UNIVERSIDAD DE CHILE -FACULTAD DE CIENCIAS -ESCUELA DE PREGRADO

“Perros guardianes de ganado y sus efectos sobre la fauna silvestre”

Seminario de Título entregado a la Universidad de Chile en cumplimiento parcial de los requisitos para optar al Título de Bióloga con mención en Medio Ambiente.

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Se informa a la Escuela de Pregrado de la Facultad de Ciencias, de la Universidad de Chile que el Seminario de Título, presentado por la **Srta. Rocío Contreras Abarca**

“Perros guardianes de ganado y sus efectos sobre la fauna silvestre”.

Ha sido aprobado por la Comisión Evaluadora, en cumplimiento parcial de los requisitos para optar al Título de Bióloga con mención en Medio Ambiente.

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BIOGRAFÍA

Nací en Chile un 3 de septiembre de 1995. Desde que era pequeña, siempre quise estudiar una carrera relacionada con la Biología, una carrera que me permitiera estar cerca de los animales y la naturaleza, y así poder ayudarlos. Acercándose mi último año de colegio encontré Biología Ambiental, y decidí que era lo más apropiado para mis deseos. Ya en la Universidad, llegué por casualidad al laboratorio del Profesor Javier Simonetti, que resultó ser el laboratorio con la línea de investigación que más me gusta, y que sigo hasta la fecha: Conservación Biológica. Próximamente seguiré participando en la generación de información en esta disciplina, con un Magíster en la Universidad de Chile, bajo la tutela del Profesor Simonetti.

A ella, la raíz de estos sueños y la llama de este brío,

Dedico todo el empeño y los momentos de frío,

Porque desde un principio, todo sacrificio,

Ha sido

Para ella

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RESUMEN

Los perros de guarda de ganado (PGG) son un método usado para disminuir las pérdidas de ganado causadas por amenazas como depredación por carnívoros silvestres, que consecuentemente reducen la persecución de carnívoros. Estos perros son considerados un método no letal y ambientalmente amigable. Esto ocurriría siempre y cuando no acosen o maten ya sea a especies objetivo (especies que afectan la producción ganadera) y no objetivo (especies que no impactan la producción ganadera). Sin embargo, los PGG han sido observados persiguiendo y depredando fauna silvestre, por lo cual su amabilidad ambiental podría ser cuestionada. Para ser efectivos, los PGG deberían provocar un cambio en la dieta de los carnívoros, disminuyendo el consumo de ganado y aumentando el consumo de presas silvestres. Dentro de este marco, en primer lugar, llevamos a cabo una revisión sistemática sobre los impactos que los PGG podrían tener sobre especies objetivo y no objetivo. Para ello, recopilamos literatura sobre tamaño corporal, comportamiento social y patrón de actividad de las especies silvestres con las cuales interactúan los PGG. Estos perros interactúan con 55 especies, principalmente mediante depredación y acoso. Las especies afectadas son mayoritariamente no objetivo y de Preocupación Menor. En segundo lugar, para evaluar los posibles cambios sobre la ecología trófica de carnívoros, analizamos heces de zorros en estancias ganaderas de Isla Riesco, Patagonia Chilena. La frecuencia de ocurrencia de ganado ovino en la dieta de zorros en la estancia con PGG fue menor en comparación a la frecuencia de ocurrencia en la estancia sin PGG. Esta evidencia apoya la idea que los PGG son ambientalmente amigables y reducen la depredación de ganado, reforzando su uso como un método ambientalmente amigable para resolver el conflicto carnívoros-ganadería.

ABSTRACT

Livestock guarding dogs (LGDs) are a method used to diminish livestock losses brought about by threats such as predation by native carnivores, which in turn reduce carnivore persecution. These dogs are considered a non-lethal, environmentally friendly method, if they do not harass or kill target (species that harm livestock production) and non-target (species that do not impact livestock production) species. However, LGDs' have been observed chasing and preying on wildlife, thus their environmental friendliness could be questioned. To be effective, LGDs should provoke changes in carnivores' diet, decreasing livestock consumption and increasing native prey consumption. Within this framework, we first carried out a literature review on the impacts LGDs could convey on target and non-target species. For this, we collected literature on body size, social behavior and activity pattern of species' that interact with LGDs. These dogs interact with 55 species, mainly through predation and harassment. Affected species are principally non-target and of Least Concern. Secondly, to evaluate LGDs' possible changes on carnivores' feeding ecology, we analyzed foxes' scats in ovine ranches from Isla Riesco, Chilean Patagonia. Ovine livestock's frequency of occurrence in foxes' diets in LGD present sites was minor as compared to that encountered in LGD absent sites. This evidence supports LGDs' environmental friendliness and efficiency in reducing livestock predation, enforcing these dogs' use as an environmentally friendly method to resolve the carnivore-livestock conflict.

GENERAL INTRODUCTION

Livestock guarding dogs (LGDs) have been used for millennia in Europe and Asia, and now at a global scale, as a non-lethal tool to deal with livestock losses due to predation by carnivores (Rigg 2001). LGDs are regarded as an environmentally friendly tool for predator's management if: 1) their use reduces retaliatory killing of carnivores and 2) they do not prey upon or harass target and non-target species (Potgieter et al. 2016). Livestock guarding dogs are indeed efficient in diminishing livestock losses (Moreira-Arce et al. 2018) but the possible negative effects these dogs could have on target and non-target species have not yet been reviewed (Gehring et al. 2010; Timm & Schmidtz 1989).

In order to make a proper and responsible use of LGDs to mitigate livestock losses and to promote carnivore's conservation in productive lands, it is necessary to understand the potential impacts these dogs can exert over other species and the circumstances in which it occurs. In fact, livestock guarding dogs have been reported to prey upon other species (Timm & Schmidtz 1989). In addition to preying, LGDs could also have sublethal effects over wildlife, such as chasing. These unwanted behaviors could result from inadequate training and management given to LGDs (van Bommel 2010). If such is the case, LGDs impacts on wildlife could be solved by correcting training and management.

The introduction of LGDs could decrease livestock's accessibility as a prey for carnivores. Thus, livestock should be a least frequent prey in carnivores' diets when LGDs are present. To be regarded as an effective method to reduce predation upon livestock, carnivore´s diet in areas where LGDs are present should contain a higher proportion of wild species rather than livestock compared to areas where livestock is not guarded by these dogs. However, whether this change occurs has yet to be assessed (Moreira-Arce et al. 2018).

