation (Pavez, 2004). Other diurnal raptors species present in the area are the Variable Hawk (*Geranoaetus polyosoma*), Southern-crested Caracara (*Caracara plancus*), Peregrine Falcon (*Falco peregrinus*) and American Kestrel (*Falco sparverius*).

In Chile, the number of studies addressing human-wildlife conflicts has increased significantly in the last 20 years (Bonacic et al., 2016; Rodriguez et al., 2019). Most of these studies refer to livestock predation by ground carnivores (e.g. Ohrens et al., 2019; Rodriguez et al., 2019). Human-raptor conflicts, however, have been poorly studied, and there is no information of the extent of these conflicts in rural socio-ecosystems of southern Chile. To fill this knowledge gap, predictive models for predation risk assessment stand as a promising tool for hazard identification and prevention of predatory attacks upon domestic animals.

Here we evaluate poultry systems in rural socio-ecosystems in the Andes of southern Chile and the farmers' perceived factorial conditions for occurrence of predation upon poultry. Specifically, we analysed and built a predictive risk model to examine the association between husbandry practices and landscape attributes with raptor predation upon chickens. We predicted that predation is reduced by two husbandry practices, including the use of a chicken enclosure to exclude raptors from the pen and presence of guard dog(s) and two landscapes attributes, including relatively high proportion of forest and high road density (see variable description in Table 1). Our predicted model is an important contribution to identify the possible effects of different non-lethal prevention actions to reduce human-raptor conflicts and promote management strategies that advocate for the protection of raptor populations in coexistence with human rural livelihoods.

2. Methods

2.1. Study area and sampling design

We conducted the study within the Villarrica watershed (39°S 71°W) located in the Districts of Pucón and Curarrehue in the La Araucanía Region of southern Chile (Fig. 1). This watershed is representative of Andean temperate forest landscapes, which are dominated mainly by deciduous trees of the *Nothofagus* genus at lower altitudes (Ibarra et al., 2014). We surveyed households within an elevation range from 230 to

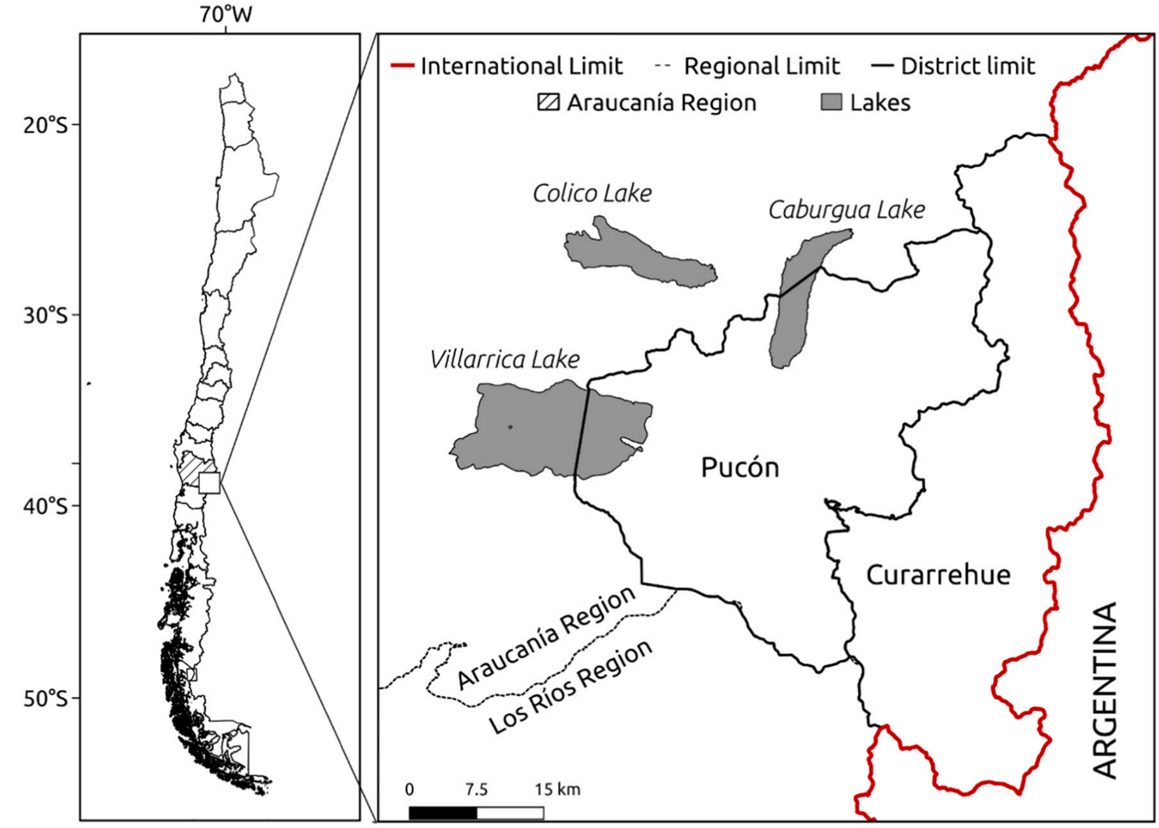

Fig. 1. Study area within the Villarrica watershed (39°S 71°W) in southern Chile to gather data on predictors for diurnal raptor predation on poultry.

950 m.a.s.l. in a mountainous topography. We randomly chose 11 different localities to apply a structured questionnaire to poultry farmers that were selected through a non-probabilistic purposive sampling approach (Robinson, 2013). We selected participants who owned a poultry system, regardless of whether they were affected by raptor attacks. The areas surveyed were characterised by a variety of habitat conditions from rural settlements with fragmented forests to zones surrounded by continuous native forests (Vergara and Ibarra, 2019).

