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Drivers of Predator Killing by Rural Residents and Recommendations for Fostering Coexistence in Agricultural Landscapes

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Predators inhabiting human-dominated landscapes are vulnerable to various anthropogenic actions, including people killing them. We assess potential drivers of predator killing in an agricultural landscape in southern Chile, and discuss the implications for policies and interventions to promote coexistence. We evaluate five different types of motivation: (i) sociodemographics and household economy; (ii) livestock loss; (iii) predator encounter rates; (iv) knowledge of legal protection (all native predators are currently protected); and, (v) tolerance to livestock predation. As the killing of native predators is illegal, the prevalence of this behavior by rural residents was estimated using a symmetrical forced-response randomized response technique (RRT), a method designed to ask sensitive questions. A total of 233 rural residents from randomly assigned sample units (4 km^2) across the study region completed our questionnaire. More conspicuous species, such as hawks (*Falconiformes sp*), foxes (*Lycalopex sp*) and free-roaming domestic dogs (*Canis lupus familiaris*), were killed by a higher proportion of farmers than more cryptic species, like the felid güiña (*Leopardus guigna*), skunk (*Conepatus chinga*) and pumas (*Puma concolor*). The proportion of respondents admitting to killing predators was highest for hawks (mean = 0.46, SE = 0.08), foxes (mean = 0.29, SE = 0.08) and dogs (mean = 0.30, SE = 0.08) and lowest for güiña (mean = 0.10, SE = 0.09), which is the only species of conservation concern we examine (considered Vulnerable on the IUCN Red List). From our five motivation categories, past killing of predators was associated with higher reported predator encounter rates (guina, hawks), lower tolerance to livestock predation (hawks, dogs), higher reported livestock loss (dogs) and sociodemographics and household economy (foxes). Our results demonstrate that a one-size-fits-all approach to predator persecution is unlikely to reduce or eliminate illegal killings for the suite of species we examined. We identify and describe two main types of intervention that could foster coexistence, improvement of livestock management and domestic dog management in rural areas, as well as discussing the potential for social marketing.

Keywords: carnivores, free-roaming dogs, illegal behavior, *Leopardus guigna*, livestock predation, random response technique, tolerance to predation

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INTRODUCTION

Predators inhabiting human-dominated landscapes are vulnerable to a diverse range of anthropogenic activities, such as land-use change, habitat degradation, hunting for meat/trade and direct persecution in retaliation for livestock predation or due to cultural norms (Ceballos and Ehrlich, 2002; Treves and Karanth, 2003; Cardillo et al., 2004; Woodroffe et al., 2005; Inskip and Zimmermann, 2009). Carnivorous mammals and birds of prey are particularly susceptible to such impacts because of their slow life histories (Purvis et al., 2000). Historically, human persecution of predators has been responsible for species population declines and contributed to extinction events (Woodroffe, 2001). To enhance predator conservation, the motivations underpinning human induced mortality need to be identified and reduced so populations may persist and recover in the long-term (Treves and Karanth, 2003).

Human-predator coexistence can be achieved when the "interests of humans and wildlife are both satisfied" (Frank, 2016; Marchini et al., 2019). The outcomes of human-predator interactions are primarily determined by two main components: (i) how humans and predators interact; and, (ii) how humans react to those interactions (Marchini et al., 2019). At their worst, these interactions result in the killing of predators. Planning for coexistence therefore entails navigating away from such a response and toward more positive outcomes for predators and people (Frank, 2016). A first step in this process is understanding what drives a person to behave in a particular way, including why they kill predators (St John et al., 2013; Marchini et al., 2019).

How humans choose to act toward predators is influenced by factors operating at intertwined social (e.g., institutions, norms) and individual levels (e.g., sociodemographic and socioeconomic characteristics, attitudes, beliefs), (Lischka et al., 2018). It is thus important to understand individual-level factors that motivate the killing of predators (St John et al., 2015). In this study, we explore how five different types of motivation relate to predator-killing behavior by rural inhabitants in southern Chile. Our five categories, and the rationale for their inclusion, are as follows:

(i) *Sociodemographics and household economy:* There is evidence that behavior toward predators can be influenced by factors including education level, age and gender (Dickman et al., 2013). For example, poor rural inhabitants with few livelihood alternatives reported hostility toward predators (Naughton-Treves and Treves, 2005), and wealth was associated with higher tolerance for predators amongst commercial ranchers in Kenya (Romanach et al., 2007). Understanding how sociodemographics and household economy relate to predator-killing behavior can facilitate the targeted delivery of mitigation strategies through, for example, audience segmentation (Jones et al., 2019).

(ii) *Reported livestock loss:* The economic impact of livestock predation may cause the persecution of carnivores (Inskip and Zimmermann, 2009; Dickman, 2010; Marchini and Macdonald, 2012; Dickman et al., 2013). Where livestock losses are positively associated with predator persecution, interventions such as predator safe enclosures can be implemented to reduce predator impacts.

(iii) *Predator encounter rates:* The opportunity to kill a predator arises when the predator and human co-occur (Marchini and Macdonald, 2012; Carter et al., 2017). If reported predator encounter rates are positively related to predator killing behavior, and if these encounters occur near livestock enclosures, the provision of technical interventions (e.g., sound or lights to scare wildlife) could be a viable solution to reduce encounters. Also, as the outcome of this encounter depends also on how humans react, behavioral change strategies can be considered.

(iv) *Knowledge of legal protection:* Rules governing the acceptable use of, and interactions with, wildlife are central to natural resource management. Although the existence of rules alone does not guarantee compliance (Keane et al., 2008), knowledge of them can encourage it (e.g., Rizzolo, 2020, 2021). If this is the case, increasing awareness of regulations may reduce levels of illegal predator killing, particularly in areas where knowledge of the rules is limited.