Within this context we reviewed the effects LGDs might have on target and non-target species by means of a bibliographic search (Chapter 1). Then, we empirically assessed LGDs effects on carnivores' diet, using foxes (*Lycalopex sp.*) in sheep ranches at the Chilean Patagonia as a subject study (Chapter 2), information that will broaden our understanding of LGDs environmental friendliness and their effectiveness.

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CHAPTER 1

ASSESING LIVESTOCK GUARDING DOGS’ ENVIRONMENTAL FRIENDLINESS: A REVIEW

ABSTRACT

Livestock guarding dogs (LGDs) have been reported to prey and harass upon other species, impacts that are currently poorly known. To better implement LGDs as an environmentally friendly method for carnivore-livestock coexistence, it is imperative to understand if and how LGDs affect target and non-target species. Management or training could prompt LGD’s misbehaviors, such as wildlife chasing thus, it is important to assess if these aspects indeed induce LGDs interactions with wildlife. Here, we evaluated the impact of LGDs on wild species and assessed for potential patterns of biological traits among affected species (activity pattern, social behavior, body mass). Due to lack of information, training and management assessment is presented qualitatively. Through a literature search in ISI Web of Knowledge and Scielo we found 26 articles on LGD-wildlife interactions, which accounted 107 study cases. LGDs affected wildlife mostly by predation and harassment. Most affected species were carnivores and cetartiodactyls, non-target (52%), and of least concern (81%). Only eight wild species’ individuals were reported to have been preyed by LGDs. Cathemeral or gregarious species were affected by LGDs more frequently than expected by chance. Body mass rendered no statistical difference. It appears that training is more related to LGDs misbehaviors than feeding. Given most affected species’ conservation status and number of wild species’ individuals that were preyed upon, the consequences of LGDs on species’ persistence could be negligible. We require studies that address number of individuals and population size of species affected by LGDs to ascertain the magnitude

of LGDs' interactions with wildlife. With the current evidence we cannot deny LGDs' environmental friendliness, thus we propose to continue the use of this method.

INTRODUCTION

In animal husbandry, predation on livestock by carnivores inflicts economic damage on individual livestock-herders (Thirgood et al. 2005). As a result, carnivores are persecuted by ranchers, resulting in carnivore population diminishment. In fact, killing of carnivores in retaliation for livestock losses (i.e. persecution) is one of the major threats for carnivore conservation worldwide (Di Minin et al 2016).

Livestock guarding dogs are regarded as an efficient tool for reducing livestock losses (Moreira-Arce et al. 2018, Rigg et al. 2011, Smith et al. 2000) and diminishing wild carnivore's persecution (González et al. 2012). Therefore, as a management tool these dogs can help both livestock-herders and carnivores' conservation, facilitating coexistence among livestock and wildlife, thus attaining land sharing (Crespín & Simonetti 2019). As long as their use reduces retaliatory killing of carnivores, LGDs are regarded as an environmentally friendly approach to deal with livestock-carnivore conflicts (Potgieter et al. 2016).

For LGDs to be considered wildlife friendly, they also should not prey upon or harass target and non-target species (Potgieter et al. 2016). However, LGDs have been reported killing and harassing wildlife, mostly by means of anecdotal and scattered information (e.g. Black & Green 1984, Dorji et al. 2012, Hansen & Bakken 1999, Smith et al. 2000, Timm & Schmidtz 1989). In fact, these problems were noticed as far as 1989, when Timm & Schmidtz (1989) stressed the need to further address LGDs' effects on wildlife. Thus, a synthesis on which species are affected by LGDs, how they are affected and to what extent, is yet missing.

Here, we reviewed available literature on LGDs in order to understand their potential impacts on wildlife species, and the biological traits of the species preyed or harassed in order to unravel if there are attributes that render some species more prone to be affected by LGDs. For every wild species with which LGD interacted, we evaluated body size (kg), activity pattern and social behavior, because these traits can be directly related to the encounter probability of predator-prey. In most cases, predators are one to three orders of magnitude bigger than their prey (Woodward et al. 2005), thus we expect species smaller than LGDs be impacted in lethal (predation) and non-lethal manners, whilst species bigger than LGDs be impacted mainly in non-lethal manners, given that the latter should be too big for LGDs to prey on. Species that live in groups are more likely to notice an approaching predator and have a lower risk of individual predation due to encounter and dilution effects (Kie 1999, Roberts 1996). Hence, we expect gregarious species to be less affected by LGDs compared to solitary ones. Livestock guarding dogs are generally active throughout day and night (van Bommel & Johnson 2014), thus, we expected LGDs to affect species regardless of their activity pattern. Further, we asses if preyed or harassed species are target or non-target, their conservation status according to IUCN (IUCN 2019) and the number of individuals reported to be affected by LGDs. We tallied effects in terms of predation, avoidance (spatial exclusion or displacement from areas in which LGDs are present), reproductive success, harassment (barking and chasing), foraging behavior or attacks (sublethal agonistic encounters).

We also assess if management conditions prompt LGDs to impact wildlife. If LGDs spend time on chasing other species instead of taking care of livestock, it conveys a problem for wildlife but also for ranchers. Chasing wildlife could emerge from a suite of factors, including 1) inadequate training and/or 2) irresponsible management (negligent feeding, water provisioning or healthcare) (van Bommel, 2010). Due to the lack of quantitative information on this subject, we finally addressed this issue qualitatively. A better comprehension of LGDs potential effects and the underlying factors will lead to an improved implementation of this non-lethal method to deal with carnivore-livestock conflicts.

METHODS

We performed a bibliographic review of studies that have addressed livestock guarding dogs and their impact on wildlife species on the ISI Web of Knowledge and Scielo databases. Search terms used were: livestock guard* OR livestock protect* AND guard* AND dog* AND wildlife*. We included publications if they referred to livestock guarding dogs' impacts (e.g. predation, harassment, chasing) on target and non-target species. Based on this suite of publications, we performed a "snowball search" on all pertinent papers cited in retrieved articles.

We included articles that do specify that the guarding dogs are protecting livestock and the type of interaction with other species. To assess the magnitude of the effects, we tallied number of individuals affected and the IUCN Red List conservation status of the species affected. We retrieved information on species' biological aspects (namely activity pattern, social behavior and body size) from Animal Diversity Web (ADW) (Myers et al. 2019) and scientific articles. To evaluate species body size, considering that LGDs weigh in average 45 kg (Rigg 2001), we categorized species as smaller (<45 kg) or bigger (>45 kg) than LGDs.