We calculated the sample size needed considering an alpha level $\alpha = 0.1$ and a t-value = 1.65 as desired level of precision. Based on recommendations provided by Bartlett et al. (2001), this calculation estimated a sample size of 83 households. To take a conservative approach, we decided to survey 100 households. From that total, we surveyed a mean of 9.1 farmers per locality (Standard Deviation SD = 1.8). A sampling unit was defined as the area where the farmers kept their chickens (including the chicken enclosure, when present) within a buffer of 0.8 ha (radius = 50 m) to cover the habitats comprising the chickens' immediate surroundings. We collected both husbandry and landscape data at each sampling unit. We included a second buffer of approximately 390 ha (radius = 1115 m) to measure landscape attributes in the habitat circumscribing the first buffer. We chose these two areas because they corresponded to the smallest and largest home range reported for the Harris's Hawk (Gerstell and Bednarz, 1999), which is a widespread raptor species in the area (Trejo et al., 2006) and one of the few with a known home range.

2.2. Data collection

This project was approved by the University of Bristol research ethics committee (Ref 85,383). We conducted the field study during the fall and winter seasons of 2019. We tested the questionnaire before the sampling stage through a pilot study in which we applied the survey to five farmers to identify potential deficiencies in the instrument. Before implementing the survey, we explained the objectives and content of the questionnaire to respondents and we asked for their individual, free, prior and educated consent. For the selection of husbandry practices and landscape variables, hereby covariates, we based our criteria on information available on the ecology of raptors in the study area (Trejo et al., 2006) and on previous published studies on raptor predation risk modelling (Table 1; Restrepo-Cardona et al., 2019; Holmern and Røskaft, 2014).

Extensive or semi-intensive family poultry describe small-scale production systems with no more than 200 birds managed for self-consumption or local sale (FAO, 2001). These systems are common in rural areas of southern Chile, where they are essential in local livelihoods and make significant contributions to animal welfare conditions, food sovereignty and nutritional quality (Sossidou et al., 2011). Through the questionnaire we inquired about husbandry practices (animal load, access to open field, implementation of preventive actions to mitigate predation, among others). Preventive actions mentioned in the questionnaire (Table 1) included use of an enclosure system, supervision, deterrents and guard dogs (dogs that show a protective behaviour towards the chickens). We also asked the farmers to describe the predation patterns within their system (presence/absence of predation upon chickens, number of chickens killed in the last year, temporality of the attacks and whether there was preference of the raptor towards a type of chicken). Farmers who reported no losses by predation within the last year were consider ‘absence’ data. Furthermore, we showed farmers pictures of the raptor species present in the area and asked them to identify, if known, the raptor(s) that preyed upon their chickens. To check the consistency of our findings we used a participant triangulation approach by cross-checking the information given in 40% of the households (n = 40). For this, we applied the questionnaire separately to one or two other family members of the same household who also regularly engaged in poultry management activities (Newing, 2011).

We obtained landscape covariates including road density, number of houses and forest proportion at the 390-ha buffer from open access layers available on the Statistics National Institute (INE) website. Forest proportion at 0.8 ha was assessed in the field by measuring the projected crown cover in the stand as percentage of the total surface (FAO, 2001). We thereafter corroborated this estimation by using Google Earth satellite imagery (CNES/Airbus) from 2019, with a resolution of 1280 × 720 and a pixel size of 0.5 m. Forest proportion refers to the percentage of area covered by dense and semi-dense native forest and arborescent scrubland. We used this method because data from open access layers was not as precise as required to calculate forest proportion in such a small area.

2.3. Modelling predation probability and generating risk maps

We used the lme4 package (Bates et al., 2011) in R studio 1.1.453 for statistical analysis. Presence/absence data from the questionnaires and covariates were analysed through a mixed-effect logistic regression fitted by maximum likelihood to establish the probability of attack following Holmern and Røskaft (2014). We used mixed-effect regression models to take into consideration the potential spatial autocorrelation of the households, which is why we established the location variable as a random effect (Holmern and Røskaft, 2014). Because we had a relatively high number of covariates, we evaluated the associations between covariates to identify strongly correlated variables and avoid including them both into the model (Yu and Liu, 2003). We identified strong relations of binary variables using Phi coefficient building 2 × 2 contingency tables and we assessed collinearity of continuous variables through a Pearson correlation (where strong correlations where given by $r_s > 0,7$; $p < 0,05$) (Schober et al., 2018).

To select the predictors, we screened each covariate in simple regressions to identify significant individual predictors. Subsequently, we combined husbandry and landscape predictors in a way that we considered all covariates tested in the simple models. We tested a total of 18 models, including simple and multiple models. Overall, we included six covariates: four husbandry practices (enclosure, supervision, deterrent, guard dog) and two landscape attributes (forest proportion at 0.8 ha and road density) (Table 2). We used Akaike's Information Criterion (AIC) to select the best fit and quality model. From the set of confidence models, we selected those with ΔAIC < 2 for model averaging to address model uncertainty (Burnham and Anderson, 2002). We used significant covariates ($p < 0.05$) to propose the preventive management measures to reduce the risk of predation because of their association with the absence of predation.

With QGIS® 3.4 software, we projected into maps the predictive probabilities from model-averaged coefficients using the multilevel B-spline interpolation from SAGA (System for Automated Geoscientific Analyses) described by Lee et al. (1997). We created two maps to compare the predictive probabilities with and without the management measures implemented by farmers.