(v) *Tolerance to livestock predation by specific predators:* People may express tolerance for wildlife by refraining from opposing conservation management and being willing to accept damage caused by wildlife (Frank, 2016). Here we use scenario-based questions to assess how farmers would respond to different levels of livestock loss by a range of predators. Furthermore, we investigate how this measure of tolerance relates to past predator killing behavior by the respondents. This sort of information can help target interventions toward the least tolerated species.

Planning for coexistence requires assessing human predator interactions at large spatial scales which is a significant challenge (Marchini et al., 2019; IUCN, 2020). Working across an extensive agricultural landscape, we estimate the proportion of rural residents who have killed nine legally protected predators, and compare these evaluations to two wild introduced species that people are permitted to control via lethal means. We also consider free-roaming domestic dogs (*Canis lupus familiaris*) because they are the main cause of livestock losses in Chile (Montecino-Latorre and San Martín, 2018). To address the challenge of asking questions about people's involvement in illegal acts, we use a symmetrical forced-response randomized response technique (RRT; Warner, 1965), a method designed explicitly for asking sensitive questions that has been used in a range of conservation settings (e.g., Razafimanahaka et al., 2012; St John et al., 2012; Gálvez et al., 2018). We examine how killing behavior can vary between species and implications this has for the design of interventions aimed at promoting sustained human-predator coexistence.

MATERIALS AND METHODS

Study Region and Sampling

Our study was conducted in the Araucanía region in southern Chile (**Figure 1**), just at the northern limit of the South American temperate forest ecoregion (39°15′S, 71°48′W) (Armesto et al.,

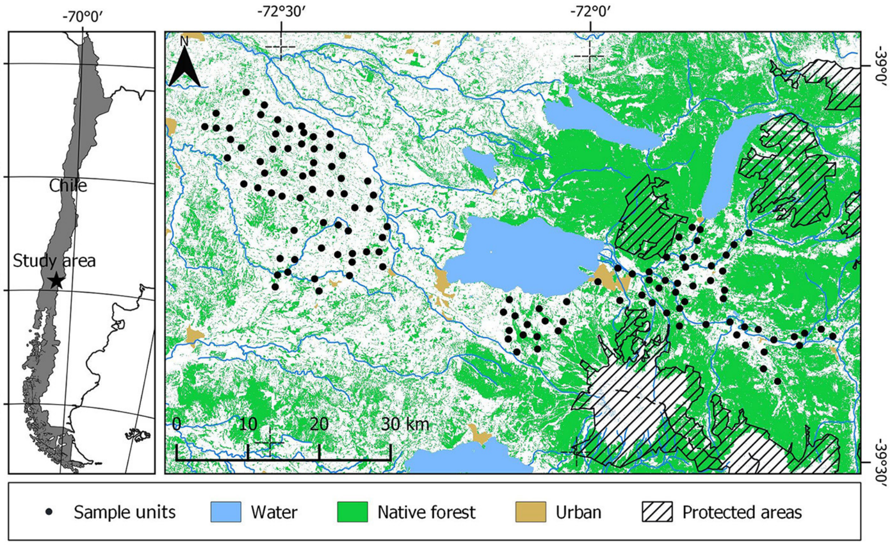

FIGURE 1 | Survey area in La Araucanía region of southern Chile. One or two households were surveyed within each of the 145 sample units (4 km^2) distributed across the study region. White background is mainly agricultural land use. Major water bodies correspond to Villarrica, Caburgua and Colico lakes. Protected areas are shown at high elevation sites within the Andes mountain range.

1998). The region comprises two distinct geographical sections common throughout southern Chile: the Andes mountain range and the central valley. Land-use in the latter is primarily intensive agriculture (e.g., cereals, livestock, fruit trees) and urban settlements. In the Andes, the agricultural lands become less intensively farmed (i.e., extensive livestock production and forestry) and are located within narrow valleys surrounded by continuous forest tracks on high slopes, which also include protected areas. The study region was divided up into a grid of 4 km^2 potential sampling units (SUs), representing a gradient of forest habitat fragmentation due to agricultural use and human settlement below 600 m.a.s.l. A total of 145 SUs were selected at random from the 230 in the grid, with 73 and 72 located in the central valley and Andes Mountains respectively.

Study Species

Our questionnaire focussed on predators that occur across the study region and that hunt small domesticated ruminants and/or poultry: (i) puma (*Puma concolor*), the largest predator present in Chile and known to predate ruminants (Murphy and Macdonald, 2010); (ii) güiña (*Leopardus guigna*), the smallest wild felid in the neotropics with a distribution restricted primarily to Chile and known to predate poultry (Sanderson et al., 2002; Gálvez et al., 2013); (iii) culpeo fox (*Lycalopex culpaeus*), a canid which will predate both small ruminants and poultry (Macdonald and Sillero-Zubiri, 2004); (iv) chilla fox (*Lycalopex griseus*), another canid which will predate both small ruminants and poultry (Macdonald and Sillero-Zubiri, 2004); (vi) Harris hawk (*Parabuteo unicinctus*); (vi) variable hawk (*Geranoaetus polyosoma*); and, (vii) Chilean hawk (*Accipiter bicolor*). All the raptors are known to predate poultry (Jimenez, 1986). To reduce the potential bias associated with respondents misidentifying species, we treated both canid species as "foxes" and all diurnal birds of prey as "hawks" in the analyses. Additionally, we included: (viii) the lesser grison (*Galictis cuja*), reported to predate on poultry (Silva-Rodríguez et al., 2007); and, (ix) Molina's hog-nosed skunk (*Conepatus chinga*), which is considered a nuisance, rather than a predator, of livestock. All nine species are protected by Chilean law (Agricultura, 1998), meaning that hunting them is prohibited. Only the güiña is of conservation concern and classified as Vulnerable by the IUCN Red List (Napolitano et al., 2015).