Results are presented quantitatively as number of study cases per variable. A study case is the number of locations in which the study was carried out, number of species affected mentioned and number of different impacts reported per species, per article (Table 1). If only a general name (e.g. deer) and not an unequivocal either vernacular (e.g. coyote) or scientific name was provided, data was considered only for the total number of case studies, no further analysis was performed. We tested for statistical differences among affected species' biological traits, by means of G tests (Zar 2010). Management and training details are analyzed only in qualitative terms due to the scarcity of data available.

RESULTS

A total of 614 articles were found of which only 15 satisfied our criteria for inclusion. We then added 11 articles by revising selected papers' citing literature, obtaining a total of 26 publications, which we reviewed thoroughly. Only four (Gingold et al. 2009, Potgieter et al. 2016, van Bommel & Johnson 2016, Vercauteren et al. 2008) of these 26 publications aimed specifically to evaluate LGDs' impacts on wildlife. All other articles referred to it anecdotally. These 26 publications addressed 107 case studies in total.

Affected taxa, interactions and effects of LGDs

In five articles (19%), the identity of the species was not specified (authors referred to: "deer", "foxes", "forest birds", "hare", "lizards", "marmots", "porcupine", "rabbits", "rodents", "squirrels"). As more than one species can be attributed to these common names, they were not considered in statistical analyses. When authors referred to "sheep", "goats" and "cows" we considered them to be the widely used species *Ovis aries, Capra hircus* and *Bos taurus*, respectively.

We found LGDs interacted with 44 species from nine taxonomic orders. Carnivores (18 species) and cetartiodactyls (17 species) were the most frequently reported affected taxa, followed by rodents (2 species), lagomorphs (2 species), diprotodonts (2 species), galliformes (1 species), passeriformes (1 species) and primates (1 species). Seven (16%) of the 44 species were domestic, including two carnivores (*Canis familiaris* and *Felis catus*), three cetartiodactyls (*Bos taurus, Capra hircus* and *Ovis* aries), one lagomorph (*Oryctolagus cuniculus*) and one galliform (*Meleagris gallopavo*) (Table 2). Livestock was reported in 31% (n=33) of case studies, whilst rabbits and turkeys were reported in 1% (n=1) of case studies each.

Non-target species comprised 52% of reported affected species (n=23) and target species corresponded to 48% (n=21) (Table 2). Of the 21 target species, 71% (n=15) were carnivores, followed by cetartiodactyls and diprotodonts (n=2, 9.5% each), one primate and one passeriform (5% each). Sixty five percent (n=15) of the 23 non-target affected species were cetartiodactyls, carnivores (n=3, 13%), lagomorphs (n=2, 9%), rodents (n=2, 9%) and one galliform (4%).

Regarding the IUCN conservation status of affected wild species (n=37), one (3%) was Near Threatened, 30 (81%) were of Least Concern, four (11%) were Vulnerable and two (5%) were Endangered (Table 2).

Livestock guarding dogs interacted with wildlife mainly through predation (44 cases, 41%) and harassment (26 cases, 24%), whereas attacks were the least frequent (12 cases, 11%). Additionally, instead of interactions, literature often mentioned indirect effects LGDs caused to wildlife: such as avoidance of sites or habitats LGDs use (23 cases, 22%), changes in behavior (increased vigilance and decreased resting) (1 case, 1%) and reduction in reproductive success (1 case, 1%) (Table 1).

Fourteen study cases (13%) summed together 20 preyed individuals, most of them (60%) pertaining to domestic species (*Oryctolagus cuniculus* [n=9], *Ovis aries* [n=2], *Canis lupus familiaris* [n=1]). The remaining seven preyed animals were native carnivores (*Acinonyx jubatus* [n=1]*, Ailurus fulgens* [n=1]*, Canis lupus* [n=1]*, Canis latrans* [n=2]*, Felis silvestris* [n=1], *Panthera pardus* [n=1]*, Otocyon megalotis* [n=1]) . Four of these species were non-target whilst six were target.

Table 1. Articles reviewed (details in Appendix 1), C.S. (case studies addressed), Species affected by LGDs and type of interaction by which species are affected. (P= predation; D= Persecution/disturbance/harassment; Ex= avoidance/exclusion/displacement; R= reproductive success; B= behavior; At= attacks)

Author (s)	C.S.	Species affected	Interaction
Andelt and Hopper	1	*“Sheep”* (*Ovis aries*)	P
Black	3	(a) *Felis catus, Canis latrans, Canis familiaris*	(a) P
Black and Green	2	*Canis latrans*	P, D
Dorji et al.	4	(a,b) *Ailurus fulgens*	(a) P (b) At
Ekernas et al.	1	*Ovis ammon*	P
Gehring et al. (a)	2	*(a) Canis lupus* *(b) Canis latrans*	(a) D (b) Ex
Gehring et al. (b)	9	*Canis lupus, Canis latrans, Mephitis mephitis, Procyon lotor, Vulpes Vulpes, Didelphis virginiana, Odocoileus virginianus, Peromyscus maniculatus, Microtus pennsylvanicus*	Ex
Gingold et al.	3	*Gazella gazella*	Ex, B, R
González et al.	1	*“Goat” (Capra hircus)*	At
Green	5	*(a)Canis latrans* *(a,b) “Sheep”* (*Ovis aries*)	(a) P (b) D

Table 1. Continued.

Author (s)	C.S.	Species affected	Interaction
Green and Woodruff (a)	5	*Antilocapra americana, Canis familairis, Canis latrans, Odocoileus hemionus, “cow” (Bos taurus)*	P
Green and Woodruff (b)	2	*“Sheep”* (*Ovis aries*)	P
Green and Woodruff (c)	8	*“Sheep”* (*Ovis aries*)	P, At
Green et al.	2	*“Sheep”* (*Ovis aries*)	P, At
Hansen and Bakken	3	*Ursus arctos, Ovis aries, Rangifer tarandus*	D
Hansen and Smith	4	*(a) Oryctolagus cuniculus* *(b) Alces alces, Capreolus capreolus, “sheep” (Ovis aries)*	(a) P (b) D
Linhart et al.	3	*“Sheep”* (*Ovis aries*)	P, D, At
Marker et al.	6	*“Sheep”* (*Ovis aries*), *“goat” (Capra hircus)*	P, D, At
McGrew and Blakesley	1	*Canis latrans*	D
Potgieter et al.	11	*Acinonyx jubatus, Canis mesomelas, Caracal caracal, Canis familiaris, Felis silvestris, Otocyon megalotis, Oryx gazella, Phacochoerus africanus., Sylvicapra grimmia, Tragelpahus oryx, Tragelaphus strepsiceros*	P
Riberio and Petrucci-Fonseca	2	*“Goat” (Capra hircus)*	P, At

Table 1. Continued.