3. Results

3.1. Poultry systems

The mean number of chickens per property was 35.49 (standard deviation, SD = 30.67), ranging from 1 to 250, although bird load did not exceeded 100 in 98% of the cases. Fifty percent of surveyed farmers also kept other types of poultry, including Muscovy duck (*Cairina moschata*) domestic turkey and domestic goose (*Anser anser*), but these were kept in small groups of two to five birds. Almost half of households (46%) also kept livestock, including cows, sheep, pigs and goats.

The farmers' main reason for raising poultry was self-consumption, but 50% would also profit from the sale of eggs and chicken meat. Sixty percent of households kept their birds free-range, 30% kept them in the open fields a few hours a day and 10% kept them always in their enclosures. Veterinary care and sanitary control of birds were rare; only 6% of the households had veterinary visits in the last year, and regular deworming was carried out only by 17% of the farmers.

3.2. Poultry predation risk based on farmer reports

Farmers reported chicken losses to raptors in 52% of the households, and it occurred in all the localities. Reported attacks from diurnal raptors occurred mainly during early hours of the morning because there was less human activity (40%), but also during the day (38%), particularly referring to Chimango Caracara, Harris's Hawk and Southern Caracara because farmers considered these species as 'tamed' birds adapted to human presence. Chickens with lighter colours (white, light brown) were considered easier targets for raptors than darker chickens because they were 'more easily seen'. Young chicks were also considered to be more susceptible to raptor attacks.

Most farmers described that predation events occurred more frequently during the dry season (65%), and they thought it was because the summer overlapped with the raptors reproductive season and the presence of new-born, easy to prey upon, domestic chicks. Farmers identified six species of raptors as the predators attacking their chickens. The most mentioned was the Harris's Hawk ($n = 42$, 32%), followed by Chimango Caracara ($n = 25$, 19%), Southern Caracara ($n = 21$, 16%), Variable Hawk (n = 21, 16%), Chilean Hawk ($n = 18$, 14%) and American Kestrel (n = 4, 3%).

From the multiple regression analysis using husbandry and landscape covariates, three models were the most supported with four to six covariates. Our results from model averaging showed that the enclosure and the guard dog presence were positively associated with the absence of predation. Road density at 390 ha and forest proportion were also positively associated with the absence of predation. On the other hand, the 95% confidence interval for supervision and deterrent's beta coefficient overlapped with zero; therefore, there was not enough evidence to determine the relation between these covariates and the outcome variable (Table 2; Fig. 2). Preventive management measures considered to build the maps were the ones positively associated with absence of predation (enclosure, guard dog and forest proportion). Road density was not considered a management measure even though it was positively associated with absence of predation because it is not possible to be managed by farmers. In Fig. 2, Map (b) shows current predictive probabilities of predation by raptors upon poultry. Lower probability of predation (blue and green) can be observed in households that implement one or more management measures to prevent the attacks; and higher probability of predation (red and orange) is present in households that did not use these measures. Map (c) shows the increase in predation probability among rural housing when management measures are absent in the entire study area (no enclosures, no guard dogs and no forest cover within the sampling unit of 0.8 ha).

4. Discussion

Our study on human-raptors conflicts in a Global Biodiversity Hotspot presents valuable original information for mitigation alternatives aiming to promote coexistence between small-scale poultry systems and raptors. Based on the farmers' experience, we identified non-lethal methods to protect chickens from raptor predation. Farmers using different materials to cover the chicken pens (e.g. criss-crossed strings, wires, or nets), having a dog that displays a protective behaviour towards the chickens (bark at the raptor and chase it, stay nearby the chickens) and maintaining a high proportion of trees with dense to semi-dense cover in their property can reduce the probability of attacks. This suggests that facilitating the implementation of these management measures by farmers could reduce the number of attacks upon chickens and improve human-raptor relationships.

The findings on the different factors influencing predation pressure coincide with the results of other similar studies. The increase in the

Table 2
Mixed linear model selection based on Akaike's Information Criterion (AIC) for estimating the predation risk of chickens by diurnal raptors in the Andean temperate forests of southern Chile.

Model structure	K[a]	AICc[b]	ΔAICc[c]	Wt[d]	Estimates (SE)[e]	95% CI
exc + g_dog + sup + for50 + road_d	7	106.55	0.00	0.48	−3.02 (1.23) −1.83 (0.58) −1.29[f] (0.69) −4.15 (1.31) −0.05 (0.02)	−5.44, −0.60 −2.97, −0.69 −2.64, 0.05 −6.72, −1.59 −0.08, −0.01
exc + g_dog + for50 + road_d	6	107.86	1.31	0.25	−2.80 (1.21) −2.23 (0.55) −3.85 (1.25) −0.04 (0.02)	−5.18, −0.42 −3.31, −1.15 −6.31, −1.39 −0.08, −0.01
exc + g_dog + sup + det + for50 + road_d	8	107.91	1.35	0.24	−2.88 (1.25) −1.92 (0.59) −1.27[f] (0.69) 0.56[f] (0.56) −4.29 (1.33) −0.04 (0.02)	−5.33, −0.44 −3.08, −0.75 −2.62, 0.09 −0.53, 1.65 −6.89, −1.69 −0.08, −0.01
g_dog + for50 + road_d	5	112.40	15.74	0.03	−1.96 (0.52) −3.67 (1.18) −0.03 (0.02)	−2.97, −9.40 −5.99, −1.35 −0.07, 1.05
exc + det + g_dog	4	122.30	17.29	0.00	−2.32 (1.15) 0.62 (0.48) −2.13 (0.49)	−4.57, −0.06 −0.32, 1.56 −3.09, −1.16
exc + supl + g_dog	6	125.53	18.97	0.00	−2.44 (1.17) −0.71 (0.62) −1.84 (0.57)	−4.72, −0.15 −1.93, 0.49 −2.96, −0.73