To examine and compare the killing behavior of respondents when a species is not legally protected, we also include all large mammals occurring in the study region that people are allowed to hunt without restriction. These comprise three introduced species: (i) hare (*Lepus capensis*); (ii) rabbit (*Oryctolagus cuniculus*); and, (iii) wild boar (*Sus scrofa*). Once again, we group the hare and rabbit together for analyses and refer to them as "lagomorphs." We also include free-roaming domestic dogs, which are an increasing problem in rural areas as they predate on wildlife (Sepúlveda et al., 2014) and livestock, especially small ruminants (Montecino-Latorre and San Martín, 2018). Currently, dogs are not mentioned specifically in the Chilean hunting law, which is the only legislative tool that classifies species as either protected or permitted to hunt (e.g., introduced or pest species).

Questionnaire Development and Delivery

The aim was to solicit information from rural inhabitants of the study region regarding their demographics and household economy, reported livestock loss, predator encounter rates, knowledge of legal protection of predators and tolerance to predation by specific predators. The questionnaire consisted of six sections. The first of these comprised sociodemographic and socioeconomic questions relating to age (years), amount of schooling (years of school and college education), livelihood activities (categorical) and monthly household income (USD; continuous). Before the data were analyzed, the dependency of residents on agricultural activities undertaken on their land parcel for their livelihood was converted into one of three categories: 1 = no dependency; 2 = partial dependency (i.e., maintained some crops and domestic animals but also had income from another sources); and, 3 = complete dependency.

The second part of the questionnaire consisted of questions regarding killing predators. Because of the sensitive nature of the questions, we employed a symmetrical forced-response RRT design (St John et al., 2010, 2012; Ibbett et al., 2021), using a die as the randomization tool. Before answering each question, respondents rolled the die and were asked to provide a truthful answer if they rolled a one, two, three or four; answer "yes," irrespective of the truth, if they rolled a five; or, answer "no," irrespective of the truth, if they rolled a six. A physical barrier, consisting of a folder, was used to block the interviewer's view of the die, so the number could not be seen. Before moving onto the sensitive questions, trial RRT questions were conducted with respondents using non-sensitive questions to ensure they understood the instructions. After piloting, 10 years was deemed to be an appropriate recollection period.

The third questionnaire section asked respondents to report livestock losses to predation over the past year, or an alternative period they could quantify (e.g., per week, per month, per year), which we could later convert to an annual measure. If the alternative period was less than a year, the respondent was asked to give an average value (e.g., average losses per week for a year). In the fourth section, participants were probed about how frequently the species were encountered, once again allowing respondents to report a time period they could relate to. We then asked if they thought the hunting of each species was permitted or illegal according to the hunting law in Chile (Agricultura, 1998). Prior to analysis, their responses were coded as: 0 = thought hunting of the species was prohibited; 1 = did not know; 2 = believed hunting of the species was permitted with the expectation that perception of legality would increasingly influence the killing of predators. These responses were further coded as either correct or incorrect according to the hunting law, representing whether or not their knowledge of the law was accurate.

The fifth section of the questionnaire presented farmers with scenarios to evaluate their tolerance to predation caused by different specific predators. Respondents had to state how they would respond to partial predation of a livestock holding of either 100 sheep or 100 chickens, depending on the predator. Respondents were asked what behavior they would display toward the predator after the loss of 2, 10, 25, 50 and >50 sheep or chickens had been experienced. For sheep predation, we assessed puma and domestic dogs, and for chicken predation we asked about güiña and "hawks." Response options included: (a) doing nothing; (b) improvement of livestock management through the use of enclosures; (c) calling wildlife authorities to alert them to the presence of the predator; (d) non-lethal capture of predator and handover to the authorities; (e) use of predator deterrents; and, (f) control via killing directly (i.e., the householder would kill the predator rather than requesting assistance from the authorities). Prior to analysis, we grouped the scenario responses into three categories of increasingly negative behavior toward predators: 0 = would remain passive and do nothing (item a); 1 = would carry out some sort of non-lethal or active management (items b-e); and, 2 = would carry out lethal control of the predator (item f). To assess if householders had access to the necessary skills and equipment required to hunt predators, we asked participants whether anyone in the household participates in sport hunting (a legal activity in Chile, which includes the use of snares, and can be conducted with a license that is inexpensive to obtain).

The final part of the questionnaire asked current management of livestock, particularly sheep and chickens. For example, we asked if the household enclosed livestock at night, the distance of the enclosure from the house, the number of domestic dogs/cats associated with the property and how they are managed overnight (e.g., free-roaming, tethered), as well as how often they are fed (meals per unit time) and the type of food they are given (categorical).

The questionnaire was piloted with 10 households occurring outside of the SUs, with one individual completing it on behalf of the entire household. The feedback from the pilot was used to improve the wording (e.g., the hypothetical question was refined to maximize clarity), time-scale (e.g., 10 year recall period) and order of questions (e.g., to make the flow of the questionnaire as logical as possible for the respondents). The data collected from the pilot were discarded.