Rigg	13	(a) *Canis lupus, Canis lupus pallipes, Canis latrans, Panthera pardus, Meleagris gallopavo* (b) *Canis latrans, Ursus arctos, Ursus americanus, Corvus corax* (c) *Canis lupus, Ursus americanus*	(a) P (b) D (c) Ex
Smith et al.	7	*(a) Ursus arctos, Ursus americanus* (b) *Canis lupus, Gulo gulo, Ursus arctos*	(a) D (b) Ex
Timm and Schmidtz	5	(a) *Odocoileus hemionus* (b) *Odocoileus hemionus, Ovis aries, Meleagris gallopavo, Lepus californicus*	(a) P (b) D
van Bommel and Johnson	3	*Rusa unicolor, Macropus giganteus, Wallabia bicolor*	Ex
Vercauteren et al.	1	*Odocoileus virginianus*	Ex

Traits of species affected by LGDs

Most species affected by LGDs had a cathemeral activity pattern (n=21, 48%), which was more than expected by chance (G=26.087, d.f.=4, p=3.039E-5) (Fig. 1a). In contrast, 12 species (27%) were diurnal, five (11%) were crepuscular/nocturnal, four (9%) were nocturnal and two (5%) were crepuscular (Table 2). Gregarious species (n=23, 52%) were more affected by LGDs than expected by chance (G=12.719, d.f.=2, p=0.002) (Fig. 1b), whereas 16 (36%) were solitary and five (12%) had a mixed behavior (Table 2). We found a wide range of affected species according to their body mass (from 0.01 to 1363 kg). We found no statistical differences of species' body mass (G=0.364, d.f.=1, p=0.546) (Figure 1c).

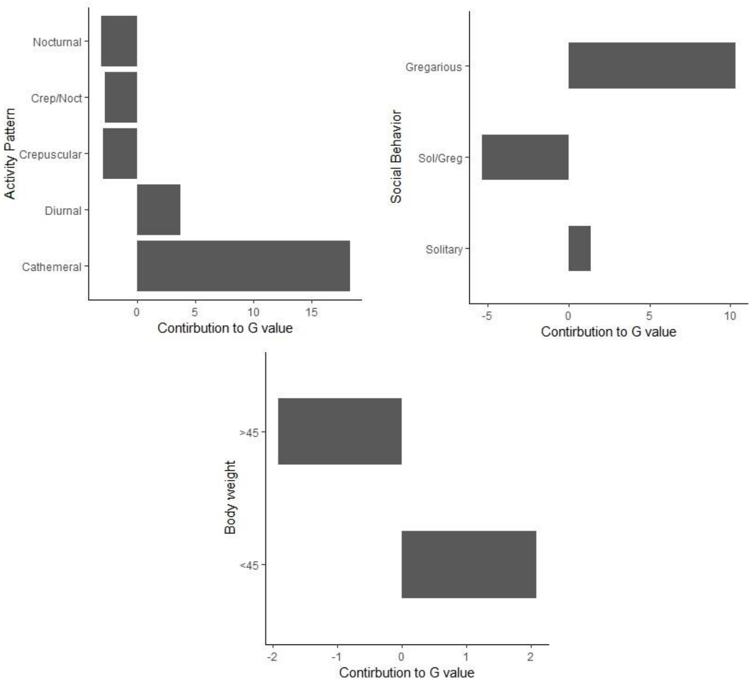

Figure 1. Contribution to the overall G value of a) each activity pattern, where "Crep/Noct" corresponds to crepuscular-nocturnal activity, b) each social behavior, where "Sol/Greg" corresponds to solitary-gregarious species, and c) each category of body weight.

Table 2. Species affected by livestock guarding dogs, whether they are target (T) or non-target (NT) ("Target"), whether they are domestic (D) or wild (W) (D/W), their body mass range ("Mass"), IUCN status ("IUCN"; NT= non threatened; LC= least concern; VU= vulnerable; EN= endangered; NC= not categorized), impact by which they are affected (P= predation; D= Persecution / disturbance / harassment; Ex= avoidance/exclusion/displacement; R= reproductive success; B= behavior; At= attacks;), their activity pattern ("AP"; C= cathemeral, Di= diurnal, N= nocturnal, Cr= crepuscular. Main activity pattern/occasional activity pattern), and their social behavior ("SB"; S= solitary, G= gregarious). NS= non-specified species. UD= undetermined. References in Appendix 2

Species (Common name)	**Target**	**W/D**	**Mass (Kg)**	**IUCN**	**Impact**	**AP**	**SB**
Carnivora							
Acinonyx jubatus (Cheetah)	T	W	35-40	VU	P	Di	S/G
Ailurus fulgens (Red panda)	NT	W	4.9-5.0	EN	P, At	N/Cr	S
Caracal caracal (Caracal)	T	W	6.5-19.5	LC	P	C	S/G
Canis familiaris (Dog)	T	D	<1-70	-	P	C	G
Canis latrans (Coyote)	T	W	7-20	LC	Ex	C	G
Canis lupus (Grey Wolf)	T	W	18-80	LC	P, Ex, D	C	G
Canis mesomelas (Jackal)	T	W	7.7-8.4	LC	P	C	G
Didelphis virginiana (Virginia Opossum)	T	W	1.9-2.8	LC	Ex	N	S
Felis catus (Cat)	T	D	4.1-5.4	-	P	C	S
Felis silvestris (Wild Cat)	NT	W	3.5-5	LC	P	C	S
Gulo gulo (Wolverine)	T	W	10.9-18.1	LC	D	C	S
Mephitis mephitis (Skunk)	T	W	1.2-5.3	LC	Ex	N/Cr	S
Otocyon megalotis (Black eared fox)	NT	W	3-5.3	LC	P	C	G
Panthera pardus (Leopard)	T	W	20-71	VU	P	C	S
Procyon lotor (Raccoon)	T	W	1.8-10.4	LC	Ex	N/Cr	S
*Ursus americanus (*Black bear)	T	W	50.1-86	LC	D, Ex	Di	S
Ursus arctos (Grizzly bear)	T	W	55-389	LC	D, Ex	C	S
Vulpes vulpes (Red fox)	T	W	3.4-8.7	LC	Ex	N	G
Cetartiodactyla							
Alces alces (Moose)	NT	W	270-771	LC	D	C	S
Antilocapra americana (Proghorn)	NT	W	58-97	LC	D	C	G
Bos taurus (Cow)	NT	D	147-1363	-	D	Di	G
Capra hircus (Goat)	NT	D	9-113	-	P, At	Di	G
Capreolus capreolus (European roe deer)	NT	W	22.6-32	LC	D	C	G/S
Gazella gazella (Arabian gazelle)	NT	W	17-29.5	EN	Ex, R, B	Di	G
*Odocoileus hemionus (*Mule deer)	NT	W	70-150[1]	LC	P, D	C	G
Odocoileus virginianus (White tailed deer)	T	W	54-135	LC	Ex	C	G