[a] Number of estimated parameters.
[b] AIC adjusted for small sample sizes.
[c] Difference in AICc between each model and the best model. This table only considers the confidence set with ΔAIC < 2.
[d] Akaike weights indicates the level of support of a model among the candidate model set.
[e] Coefficients' estimates are listed in the same order of covariates as presented in the 'Model structure' column.
[f] Beta estimates with 95% confidence intervals that overlap zero and were therefore considered non-informative.

frequency of predation during the raptor breeding season and higher susceptibility of small chickens was also reported by Nyirenda et al. (2017). They studied farmer-raptor conflicts in Zambia and explored the anthropogenic threats to raptors by understanding the farmers' perceptions, attitudes and practices. They suggested that farmers perceived higher predation on small chickens and during the raptor reproductive season due to the higher energetic demands and that young chicks are weaker and highly nutritious. These assumptions are based on the traditional ecological knowledge of local farmers (Nyirenda et al., 2017; Usher, 2000) and quantitative data could provide evidence to assess whether this conception is true. Nonetheless, other confounding factors that influence predation risk should also need to be considered, such as poultry density and husbandry, predator and alternative prey density and implementation of other predator control programs.

We used a mixed-effect logistic regression that served to assess the effectiveness of countermeasures implemented by locals based on their experience. The results of our model do not contradict what is stated in the scientific literature. The use of enclosure is also reported by Harradine et al. (1997) who suggested that the use of overhead netting materials was considered at least partly useful to protect pheasants by 83% of gamekeepers in Scotland. The counterargument for this measure is that some gamekeepers can find it costly, unpractical and would not implement it because it prevents pheasants to leave the pen as they mature. Similarly, in our study some farmers were not willing to keep their birds inside an enclosure all the time because they value meat flavour and wellbeing of the birds under a free-ranging scheme. This could bring difficulties in the implementation of this management measure. Considering that maintaining an enclosure is a good measure to avoid predation when the structure is well maintained (Parrott, 2015), an alternative could be to release the birds at a time of day where there is more human activity in the yard and, therefore, more supervision. This, along with accustoming chickens to stay close by regularly feeding them around people and near the house, would allow the protection of poultry during the time when predation pressure is higher.

Further research is needed to evaluate the efficiency of this scheme and its acceptability by farmers. The acceptability of different management measures is highly correlated with human perceptions on its effectivity and practicality (Nyirenda et al., 2017), which is why some authors have stressed the importance of using participatory decision making when managing these conflicts (Redpath et al., 2004; Restrepo-Cardona et al., 2020). In addition, more empirical data on adequate confinement systems would help to keep poultry protected while safeguarding their welfare, not only by reducing predation but also by providing space for sheltering, exploring and grazing.

Guard dogs have successfully reduced predation, mainly from mammalian carnivores such as coyotes (*Canis latrans*), foxes, cougars (*Puma concolor*), among others (Andelt and Hopper, 2000; Gehring et al., 2010). However, only few articles mention guard dogs as deterrents of raptors and these are mainly based on testimonial evidence and questionnaire surveys to farmers (Nyirenda et al., 2017; Margalida et al., 2014). In our study, most people who had dogs that barked at raptors and ground carnivores were not affected by predation. Dogs need to show appropriate protective behaviour and this can be enhanced with conditioning techniques (Gehring et al., 2010) and it is advised that they establish a bond with the flock by being raised with it from a young age (Rigg et al., 2011). Further empirical research is needed to determine the effectiveness of the use of guard dogs in protecting poultry from raptors and the appropriate techniques to train and raise of them.

Our results show that a high forest proportion was associated with absence of predation. Landscape features have been previously included as factors potentially affecting the levels of livestock and poultry predation (Restrepo-Cardona et al., 2019; Nyirenda et al., 2017; Holmern and Røskaft, 2014; Palma et al., 2006). In Portugal, a study analysed the diets of 22 breeding pairs of Bonelli's Eagles (*Hieraaeutus fasciatus*) and contrasted these data with landscape composition and prey