The final questionnaire (**Appendix S1** in **Supplementary Material**) was administered face-to-face with a household representative, with one or two households sampled per SU, during May to September 2013. Questionnaires were administered by NG who is Chilean and has lived in the study region for over 10 years. The gender of the household representative was dependent on the individuals present when the household was approached and who appointed themselves the representative. Due to the traditional roles of males in rural Latin-American societies in relation to dealing with outsiders and/or officials, our sample was predominantly male (80%). Overall, the sampling strategy covered 66% of the households within each 4 km^2 SU in the study region (Gálvez et al., 2018).

The study was approved by the School of Anthropology and Conservation Research and Research Ethics Committee at University of Kent, and the Pontificia Universidad Católica Ethics committee. Data collection was anonymous and free prior informed consent was sought from all participation.

Data Analysis

Data analyses were conducted in R version 3.2.0 (R Core Team, 2015). The proportion of respondents admitting to killing each predator species was estimated using the model of Hox and Lensvelt-Mulders (2004):

$$\pi = \frac{\lambda - \theta}{s}$$

TABLE 1 | Sociodemographic and socioeconomic characteristics of questionnaire respondents living within the Araucanía region of southern Chile ($N = 233$).

Sociodemographic and socioeconomic characteristics	Mean	SE	Median	Minimum	Maximum
Property size (ha)	98	0.85	29	1	1,200
Time living at the property (years)	35	0.09	35	1	87
Age (years)	56	0.06	55	22	87
Amount of schooling (years)	10	0.01	10	0	18
Household income (USD per month)	558	2.81	341	59	5,934
No. of small ruminants	14	0.07	10	0	170
No. of chickens	23	0.09	18	0	120

where π is the estimated proportion of people in the sample who have undertaken the behavior, λ is the proportion of respondents who said "yes," θ is the probability of the answer being a forced "yes," s is the probability a respondent had to answer the question truthfully. A total of 10,000 bootstraps samples were run to calculate 95% confidence intervals, accounting for sample and RRT method uncertainty. All continuous predictors were z-transformed to standardize the scale of effects. Before exploring which of our explanatory variables may predict killing behavior for each specific predator, we checked them for collinearity using a Spearman's rank correlation coefficient matrix. Variables with Spearman's $|rho| > 0.7$ were removed from the analysis. Between correlated variables, we left those that were easier to interpret. For example, years of schooling, farm size and hunting for sport were correlated with income, thus leaving the latter as an easier value to interpret. Similarly, the use of night enclosures for chickens and sheep were correlated with land parcel dependency for their livelihood. Consequently, a total of eight potential predictors were retained from our five categories: (i) age, annual household income, the dependency of residents on livestock holdings (sheep or chickens) and crops on their land parcel for their livelihood; (ii) reported livestock loss (reported animals lost/year); (iii) reported predator encounter rates; (iv) knowledge of legal protection; and (v) tolerance to livestock predation by specific predator.

The RRlog function in the R package RRreg (Heck and Moshagen, 2018) was used to conduct multivariate logistic regression using the model for a symmetrical forced-response RRT data. For each predator, we fitted a logistic regression model with the potential predictors of killing behavior and evaluated their significance with likelihood ratio tests (LRT ΔG^2). First, a full model (i.e., all eight predictors) was evaluated. Full models of güiña and domestic dogs had convergence problems or generated nonsensical estimates (e.g., p-value of 1). We removed variables from the full model, in a backward manner, to identify predictors that triggered extreme estimates. Simultaneously, we conducted a univariate analysis of each predictor, as well as a multivariate subset of predictors to evaluate stability of estimates and consistency regarding significance and direction of relationships. We retained predictors in the model that allowed stability. None of the excluded predictors resulted in significant estimates in either the univariate or multivariate subset models. Only sociodemographic and household economy predictors were excluded across all the predator models and this was because their inclusion created instability (**Appendix S2** in **Supplementary Material**).

RESULTS

The questionnaire was completed in full by 233 rural residents (response rate of 99% of households approached) living within the study region (**Table 1**). Most respondents were male (80%), had grown up in a rural area (80%) and lived at their property full-time (97%). One farm was very large (1,200 ha), but most were considerably smaller (median = 29 ha). Respondents had 10 years of formal schooling on average, with 50% having received between 7 and 12 years of education. A high percentage of respondents (82%) reported that their dogs were left free to roam at night and the mean number of dogs per household was 3 (SE = 0.01; range = 1–28).

Pumas, güiñas and the lesser grisson were rarely encountered by respondents, while hawks and lagomorphs were frequently observed. Indeed, most of the rural residents reported seeing lagomorphs and hawks everyday (**Table 2**). Most respondents knew how the hunting law related to each species, with the exception of free-roaming domestic dogs that were perceived incorrectly as being protected by the hunting law (**Table 2**).

The reported predators of sheep were puma (43% of respondents had experienced livestock loss via this species), domestic dogs (41%) and, to a much lesser extent, foxes (6%). The number of sheep killed per year was similar across predators, with most respondents stating <10 are lost on average (**Figure 2A**). However, there were some outliers where dogs had killed substantial numbers of sheep. The main reported poultry predators were hawks (75%), foxes (50%) and güiña (16%), with the reported number of animals predated per year highest for hawks and foxes (**Figure 2B**).

Across all the scenarios designed to measure tolerance to the predation of livestock holdings, a significantly larger proportion of respondents said they would kill free-roaming domestic dogs, compared to pumas (**Figure 3**). Moreover, compared to other predators, the proportion of rural residents stating that they would kill domestic dogs was relatively high (>0.6). For all species, the rate of increase in the proportion of respondents

TABLE 2 | Questionnaire respondents' ($N = 233$) knowledge of how the hunting law in Chile relates to each of the predators in our study, and the frequency of encounters they have with each species on their property or surroundings.