Species (Common name)	**Target**	**W/D**	**Mass (Kg)**	**IUCN**	**Impact**	**AP**	**SB**
Oryx gazella (Gemsbok)	NT	W	180-240	LC	P	Cr	G/S
Ovis ammon (Argali)	NT	W	110-182[2]	NT	P	C	G
Ovis aries (Sheep)	NT	D	20-200	-	P, D	Di	G
Phacochoerus africanus (Common warthog)	NT	W	50-150	LC	P	Di	G
Rangifer tarandus (Caribou)	NT	W	55-318	VU	D	Di	G
Rusa unicolor (Sambar)	T	W	<225-320	VU	Ex	Cr/N	G/S
Sylvicapra grimmia (Common duiker)	NT	W	183	LC	P	Di	S
Tragelaphus oryx (Eland)	NT	W	500-600	LC	P	Cr	G
Tragelaphus strepsiceros (Greater kudu)	NT	W	1803	LC	P	C	G
Primate							
Papio ursinus (Baboon)	T	W	15-31	LC	P	Di	G
Diprotodontia							
Macropus giganteus (Eastern grey kangaroo)	T	W	40-90	LC	Ex	N/Cr	G
Wallabia bicolor (Swamp wallaby)	T	W	17[2,3]	LC	Ex	C	S
Lagomorpha							
Lepus californicus (Black-tailed jackrabbit)	NT	W	1.5-2.8	LC	D	N	S
Oryctolagus cuniculus (Rabbit)	NT	D	3.68-3.81[4]	-	P	C	G
Rodentia							
Microtus pennsylvanicus (Meadow vole)	NT	W	0.0443	LC	Ex	C	S
Peromyscus maniculatus (Deer mouse)	NT	W	0.01-0.025	LC	Ex	N	S
Aves							
Galliform							
Meleagris gallopavo (Wild turkey)	NT	D	3.6-11	-	P, D	Di	G
Passeriforme							
Corvus corax (Common raven)	T	W	0.693-1.2	LC	D	Di	G

[1] Data for *Odocoileus hemonius*
[2] Data for adult males
[3] Mean mass.
[4] Mean mass for males and females, respectively.

Training and management related to behavioral problems of LGDs

Specifications about training or management of LGDs were scarce and heterogeneous. Eighteen of the 26 articles (69%) mentioned some aspect about LGDs training (e.g.

rearing age, minimizing human contact, spanking and scolding LGDs that chase or bite sheep) (see Hansen & Bakken 1999, Marker et al. 2005, Potgieter et al. 2016, Rigg 2001). Moreover, type of food given to LGDs (e.g. commercial dog food, rice, milk, human food scraps) or the frequency of feeding (i.e. once, twice a day) was only mentioned in six and three articles, respectively. In the remaining articles LGDs training or management were not even mentioned.

Only five authors explicitly mentioned the relationship between training and management and LGDs' behavioral problems. Two attributed them to errors in the imprinting process (Hansen & Smith 1999; Rigg 2001), specifically "poor and late" socialization (Rigg 2001). Three related behavioral problems with feeding, albeit contradictorily. One author related behavioral problems with excessive feeding (Green & Woodruff 1990), but other mentioned that over feeding was not the problem (Timm & Schmidtz 1989) and a last one indicated dogs' behavior was unrelated to the care given to them (Potgieter et al. 2016).

Even though unrelated to training and management, Green & Woodruff (1990) mentioned boredom is related to LGDs' behavior problems (chasing and attacking sheep). Nonetheless, we are unaware of how Green & Woodruff (1990) determined LGDs were bored and thus, this aspect appears irrelevant for management implications.

DISCUSSION

Livestock guarding dogs are considered environmentally friendly assuming they do not prey or harass target and non-target species (Potgieter et al. 2016). Given the increasing use of LGDs in rangelands worldwide and the evidence of them preying and harassing on other species, it is urgent to comprehensively evaluate LGDs' interactions with wildlife, their effects and their animal welfare implications (see Allen et al. 2019, Gingold et al. 2009, Timm & Schmidtz 1989). Our review addressed this topic.

Surprisingly we found that most of the evidence (88% of the reviewed papers) of LGDs interacting with wildlife is anecdotal. After three decades since Timm & Schmidtz (1989) called for further research to better understand the interactions LGDs could display with wildlife, we found only four (15%) studies that explicitly addressed this issue. This lack of information or empirical evaluations of LGDs effects on wildlife impairs our understanding of their potential influence in ecosystems as well as the development of best practices to manage them.

Our study reveals that livestock guarding dogs may have lethal and non-lethal effects on a wide variety of species, either domestic or wild. Most affected species were wild (88%) and non-target (58%), and main impacts inflicted by LGDs were predation (42%) and harassment (24%). Even though quantitative evidence of LGDs' predation over wildlife is highly limited, with only 13% (n=14) of study cases, it suggests that the magnitude of predation of these dogs may not be a threat to species' conservation. From the 20 preyed animals more than half (60%) were domestic, therefore, this information does not depict a conservation related problem. Wild species lost one to maximum two individuals per species. For example, one cheetah (*Acinonyx jubatus*) was killed by an LGD in Namibia, however, it was the only event reported for this species in a whole year following the introduction of LGDs while farmers were reported to stop killing cheetahs (Potgieter et al. 2016). In order to better understand the actual and eventual impacts of LGDs on species survival, especially those species affected by means of predation or attacks, it is important to accurately assess both the number of individuals and local population sizes of native species.