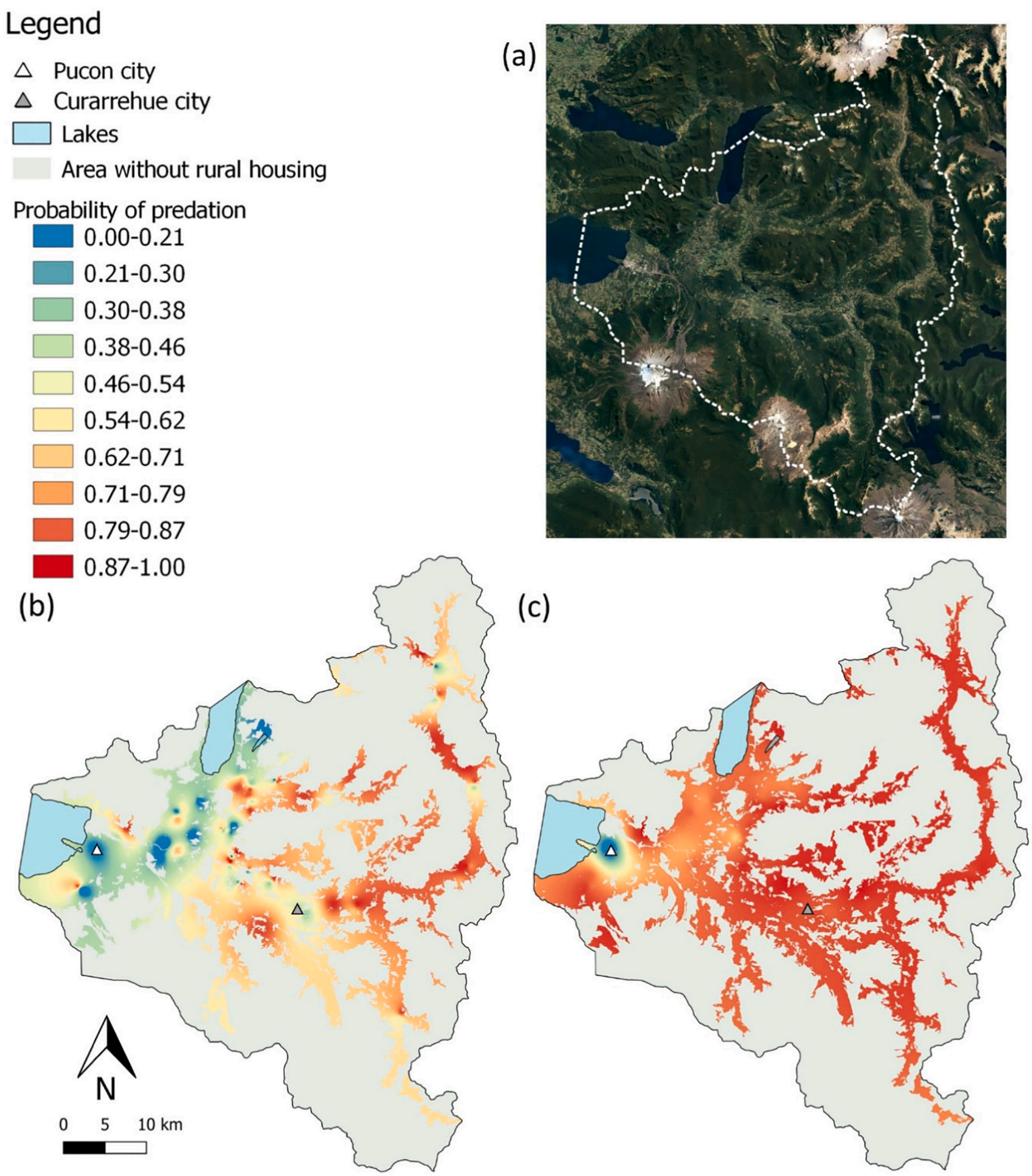

Fig. 2. (a) Google satellite image of the study area. (b) Risk map showing predicted probabilities of predation including data on farmers that use husbandry measures (enclosure, guard dog) and current data on forest proportion at 0.8 ha. (c) Risk map simulates a reality where farmers do not implement husbandry measures and that maintain farms with zero forest cover. (b) and (c) are projected based on the model-averaged predicted probabilities and exclude areas without rural housing as these are not considered areas at risk.

availability. They concluded that areas with relatively high forest proportions reduced the domestic prey content in the eagles' diet because there was high availability of wild prey species (Palma et al., 2006). Restrepo-Cardona et al. (2019) also conducted a dietary analysis with Black-and-chestnut Eagle (*Spizaetus isidori*) in Colombia and found that domestic fowl was the most important prey in the most deforested sites. Despite the cited studies have measured predation impact from a different perspective, as they are using raptors' dietary data rather than farmers' perception data, it is interesting to note that we have reached similar conclusions.

Similarly to our study, Holmern and Røskaft (2014) worked with farmers in the Serengeti National Park, Tanzania, with whom they found that perceived predation increased with distance to the closest natural protected area. We agree with their conclusions that this might be due to lower densities of natural prey in less dense forests near villages and agricultural lands. Another positive outcome of a relatively high forest proportion is that it provides shelter from wind and rain, shade and areas of contrasting light that improve the chickens' welfare (Jones et al., 2007) Alternatively, supplementary cover, such as brash structures or refuges of any type, has been proposed as an alternative to trees because it can fulfil a similar role (Parrott, 2015).

Considering that higher forest proportions provide higher availability of wild prey and natural protection for the chickens, the alarming deforestation levels in southern temperate forests could have a serious impact not only upon chicken predation, but also raptor conservation. Therefore, forest conservation and restoration initiatives should be matters of common interest for both farmers and conservationists alike. Efforts should not only be focused on farming practices for protecting poultry, but also on public policies focused on decreasing deforestation rates. Here relies the relevance of current forest restoration projects being implemented in southern Chile, where community-based initiatives supported by the National Forest Corporation (CONAF), are promoting reforestation using native species from the area (CONAF, 2017).

An ecosystem is composed of multispecies assemblages with complex social-ecological interactions. Other native and invasive predators were also mentioned as conflictive in our surveys, such as Kodkod Cat (*Leopardus guigna*), foxes (*Lycalopex spp*), American Mink (*Neovison vison*) and domestic dogs, but most of the predation events were attributed to avian predators. This might be an overestimation because diurnal raptors can be seen attacking the flock during the day and are regularly sighted flying over the fields, whereas ground predators tend to be less conspicuous (Holmern and Røskaft, 2014). Also, diurnal raptors tend to leave the carcass where they killed it, unlike several ground carnivores that tend to carry it away to hide it, feed their offspring or eat in a quiet place (Stahl et al., 2002).