Species	IUCN red list status	Hunting is legally permitted	Respondents' knowledge of legal hunting status for each species (%)		Respondents' reported encounters with species (per year)	
			Correct	Do not know	Mean (SE)	Median
Puma	LC	No	99	1	1.8 (0.02)	0.2
Güiña	V	No	79	17	0.2 (0.00)	0.0
Foxes	LC	No	94	3	41.2 (0.34)	12.0
Hawks	LC	No	78	15	204.0 (0.70)	360.0
Molina's hog-nosed skunk	LC	No	70	20	23.7 (0.21)	12.0
Lesser grison	LC	No	62	30	2.8 (0.10)	0.0
Domestic dog	–	Not included in hunting law	28	26	81.8 (0.57)	12.0
Lagomorphs	–	Yes	77	10	319.0 (0.45)	360.0
Wild boar	–	Yes	55	13	6.4 (0.11)	0.0

The International Union for Conservation of Nature (IUCN) Red List status is provided for each predator as an indication of conservation status. "Foxes" refers to both culpeo (Lycalopex culpaeus) and chilla foxes (Lycalopex griseus). "Hawks" refers to all diurnal birds of prey. "Lagomorphs" refers to rabbits and hares.

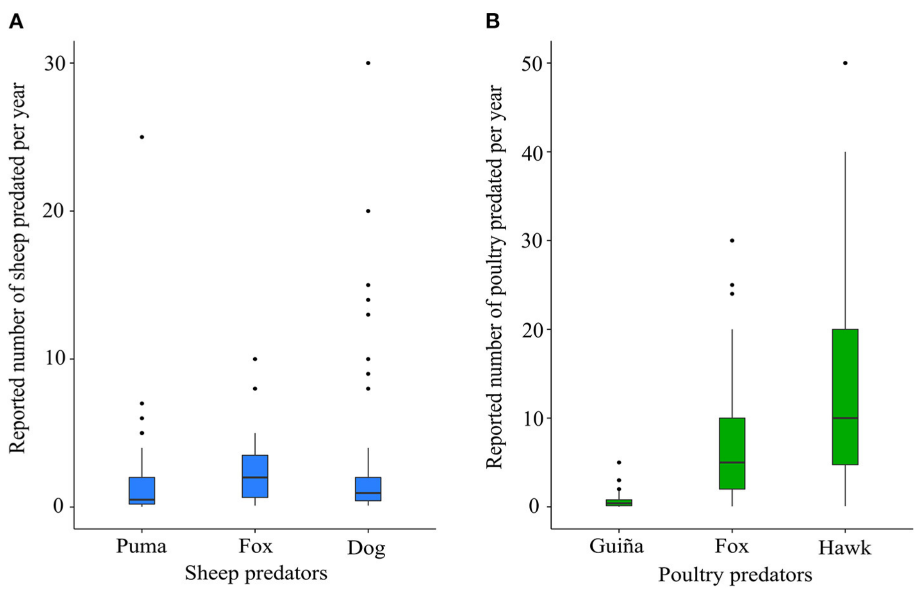

FIGURE 2 | The number of reported **(A)** sheep and **(B)** poultry killed by predators per year provided by rural inhabitants of the Araucanía Region of southern Chile ($N = 233$).

stating that they would kill a predator was greatest between 2 and 25 livestock killed, remaining constant for >25.

The proportion of respondents who reported killing predators via RRT varied across species (**Figure 4**). For puma, the 95% confidence intervals overlap zero, suggesting that the behavior may not have occurred in the past decade, or that the occurrence was very low. Only a small proportion of rural residents (10%) report killing güiña, while estimates for domestic dogs, foxes and hawks were greater (30–40%). There were large differences in the proportion of respondents reporting hunting legally; many hunted lagomorphs whilst few hunted wild boar.

Factors associated with killing behavior reported via RRT varied by species (**Table 3**). The probability that a respondent had killed güiña or hawks increased with encounter frequency (güiña $\beta = 0.86$, se $= 0.63$ $p = 0.04$; hawk $\beta = 0.62$ se $= 0.30$, $p = 0.04$), whereas the likelihood of fox killing rose with the extent of economic dependency the rural resident had on their land parcel ($\beta = 0.72$, se $= 0.35$, $p = 0.03$). Respondents who were less tolerant to predation were significantly more likely to report killing hawks in the case of chickens ($\beta = 1.07$, se $= 0.41$, $p = 0.004$) and dogs in the case of sheep ($\beta = 2.79$, se $= 1.88$, $p = 0.0003$). Reported loss of sheep was also positively and significantly related to reported dog killing ($\beta = 3.52$, se $= 1.74$, $p = 0.01$). The RRT data on puma killing were not modeled due to the exceptionally low prevalence of this behavior (**Figure 4**).