Eighty-one percent of species affected by LGDs are categorized as “Least concern”, thus the consequences of LGDs over these species could be negligible. For example, one bat-eared fox (*Otocyon megalotis*) was reported to have been killed by an LGD, since this small canid is common and widespread and has a stable population trend this predation event could not threat bat-eared foxes’ persistence (see Hoffmann 2014). Special attention should be payed to threatened species, to which pressure from LGDs could have a greater impact on their survival. Such is the case for cheetah (*Acinonyx jubatus*) and leopard (*Panthera pardus*), both categorized as vulnerable (IUCN 2019), and for which one individual was reported to have been preyed by LGDs. Regardless, LGDs attacking any species should be corrected immediately. To accomplish this, van Bommel (2010) recommends that LGDs that chase wildlife should be given fence training or better fences should be installed.

LGDs ought also not be prejudicial to herders and other people’s animals. In 33% of study cases livestock and other rearing animals such as turkeys (*Meleagris gallopavo*) and rabbits (*Oryctolagus cuniculus)* were negatively affected by LGDs. This kind of interaction, especially with livestock, is probably due to errors in training and management and has been thoroughly analyzed with recommendations on how to correct them (van Bommel 2010). In our review the European rabbit was categorized as a domestic species since they were farm animals from a location outside its native range (Smith & Boyer 2008).

Among articles that aimed to evaluate LGDs’ effect on other species, there are none in which no effects were encountered. However, we known that LGDs can have no lethal effects on wildlife. By analyzing 21 LGD’s feces from Isla Riesco, Chile, we found that LGDs consumed sheep, rats (*Rattus rattus*) and plants. No native prey was found

(Contreras et al. unpublished). To our knowledge this is the first quantitative evidence proving LGDs do not negatively interact with wildlife. We urge scientists to conduct more such studies, so we can further understand LGDs effects on wildlife.

Additionally, it is noteworthy that we intended to evaluate number of LGDs that interact with wildlife in order to assess if and how many LGDs are not so wildlife friendly. However, we were unable to analyze this aspect due to the heterogeneity and lack of papers that specified the number of LGDs studied. While some authors assessed the number of LGDs impacting wildlife (e.g. Potgieter et al. 2016), others only reported ranchers' anecdotes regarding LGDs interactions on wildlife, not specifying the number of dogs involved (e.g. Gehring et al. 2006). Thus, we ignore how many LGDs are indeed impacting wildlife as well as we ignore how many LGDs are currently working worldwide.

We found differences in the frequency of affected species according to the traits we evaluated. Regarding species' activity pattern, species impacted by LGDs were mostly cathemeral. This agrees with LGDs cathemeral activity pattern, which has also been described as dependent on predators' activity time (e.g. van Bommel & Johnson 2014). Livestock guarding dogs in Victoria, Australia, are active throughout the day but exhibit high levels of activity during the night with peaks of activity during sunrise and sunset, in response to the activity patterns of dingoes and red foxes, the main predators of the area (van Bommel & Johnson 2014). It is then expected that wildlife (other than carnivores) with the same activity pattern as carnivores (depending on location) are more prone to be affected by LGDs due to a highest probability of encounter in different times along the day.

Contrary to our predictions, we found more gregarious species affected than would be expected by chance. LGDs might be able to detect grouped species more easily as compared to solitary species, due to higher intensity olfactory signals, increasing their probability of detection (Treisman 1975). Additionally, given that most gregarious species are large to median herbivores, they are probably easier for LGDs to visually detect.

According to our analysis, LGDs interact with species regardless of their body size. Both larger than LGD and smaller than LGD species were mostly affected by means of predation (n=11 each). LGDs could perceive medium to large species as a threat (van Bommel & Johnson 2016), thus their aggressive response towards these species is probably in defense of their flock. On the other hand, smaller species could be regarded mainly as prey. Additionally, smaller species showed high avoidance (n=9), which agrees with the view of LGDs as surrogate top predators that create a “landscape of fear” for mesopredators and herbivores (van Bommel & Johnson 2016).

Given the heterogeneous nature of information provided on LGD training and the few articles that addressed type of and frequency of food provision (six and three articles, respectively) we were not able to establish if and how these factors influence LGDs interaction with other species. Nonetheless, one study addressed this matter and concluded LGDs’ care (i.e. quality of food provided and time spent with the dog) does not influence their behavior. Moreover, their behavioral problems appear to be more related to training than feeding (see Potgieter 2011). However, as there is only one study that addresses the role of care on LGDs behavior, we cannot draw any conclusions. Instead, based on interviews to herders about their LGD care (Peñaranda unpublished), poorly fed LGDs will be more prone to misbehave, either leaving their herd or affecting other species. More studies are needed regarding this matter. It is imperative to care for LGDs, both for the positive effect it might have on LGD behavior (thus reducing negative effects on wildlife) as for LGDs’ wellbeing.

The available evidence we found, does not support the idea that LGDs are not environmentally friendly. Even though it is possible that LGDs interact negatively with wildlife, possibly affecting their welfare (see Allen et al. 2019), according to our review LGDs inflict far less damage on wildlife as compared to other widespread, non-selective and less efficient methods (see Johnson et al. 2019, Moreira et al. 2018, Treves & Naughton-Treves 2005)especially lethal ones. We consider the proposed replacement of LGD use with ground shooting (Allen et al. 2019) as poorly founded. Although the harmfulness of lethal control methods and the use of LGDs in carnivore-livestock conflicts may be arguable in terms of animal welfare, the main goal of alternative livestock management tools is carnivore and ecosystem conservation, thus, carnivore control methods ought to maximize carnivore population persistence while minimizing livestock losses. However, recent reviews have shown that lethal control methods do not decrease livestock losses in the long term (Moreira et al. 2018, Treves et al. 2016) and high hunting rates on native carnivores are still persistent, which could have negative effects on carnivore conservation (Ripple et al. 2014). For example, livestock herders have been estimated to illegally hunt as much as 160 culpeo foxes (*Lycalopex culpaeus*) in the Chilean Patagonia in a year (Peñaranda unpublished), and in Wisconsin, United States, a minimum of 390 wolves were estimated to have been illegally hunted in a nine year period (Olson et al. 2015). In contrast, in the literature we found, LGDs only preyed on eight individuals pertaining to seven wild carnivore species in three countries, and LGDs can reduce carnivore losses to hunting (González et al. 2012). While searching for a 100% environmentally friendly method, is it better to risk carnivore persistence to shooting or is it worth to apply a cost-effective method that will save more carnivores than it will lose? Considering the evidence we portray here and LGDs' efficiency in diminishing livestock losses (Moreira et al. 2018), assuring ranchers' economical assets (see Smith et al. 2000) and reducing retaliatory killing of carnivores (González et al. 2012) , the use of LGDs as a non-lethal carnivore control method seems to be the most environmentally friendly method available, as long as ranchers pay special attention to LGD care and training and correct them when necessary.