Research concerning raptor predation on poultry is limited, especially in developing countries where financial and technical limitations move resources towards other priorities (Nyirenda et al., 2017). When information about the matter is scarce, it has been proposed that the use of local ecological knowledge (or situated knowledge) can help develop management plans by understanding how people's experience influence their practices (Becker and Ghimire, 2003; Usher, 2000). Questionnaires are regularly used to gather information on human-wildlife interactions because it is an effective and inexpensive method that provides broad evidence (Naughton-Treves and Treves, 2005). However, data must be carefully interpreted to take cautious conclusions because respondents may be biased towards personal economic or political interests (Dickman, 2010). In relation to this, Holmern and Røskaft (2014) emphasize that in perception studies, the farmers' view may be influenced by a lack of interactions with wildlife which may exacerbate their notion of the conflict. The latter highlights the importance of coupled studies that combine social and ecological empirical data to design management options for predation conflicts adapted to local contexts (Lischka et al., 2018).

Even though supervision did not show any association with predation events, research elsewhere indicates that most of the attacks on domestic animals occur when they are kept unattended and unsupervised (Rodriguez et al., 2019). Moreover, the use of deterrent has also been reported as having a varying (and generally low) level of success because raptors can habituate to them (Parrott, 2015). On the other hand, there are a number of other preventive measures that were not mentioned by any of the farmers but that have been reported by other authors. Management measures such as providing diversionary feeding to raptors, giving financial incentives to farmers and educational programmes are initiatives that have had relative success in other contexts and that have been often accepted by stakeholders (Parrott, 2015; Redpath and Thirgood, 2009).

To our knowledge, diversionary feeding has never been used in Chile as a management measure for any species. On the other hand, the Agricultural Insurance Committee (Agroseguros) of the Ministry of Agriculture in Chile, offers a Livestock Insurance as a means to reduce conflict with terrestrial carnivores (Instituto de Desarrollo Agropecuario (INDAP), 2020), but not with raptors. This program involves filed investigations to identify whether predatory attacks were in fact done by wild terrestrial predators instead of dogs. This has helped developing a data base of livestock predation by carnivores across Chile that unfortunately does not exist for raptor attacks on poultry. We consider it is necessary to apply verification protocols for poultry damage claims in Chile for both promoting legitimate compensation programs and for building a reliable source of information on human-predator conflicts.

Addressing predation upon domestic animals requires long-term efforts to understand the foundations of the problem and empirically test possible solutions. In the United Kingdom, it took nearly ten years for a group of scientists to reach agreements with other interested parties and start testing different techniques to reduce raptors' predation impact on game species (Redpath and Thirgood, 2009; Watson and Thirgood, 2001). These authors highlight that dialogue, commitment and participation are vital aspects to find solutions to a problem that at first seems impossible to resolve. To this date, there are no cases of long-term work for managing human-predator conflicts in Chile because financial funds are scarce and the few resources that are destined for human-predator conflicts go to farmers in conflict with terrestrial carnivores.

We consider that our study has potential limitations that should be noted. We focused our research in the perceived predation impact and it would have been interesting and informative to compare these results with information on chicken losses through raptor dietary studies (Palma et al., 2006) or field observations (Ballejo et al., 2020). Moreover, we could have included different carnivore species to measure predation impact among different animal groups. This was conducted by Stahl et al. (2002) in a study where they trained farmers on how to recognize the signs that different types of predators leave on a fresh carcass. Applying this approach could help to provide clearer knowledge on poultry losses and specific management measures for the predators involved, although some techniques are likely to protect chickens from a variety of predators (i.e., guard dogs, enclosure).

On the other hand, it would have been interesting to collect data during the breeding season to evaluate whether there was a difference in the perception of predation between seasons. We consider another limitation the fact that there is a gap in the knowledge of human-raptor conflicts in Chile, which prevented us from providing a strong theoretical background of the impact of chicken predation by raptors in Chilean family poultry systems.

Predator management is a challenge that necessarily involves dealing with the systems' ecological and socio-political foundations. Farmers' detrimental actions towards raptors can hinder conservation initiatives and the natural recovery of these key top-down ecosystem modulators. The success of raptor conservation widely depends on effectively increasing tolerance from local communities within social-ecological rural landscapes. This study is the first step towards effectively addressing the human context of this conflict in Chile. Our results are an important contribution to promote public engagement and the socio-political change required to move forward into a future of coexistence between humans and predators.

CRediT authorship contribution statement

Rocío Almuna: Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, Visualization, Writing – Original Draft, Writing – Review & Editing.

J. Manuel Cruz: Methodology, Investigation, Formal Analysis, Visualization.

F. Hernán Vargas: Validation, Resources, Funding acquisition, Writing – Original Draft.

J. Tomás Ibarra: Supervision, Conceptualization, Validation, Resources, Writing – Original Draft, Writing – Review & Editing.

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.

Acknowledgements

This research was conducted as thesis project of R.A.M. during the graduate program Master in Global Wildlife Health and Conservation at the University of Bristol. We would like to thank Dr Andrew Kennedy for his support and guidance during the development of this project. R.A.M. was funded by BECAS CHILE Study Abroad Graduate Scholarship 2018-2019. This project was funded by the The Peregrine Fund, FONDECYT Regular/ANID (1200291), the Center for Intercultural and Indigenous Research–CIIR (ANID/FONDAP/15110006), the Center of Applied Ecology and Sustainability–CAPES (ANID PIA/BASAL FB0002), ANID/REDES (190033), the Vicerrectoría de Investigación (VRI) from Pontificia Universidad Católica de Chile (GRANT: 7512-023-81), and the ANID – Millennium Science Initiative – Center for the Socioeconomic Impact of Environmental Policies, CESIEP Code NCS13_004. We acknowledge the staff at the 'Kod Kod: Lugar de Encuentros' for all the support during fieldwork.

Appendix A. Supplementary data

The questionnaire (Appendix S1) is available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author. Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2020.108795.