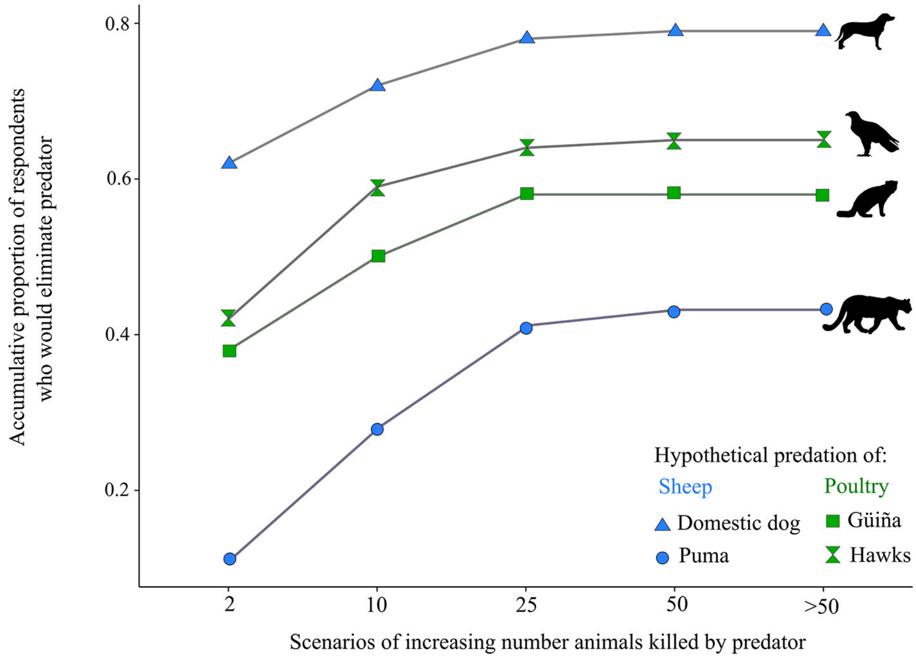

FIGURE 3 | Tolerance to livestock predation as the proportion of questionnaire respondents (*N* = 233) reporting that they would kill a specific predator in response to an increasing quantity of hypothetical livestock killed. The baseline for each scenario was that a farmer had a total of 100 sheep or chickens and experienced losses of 2, 10, 25, 50 and >50 individuals as a consequence of predation. The puma and domestic dog are sheep predators, whereas hawks and güiña are the poultry predators.

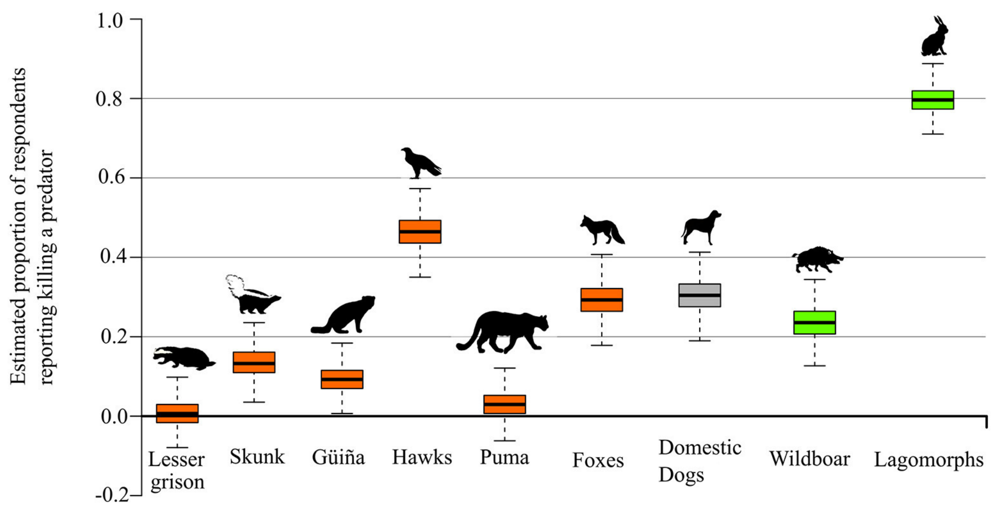

FIGURE 4 | The proportion of questionnaire respondents (*N* = 233) admitting to killing a species in the past decade. Values were estimated by the randomized response technique (RRT) and 95% confidence intervals were obtained from 10,000 bootstrapped samples. The species are grouped according to whether or not hunting is permitted under Chilean hunting law or not (illegal to hunt native species, orange; legal to hunt introduced species, green). Domestic dogs (gray) are not listed as either legal or illegal to hunt in the law.

DISCUSSION

Securing the long-term persistence of predator populations in human-dominated landscapes requires effective conservation management policies and interventions informed by evidence (Linnell et al., 2001). Our results highlight that a one-size-fits-all approach to minimizing persecution is unlikely to reduce or eliminate illegal killings across all the key predators in our study region. A high proportion of our respondents reported engaging in legal hunting (e.g., shooting of lagomorphs and

TABLE 3 | The relationship between illegal killing of predators and potential predictors of the behavior amongst questionnaire respondents (*N* = 233).