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APPENDIX 2

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CHAPTER 2

FOX'S (*LYCALOPEX SP.)* TROPHIC NICHE IN LIVESTOCK GUARDING DOGS' PRESENCE

ABSTRACT

Livestock guarding dogs (LGDs) are a socially accepted non-lethal method used to decrease livestock losses against several carnivores and thus, contribute to carnivore conservation by reducing predator retaliatory killings. LGDs efficiency has been largely proven, but several aspects regarding these dogs' effects on wildlife are still pending. One of the effects LGDs could have on wildlife is changing carnivores' diets, specifically a reduction in livestock consumption. By protecting livestock, LGDs should decrease livestock availability for carnivores. Thus, we expected a decrease of livestock frequency in carnivore's diets, an increase of native prey occurrence and a wider niche breadth in areas with LGDs compared to areas without LGDs. We collected and analyzed culpeo (*Lycalopex culpaeus)* and chilla (*Lycalopex griseus*) foxes' (scats in Isla Riesco, southern Chile, in two ranches: one with and one without livestock guarding dogs. We measured frequency of occurrence per scat, niche breadth and niche superposition among sites. Due to small sample size for chilla foxes' scats, we statistically analyzed and calculated niche measures only for culpeo foxes. Only *Berberis microphylla* berries differed among sites, with a higher frequency of occurrence in the LGD-present one. Foxes' niche breadth was statistically wider in LGD presence, in agreement with our prediction, however, it is highly similar to foxes' niche in LGD absence (α=0.747). A major

abundance of *Berberis microphylla* shrubs in the LGD-present site could explain the higher frequency of occurrence of this berry. Albeit frequency of occurrence of sheep was not statistically different among sites, the tendency we found suggest LGDs reduce livestock depredation; further evidence is needed to test our predictions and results in other contexts, such as different landscapes and seasons.

INTRODUCTION

Livestock guarding dogs (LGDs) are a widely used tool to diminish livestock losses to predation (Rigg 2001). Besides LGDs not killing target carnivores, in comparison to lethal techniques, these dogs are considered more effective, cheaper and more selective toward the species which they are intended to deter (Green et al. 1984). Therefore, the use of LGDs is an ethically and socially accepted non-lethal method for predation management (Green et al. 1984, Smith et al. 2000).

In order to be effective LGDs should decrease livestock consumption by predators. Surprisingly, diet analyses of carnivores in LGD presence have not been carried out (see Moreira-Arce et al. 2018). If LGDs protect livestock and thus change its accessibility for predators, predators' diet composition should differ when LGDs are present as compared to when LGDs are absent. Specifically, predators in LGD present sites ought to consume less livestock and more native prey, which in turn would increase their niche breadth as compared to predators' diets in areas where LGDs are not deployed. Here we test this hypothesis comparing diet composition of native foxes in Chilean Patagonia in sheep ranches that differ in the use of LGD as a predation deterrent.

In the Magallanes region, located in southern Chile, animal husbandry, especially ovine (INE 2007), is carried out extensively throughout the landscape, being one of the main economic activities of the area. In these rangelands, livestock predation by native carnivores (puma (*Puma concolor),* culpeo fox (*Lycalopex culpaeus)* and chilla fox (*Lycalopex griseus*) accounts for almost half (54%) of ovine losses (INE 2018). Thus, any advance in the search for solutions to halt or diminish these losses, for example knowledge on LGDs and promotion of these dogs as a non-lethal control method, should help carnivore-livestock coexistence in Magallanes' rangelands.

In this research, we aimed to evaluate the effect that LGDs might have on native carnivores' diet, i.e. foxes. Specifically, we aimed to: i) evaluate differences in the consumption of sheep in foxes' diet, and ii) evaluate changes in foxes' trophic niches, regarding niche breadth and overlap, by comparing foxes' diets in LGD present and LGD absent sites.

METHODS

Study area

This study was carried out on sheep ranches at Riesco Island (53°00'00"S, 72°30'00"W), in the Chilean Patagonia. In Riesco Island, around 147.00 sheep heads are herded, from which ca. 150 sheep per farm per year are lost to predation (Soto 2001). Albeit some authors consider chilla foxes as mainly scavengers (e.g. Novaro et al. 2000) both culpeo and chilla foxes indeed prey and scavenge on sheep (see Medel & Jaksic 1988). Culpeo foxes prey on sheep throughout the year and are responsible for most ovine losses in the Chilean Patagonia (INE 2018), whereas chilla foxes are a threat especially to lambs during and after the parturition season which is the most important time of the year for livestock producers (Palacios et al. 2012).

Scats collection and identification

We studied foxes' diet in two ranches: "Estancia Anita Beatriz Ranch", which employs two to three LGDs and "Rancho Ankel", which does not. These farms are located 10 km from each other and possess similar vegetation cover proportions, composed of *Nothofagus* forests, *Berberis microphylla* and *Chiliotrichum diffusum* shrubs, peatlands and grasslands for cattle raising (Yusti-Muñoz 2019).

We collected foxes' scats during summer (February-March) of 2018 in both ranches. We searched for scats along stablished transects used to review camera traps that were part of a broader study of livestock-LGDs-carnivores' interactions. Scats were photographed *in-situ*, collected in labeled paper bags, and air-dried. To differentiate fox species to which each scat pertained to, we measured scats diameter at their widest section directly or over photographs using Image J Software (Rueden et al. 2017). After Palacios et al. (2012), we considered those scats <11.8 mm in diameter to belong to chilla foxes and those >12 mm in diameter to belong to culpeos.