References

Andelt, W., Hopper, S.N., 2000. Livestock guard dogs reduce predation on domestic sheep in Colorado. J. Range Manag. 53, 259–267.
Ballejo, F., Plaza, P.I., Lambertucci, S.A., 2020. The conflict between scavenging birds and farmers: field observations do not support people's perceptions. Biol. Conserv. 248, 108627.
Bartlett, J.E., Kotrlik, K.W., Higgins, C.C., 2001. Organizational research: determining appropriate sample size in survey search. Inf. Technol. Learn. Perform. J. 19 (1), 43–50.
Bates, D., Maechler, M., & Bolker, B. (2011). Lme4: linear mixed-effects models using S4 classes version 0.999375-42.
Becker, C.D., Ghimire, K., 2003. Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador. Conserv. Ecol. 8 (1).
Bonacic, C., Amaya-Espinel, J.D., Ibarra, J.T., 2016. Human-wildlife conflicts: an overview of cases and lessons from the Andean region. Ch. 8. In: Aguirre, A.A., Sukumar, R. (Eds.), Tropical Conservation: Perspectives on Local and Global Priorities. Oxford University Press, Oxford, U.K. pp, pp. 109–125.
Burnham, K.P., Anderson, D.R., 2002. Model Selection and Inference: A Practical Information-theoretic Approach, second ed. Springer-Verlag, New York, USA.
CONAF. (2017). Estrategia Nacional de Cambio Climático y Recursos Vegetacionales 2017–2025, Chile. Retrieved from https://redd.unfccc.int/files/chile_national_redd_strategy.pdf.
Dickman, A.J., 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. Anim. Conserv. 13 (5), 458–466.
Echeverría, C., Coomes, D., Salas, J., Rey-Benayas, J.M., Lara, A., Newton, A., 2006. Rapid deforestation and fragmentation of Chilean temperate forests. Biol. Conserv. 130 (4), 481–494.
FAO, 2001. Global Forest Survey – Field Site Specification and Guidelines. Forest Resources Assessment programme of FAO. FRA working paper. Draft. Rome.
Gehring, T.M., Cauteren, K.C.V., Landry, J., 2010. Livestock protection dogs in the 21st century: is an ancient tool relevant to modern conservation challenges? BioScience 60 (4), 299–308.
Gerstell, A.T., Bednarz, J., 1999. Competition and patterns of resource use by two sympatric raptors. Condor 101, 557–565.
González, A., Novaro, A., Funes, M., Pailacura, O., Bolgeri, M.J., Walker, S., 2012. Mixed-breed guarding dogs reduce conflict between goat herders and native carnivores in Patagonia. Human-Wildlife Interactions 6 (2), 327–334.
Harradine, J., Reynolds, N., Laws, T., 1997. Raptors and Gamebirds—A Survey of Game Managers Affected by Raptors. BASC, Wrexham.
Holmern, T., Røskaft, E., 2014. The poultry thief: subsistence farmers' perceptions of depredation outside the Serengeti National Park, Tanzania. Afr. J. Ecol. 52 (3), 334–342.
Ibarra, J.T., Martin, K., Drever, M.C., Vergara, G., 2014. Occurrence patterns and niche relationships of sympatric owls in south American temperate forests: a multi-scale approach. For. Ecol. Manag. 331, 281–291.
Instituto de Desarrollo Agropecuario (INDAP), 2020. INDAP Agricultural Insurance. Ministerio de Agricultura Retrieved from. https://www.indap.gob.cl/seguros.
Jaksic, F.M., Pavez, E., Jiménez, J.E., Torres-Mura, J.C., 2001. The conservation status of raptors in the metropolitan region, Chile. Journal of Raptor Research 35 (2), 151–158.
Jones, T., Feber, R., Hemery, G., Cook, P., James, K., Lamberth, C., Dawkins, M., 2007. Welfare and environmental benefits of integrating commercially viable free-range broiler chickens into newly planted woodland: a UK case study. Agric. Syst. 94 (2), 177–188.
Kenward, R.E., 1999. Solving raptor-human conflicts. Journal of Raptor Research. 33 (1), 38.
Kissling, D.W., Fernández, N., Paruelo, J.M., 2009. Spatial risk assessment of livestock exposure to pumas in Patagonia, Argentina. Ecography 32 (5), 807–817.
Lee, S., Wolberg, G., Shin, S.Y., 1997. Scattered data interpolation with multilevel B-splines. IEEE Transactions On Visualisation and Computer Graphics 3 (3).
Lischka, S.A., Teel, T.L., Johnson, H.E., Reed, S.E., Breck, S., Don Carlos, A., Crooks, K.R., 2018. A conceptual model for the integration of social and ecological information to understand human/wildlife interactions. Biol. Conserv. 225, 80–87.
Margalida, A., Campión, D., Donázar, J.A., 2014. Vultures vs livestock: conservation relationships in an emerging conflict between humans and wildlife. Oryx 48 (2), 172–176.
Marshall, K., White, R., Fischer, A., 2007. Conflicts between humans over wildlife management: on the diversity of stakeholder attitudes and implications for conflict management. Biodivers. Conserv. 16 (11), 3129–3146.
Miller, J.R.B., 2015. Mapping attack hotspots to mitigate human–carnivore conflict: approaches and applications of spatial predation risk modeling. Biodivers. Conserv. 24 (12), 2887–2911.
Myers, N., Mittermeler, R.A., Mittermeler, C.G., Da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858.