Species	Predictors	Coefficient	SE	*p*	Odds ratio	Odds ratio	
						Lower CI	Upper CI
Güiña	(Intercept)	−3.5	2.47	0.17	0.03	0	3.84
	Age[a]	–	–	–	–	–	–
	Income	0.23	0.33	0.52	1.26	0.66	2.4
	Land parcel dependency[a]	–	–	–	–	–	–
	Livestock holdings (chickens)	−1.24	1.48	0.35	2.95	0.45	19.19
	Knowledge of legal protection	1.08	0.96	0.53	0.29	0.02	5.28
	Reported encounter rate	**0.86**	**0.63**	**0.04**	**2.37**	**0.7**	**8.11**
	Reported livestock loss	0.1	0.43	0.81	1.11	0.48	2.56
	Tolerance to livestock predation	0.02	1.38	0.99	1.02	0.07	15.34
Hawk	(Intercept)	−2.04	0.96	0.02	0.13	0.02	0.86
	Age	0.42	0.31	0.13	1.52	0.83	2.78
	Income	−0.01	0.28	0.97	0.99	0.57	1.71
	Land parcel dependency	0.43	0.38	0.24	1.54	0.73	3.23
	Livestock holdings (chicken)	0.08	0.7	0.91	1.08	0.28	4.23
	Knowledge of legal protection	−0.02	0.53	0.97	0.98	0.35	2.77
	Reported encounter rate	**0.62**	**0.3**	**0.04**	**1.85**	**1.03**	**3.34**
	Reported livestock loss (chickens)	0.43	0.35	0.2	1.53	0.78	3.02
	Tolerance to livestock predation	**1.07**	**0.41**	**0.004**	**2.92**	**1.32**	**6.49**
Fox	(Intercept)	−2.30	0.89	0.00	0.10	0.02	0.58
	Age	−0.11	0.26	0.66	0.89	0.54	1.48
	Income	−0.38	0.53	0.33	0.69	0.24	1.93
	Land parcel dependency	**0.72**	**0.35**	**0.03**	**2.05**	**1.04**	**4.07**
	Livestock holdings (chicken)	0.10	0.24	0.66	1.11	0.69	1.79
	Knowledge of legal protection	−0.77	1.14	0.42	0.46	0.05	4.31
	Reported encounter rate	0.22	0.24	0.35	1.25	0.78	1.99
	Reported livestock loss (chickens)	−0.03	0.23	0.89	0.97	0.61	1.53
Dog	(Intercept)	−5.73	3.31	0.00	0.00	0.00	2.12
	Age	−0.55	0.37	0.10	0.58	0.28	1.19
	Income	−0.20	0.32	0.51	0.82	0.44	1.54
	Land parcel dependency	0.17	0.41	0.68	1.18	0.53	2.63
	Livestock holdings (sheep)[a]	–	–	–	–	–	–
	Knowledge of legal protection	0.28	0.34	0.41	1.32	0.68	2.60
	Reported encounter rate	0.06	0.38	0.87	1.06	0.50	2.24
	Reported livestock loss (sheep)	**3.52**	**1.74**	**0.01**	**33.62**	**1.12**	**1008.17**
	Tolerance to livestock predation	**2.79**	**1.88**	**0.0003**	**16.35**	**0.41**	**657.10**

[a] *These predictor variables were excluded from the full model (i.e., all predictors included) due to model instability (i.e., convergence or non-sensical estimates). None of the excluded predictors resulted in significant estimates in either the univariate or multivariate subset models. Reported coefficients, standard errors, odds ratios and their 95% confidence intervals were derived from a multivariate logistic regression which incorporates the known probabilities of the forced-responses obtained with the randomized response technique (RRT). We tested eight non-correlated predictors of five categories of predator killing behavior: (i) sociodemographic and household economy predictors—age (years), annual household income (USD), the dependency of the rural residents on their land parcel for their livelihood (1 = no dependency; 2 = partial dependency; 3 = complete dependency) and livestock holdings (sheep or chickens); (ii) reported livestock loss (animals lost/year); (iii) reported predator encounter rates (frequency of encounters/year); (iv) knowledge of legal protection (0 = hunting prohibited; 1 = do not know; 2 = hunting permitted); and (v) tolerance to livestock predation by a specific predator (0 = do nothing; 1 = manage predator; 2 = kill predator). All continuous variables were standardized to z-scores. Significance was at the p = 0.05 level and is indicated in bold. Hypothetical predation scenario was not included as a variable for foxes as the species was not included in this section of the questionnaire.*

wild boar), indicating that they are likely to possess the skills and resources to potentially kill predators illegally. We found that more conspicuous species, such as hawks, foxes and free-roaming domestic dogs, were killed by a higher proportion of farmers than more cryptic species, like güiñas, skunks and pumas. Indeed, from our five motivation categories, past killing of predators (i.e., yes/no) was associated with higher predator encounter rates for güiña and hawks, lower tolerance to livestock predation (hawks, dogs), higher livestock loss (dogs) and higher dependence of households on their land parcel (foxes). These drivers have implications for planning future coexistence interventions which we group into two main types: (i) improving livestock management; and (ii) better domestic dog management within rural areas.

The significant relationship between reported encounter rate and both güiña and hawk killing reported via RRT highlights the need for enhanced poultry management. The güiña is the only threatened predator that is found within the agricultural landscape, and it is probable that their low encounter rate explains the relatively low prevalence of killing. When presented with the hypothetical scenario of a güiña predating their chickens, many of the respondents reported that they would kill the offending animal. However, tolerance to livestock loss was not a significant predictor of respondents' past güiña killing behavior. This reflects the negative opinions rural residents have of güiña (Herrmann et al., 2013). Our results suggest that the prevalence of güiña killing would be higher if encounter rates were greater. People normally kill güiñas when they are caught inside the chicken coop (Sanderson et al., 2002; Gálvez et al., 2013) and hawks are usually killed when detected surrounding chicken enclosures. Managing poultry by housing them at night would minimize losses by the predominantly nocturnal güiña (Hernandez et al., 2015), while properly trained and managed guard dogs and the addition of tree cover around chicken enclosures could reduce hawk predation (Almuna et al., 2020).