Naughton-Treves, L., Treves, A., 2005. Socio-ecological factors shaping local support for wildlife: crop-raiding by elephants and other wildlife in Africa, In Woodroofe, R., Thirgood, S.J., Rabinowitz, A. (Eds.), People & Wildlife: Conflict or Coexistence? Cambridge University Press, pp. 252-277.
Navarro-López, J., Fargallo, J.A., 2015. Trophic niche in a raptor species: the relationship between diet diversity, habitat diversity and territory quality. PLoS One 10 (6), e0128855.
Newing H. 2011. Conducting research in conservation: a social science perspective. Page Igarss 2014. Routledge, New York, U.S.A.
Nyirenda, V.R., Musonda, F., Kambole, S., Tembo, S., 2017. Peasant farmer-raptor conflicts around Chembe bird sanctuary, Zambia, Central Africa: poultry predation, ethno-biology, land use practices and conservation. Anim. Biodivers. Conserv. 40 (1), 121–132.
Ohrens, O., Bonacic, C., Treves, A., 2019. Non-lethal defense of livestock against predators: flashing lights deter puma attacks in Chile. Front. Ecol. Environ. 17 (1), 32–38.
Palma, L., Beja, P., Pais, M., Da, L.C., 2006. Why do raptors take domestic prey? The case of Bonelli's eagles and pigeons. 1075–1086.
Parrott, D., 2015. Impacts and management of common buzzards Buteo buteo at pheasant Phasianus colchicus release pens in the UK: a review. Eur. J. Wildl. Res. 61 (2), 181–197.
Pavez, E., 2004. Descripción de las aves rapaces chilenas. In: Muñoz-Pedreros, A., Rau, J., Yáñez, J. (Eds.), Aves rapaces de Chile. CEA Ediciones, Valdivia, Chile, pp. 29–104.
Pincheira-Ulbrich, J., Rodas-Trejo, J., Almanza, V.P., Rau, J.R., 2008. Estado de conservación de las aves rapaces de Chile. Hornero 23 (1), 5–13.
Redpath, S., Thirgood, S., 2009. Hen harriers and red grouse: moving towards consensus? J. Appl. Ecol. 46 (5), 961–963.
Redpath, S.M., Arroyo, B.E., Leckie, F.M., Bacon, P., Bayfield, N., Gutiérrez, R.J., Thirgood, S.J., 2004. Using decision modeling with stakeholders to reduce human-wildlife conflict: a raptor-grouse case study. Conservation in Practice 18 (2), 350–359.
Restrepo-Cardona, J. S., Márquez, C., Echeverry-Galvis, M. Á., Vargas, F. H., Sánchez-Bellaizá, D. M., & Renjifo, L. M. (2019). Deforestation may trigger black-and-chestnut eagle (*Spizaetus isidori*) predation on domestic fowl. Tropical Conservation Science, 12, 194008291983183.
Restrepo-Cardona, J.S., Echeverry-Galvis, M.Á., Maya, D.L., Vargas, F.H., Tapasco, O., Renjifo, L.M., 2020. Human-raptor conflict in rural settlements of Colombia. PLoS One 15 (1), e0227704.
Rigg, R., Findo, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C., MacDonald, D.W., 2011. Mitigating carnivore-livestock conflict in Europe: lessons from Slovakia. Oryx 45 (2), 272–280.
Robinson, O.C., 2013. Sampling in interview-based qualitative research: a theoretical and practical guide. Qual. Res. Psychol. 11 (1), 25–41.
Rodriguez, V., Poo-Muñoz, D., Escobar, L.E., Astorga, F., Medina-Vogel, G., 2019. Carnivore – livestock conflicts in Chile: evidence and methods for mitigation. Human-Wildlife Interactions 13 (1), 50–62.
Schober, P., Boer, C., Schwarte, L.A., 2018. Correlation coefficients: appropriate use and interpretation. Anesth. Analg. 126 (5), 1763–1768.
Sossidou, E.N., Dal Bosco, A., Elson, H.A., Fontes, C.M.G.A., 2011. Pasture-based systems for poultry production: implications and perspectives. World's Poultry Science Journal 67 (1), 47–58.
Stahl, P., Ruette, S., Gros, L., 2002. Predation on free-ranging poultry by mammalian and avian predators: field loss estimates in a French rural area. Mammal Rev. 32 (3), 227–234.
Trejo, A., Figueroa, R., Alvarado, S., 2006. Forest-specialist raptors of the temperate forests of southern South America: a review. Revista Brasileira de Ornitología 14 (4), 317–330.
Treves, A., Wallace, R.B., White, S., 2009. Participatory planning of interventions to mitigate human-wildlife conflicts. Conserv. Biol. 23 (6), 1577–1587.
Treves, A., Martin, K.A., Wydeven, A.P., Wiedenhoeft, J.E., 2011. Forecasting environmental hazards and the application of risk maps to predator attacks on livestock. BioScience 61 (6), 451–458.

Usher, P.J., 2000. Traditional Ecological Knowledge in Environmental Assessment and Management.
Vergara, G., Ibarra, J.T., 2019. Paisajes en transición: gradientes urbano-rurales y antropización del bosque templado andino del sur de Chile. Revista de Geografía Norte Grande 73, 93–111.
Washburn, B.E., 2016. Hawks and owls. Wildlife Damage Management Technical Series 6, 17. Retrieved from. http://www.biodiversitylibrary.org/bibliography/15130.
Watson, M., Thirgood, S., 2001. Could translocation aid hen harrier conservation in the UK? Anim. Conserv. 4 (1), 37–43.
Yu, L., Liu, H., 2003. Feature selection for high-dimensional data: a fast correlation-based filter solution. In: Proceedings of the 20th International Conference on Machine Learning (ICML-2003). DC, Washington.