Reported livestock predation levels only predicted respondents' predator killing behavior for free-roaming domestic dogs. Tolerance for livestock loss due to dogs was also significantly related to their dog-killing behavior as reported via RRT, and rural residents reported lower levels of tolerance for livestock predation by dogs than for all the other predators. For example, 62% of respondents reported that they would kill a dog if they lost just two sheep, whereas just 11% said the same for puma. Our findings, combined with anecdotal evidence from informal conversations with respondents, suggest that domestic dogs in rural areas are viewed negatively with respect to sheep predation, as is the case elsewhere in Chile (Villatoro et al., 2019). The extent of the issue was illustrated by the fact that dogs were reported to have predated sheep on more than 40% of the farms. Rural residents continually mentioned domestic dogs as their main livestock predation "problem," together with the perception that it was illegal to kill dogs according to the Chilean hunting law. At the time of data collection, many respondents (30%) reported killing dogs and the legal status of domestic dogs lacked clarity. However, in 2017, a new law came into force that was strongly lobbied for by animal rights groups which prohibited euthanasia and lethal control of domestic dogs irrespective of their involvement in sheep predation. The law should be revised as a way to dissuade the "shoot, shovel and shut up" dynamic which is likely to be occurring. The current situation aligns the desires of conservationists who are concerned that dogs kill wildlife in Chile (Silva-Rodríguez and Sieving, 2012) with that of rural residents, but increases tensions with animal rights groups. This emerging conflict requires resolution strategies (Redpath et al., 2013) that could improve dog welfare, reduce free-roaming behavior and, in turn, lead to a decline in livestock and wildlife predation. While sterilization programs may reduce dog births and population sizes over time, the main challenge in rural areas is to influence the social acceptability of free-roaming behavior and overcome peoples reticence to tether or restrict their movement (Villatoro et al., 2019 and shown in this study).

Over three quarters of our respondents knew how the hunting law in Chile related to each of the native predators. Nonetheless, across all species, respondents' knowledge of the law was not significantly related to their reported killing behavior. This suggests that, as observed in other studies (e.g., Rowcliffe et al., 2004), knowledge of laws neither guarantees compliance nor translates into tolerance for predators. The limited level of on-the-ground enforcement and thus low perceived risk of sanctions (Rowcliffe et al., 2004) may explain why some predator persecution still occurs in the study system. However, increased enforcement seems highly unlikely at present given budget restrictions for wildlife programs within the Ministry of Agriculture in Chile (Maldonado, 2018), making this an inefficient tool to reduce the killing of predators. Social marketing campaigns offer an alternative approach to encouraging behavior change. Well-designed, targeted and evaluated social marketing interventions can promote tolerance and coexistence (Veríssimo et al., 2019). For example, campaigns encouraging farmers to adopt predator deterrents could successfully reduce encounter probabilities (e.g., Ohrens et al., 2019; Almuna et al., 2020). Rather than purely disseminating information about prohibitive laws, messages that focus on what to do in case of encounters and the benefits associated with predator presence in landscapes (e.g., pest control) may improve tolerance (Slagle et al., 2013; Bruskotter and Wilson, 2014). The link between knowledge of benefits, tolerance and killing-behavior remains relatively understudied, but would be an interesting and potentially fruitful avenue for future research in this study system.

While randomized response techniques are reportedly harder for respondents to understand compared to other specialized questioning techniques (Davis et al., 2019), we deployed a symmetrical forced-response RRT design reputed for design efficiency (Lensvelt-Mulders et al., 2005) and encouraging more honest reporting of sensitive information (Ostapczuk et al., 2009). In recognition of the challenges associated with investigating sensitive topics, specialized questioning techniques such as RRT are increasingly being used in conservation to provide greater anonymity to respondents, improve response rates and decrease biases. However, a recent review of RRT applications in conservation provides evidence that whilst RRTs typically outperform direct questions in other disciplines, they do not yet do so in conservation (Ibbett et al., 2021). Prior to committing to incorporating any form of specialized questioning technique into a study, we encourage researchers to consider factors such as topic sensitivity, suspected prevalence (e.g., common or rare), achievable sample size and the type of estimate required (Nuno and St. John, 2015; Hinsley et al., 2019; Ibbett et al., 2021). Additionally, while our survey was conducted on behalf of the entire household, the majority of respondents were male. Our analyses and recommendations (e.g., targeted social marketing) may therefore not fully capture the role women play in predator persecution, as gender has been found to be important for understanding human-wildlife dynamics and conservation in other contexts (e.g., Agu and Gore, 2020). Nonetheless, in-depth qualitative investigations in our study region have shown that women can hold negative perceptions toward wild predators when they predate on livestock (Benavides, 2020).

Our intensive data collection over a relatively large area provides important information at a scale necessary for planning and delivering coexistence. Identified drivers may also be used as surrogates or proxies for the actual killing of predators in some contexts. For instance, the hypothetical predation scenarios (i.e., tolerance to predation by specific predator; **Table 3**) for hawks and domestic dogs were related to reported killing behavior, suggesting that the scenario-based questions can be a useful proxy measure of involvement in sensitive acts. Meaningful engagement with people bearing the economic, physical, and psychological costs of predator-coexistence is crucial to navigate toward coexistence (Redpath et al., 2015; Pooley et al., 2016) and, while it may be impossible to eradicate the illegal killing of predators, increased tolerance becomes more viable once drivers of persecution are identified and tailored interventions are implemented. Identification of relevant drivers in this particular landscape offers conservationists a more targeted species-specific toolbox to inform the development of interventions, such as the importance of improved chicken enclosures for güiña and hawks, use of deterrents to reduce predator encounters, social marketing to improve outcomes when encounters do occur and to increase the social acceptability of restricting free-roaming dogs. Once implemented, the performance of the interventions need to be evaluated. Our work provides a baseline to assist in monitoring the prevalence of predator killing behavior.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the School of Anthropology and Conservation Research and Research Ethics Committee at University of Kent, and the Pontificia Universidad Católica Ethics Committee. Data collection was anonymous and free prior informed consent was sought from all participation. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NG carried out field work, analyses, and elaborated figures. All authors designed the study and questionnaire instrument, and contributed significantly to the writing of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2021.712044/full#supplementary-material

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