Scat analysis

Scats were washed with water through a 600 µm strainer, separating the digested from the undigested material (Reshmawala et al. 2018). Bones, hair, feathers, insects, seeds, fruits, leaves and other vegetable material were retrieved for identification to the finest level possible. Unidentified remains, mainly corresponding to bone splinters, were not considered in the analysis. Insect remains were identified using a classification key for insects present in Chile (Peña 1987), by comparison with reference collections from the Museo Nacional de Historia Natural of Chile (MNHN) and expert's knowledge. We considered insects of 2 cm in body length and above to be fox prey (Crespín 2019). Insects smaller than 2 cm and those that could not be identified to genera (so their size is unknown) were thus excluded from analyses.

To identify mammal bone remains and teeth we used keys (Reise 1973, Pearson 1995), and compared them with reference collections from the MNHN. Hairs were identified through cuticle pattern comparison (Zafarina & Panneerchelvam 2009). We washed hairs in hot water and detergent, rinsed them in water and air-dried them (modified from Teerink 1991). Once hairs were dry, an imprint of their cuticular pattern was made by placing individual or couples of selected hairs on a slide with clear nail polish. When the nail polish hardened, hairs were gently removed (Zafarina & Panneerchelvam 2009). Two hundred slides with approximately 250 hair cuticular imprints were compared with specialized keys (Chehébar & Martín 1989, Teerink 1991). Prey items were identified to species and genera level when possible.

Diet comparison and data analysis

To describe foxes' diet from each ranch, we used frequency of occurrence of food items per scat (FO_{scat}), corresponding to the number of feces containing a given food item divided by the total number of feces (Klare et al. 2011). Frequency of occurrence per scat is the recommended method for analyzing diet when quantitative methods cannot be used, such as biomass ingested models, relative volume or mass estimations per scat (see Klare et al. 2011).

We evaluated differences in sheep and native prey consumption between ranches, as a measure of effectiveness of LGDs in reducing livestock consumption, using chi-square test for contingency tables for each food item category (Reynolds & Aebischer 1991, Zapata et al. 2005). For this, we grouped prey items in seven main categories: large livestock (horses (*Equus caballus*) and cows (*Bos taurus)*), sheep (*Ovis* aries), Calafate (*Berberis microphylla*), hares (*Lepus* europaeus), insects >2cm of body size, rodents and birds.

We evaluated changes in foxes' trophic niche in presence and absence of LGDs by means of niche breadth and overlap. We calculated both these measures considering all preyed species (not grouped), except fox hair (*Lycalopex sp.*), larvae and insects <2 cm. We used Herrera's trophic diversity index for presence/absence data (Herrera 1976) to measure niche breadth:

$$D = -\sum_{i-1}^{s} lg\, \widehat{p_{\imath}}$$

where $\widehat{p_{\imath}}$ is the frequency of occurrence per scat of a given prey category and *s* is the total number of qualitative prey categories. High values of *D* imply individual trophic preferences are very different or the species/population is generalist (Correira 2002), therefore low values of *D* imply specialist species and/or individuals with similar preferences. To determine if foxes' niche breadths differed statistically between ranches, we performed jackknife on items' frequency of occurrence in foxes' diets (Jaksic 2001). Then we compared the calculated pseudo values from the bootstrap through a Wilcoxon rank sum test, due to the non-normal distribution of the data.

To evaluate niche overlap, we used Pianka's (1973) index:

$$\alpha = \frac{\Sigma p_i q_i}{(\Sigma p_i^2 \Sigma q_i^2)^{\frac{1}{2}}}$$

where $p_i$is the relative occurrence of prey i in population p, and $q_i$is the relative occurrence of prey i in population q. This index renders values ranging from 0 to 1, representing complete dissimilarity and complete similarity, respectively. We performed Bootstrap and Chi-square test in Excel, and Wilcoxon rank sum test in R ver.3.6.1 (R Core Team 2019).

Additionally, we evaluated our sample's statistical power by means of a chi squared power test for a 2x2 contingency table (Dytham 2011) in R ver.3.6.1 (R Core Team 2019).

We did not include in diet's description and comparisons those hairs of foxes *(Lycalopex sp.)* and pumas (*Puma concolor*) found in scats, because it is not possible to determine whether these occurrences were due to self-grooming or scavenging.

RESULTS

We collected 151 fox feces, 81 in LGD presence and 70 in LGD absence. We were unable to measure all feces, due to the condition we found them in (*i.e.* shapeless/destroyed feces). Thus, we could infer fox species for 116 scats. A total of 108 scats pertained to culpeo foxes, with 55 found in LGD presence and 53 in LGD absence. Only nine feces pertained to chilla foxes, with three found in LGD presence and 6 in LGD absence. Due to this small sample size, we described only culpeo diet.

Culpeo fox diet

Sheep had the third highest frequency of occurrence in both sites. The frequency of occurrence of sheep in feces in LGD absence was 14% higher than in LGDs presence, although, this difference was not statistically significant (X^2 =0.68, d.f.=1, p=0.41). Our sample size possesses only 13% statistical power (w=0.0795, N=108, d.f.=1, sig.level =0.05).

Plants were the most common items found in culpeo foxes' feces, in both sites, followed by sheep, insects and rodents (Table 1). Only *Berberis microphylla* (χ^2=10.64, d.f.=1, p=0.0011, Table 1) was statistically more frequent in foxes' feces in LGD presence. Frequency of occurrence of all other prey items were not statistically different among sites ("Insects": χ^2=1.8643, d.f.=1, p=0.1721; "Rodents": χ^2=0.1789, d.f.=1, p=0.6723; "Large livestock": χ^2=0.0029, d.f.=1, p=0.9566; "Sheep": : χ^2=0.6831, d.f.=1, p=0.4085; "Hare": χ^2=0.5847, d.f.=1, p=0.4445; "Birds": χ^2=0.1467, d.f.=1, p=0.7017).

Table 1. Number of scats in which each prey category was found (n) and frequency of occurrence per scat (FO_{scat}) in culpeo (*Lycalopex* culpaeus) foxes' diet in LGD presence and absence.

	LGD presence		LGD absence	
Food category	n	FO_{scat}	n	FO_{scat}
Mammalia				
Cetaartiodactyla				
Large livestock*	4	0.07	4	0.08
Bos taurus (cf)	4	0.07	3	0.06
Equus caballus	0	0.0	1	0.02
*Ovis aries**	31	0.56	34	0.64

Carnivora				
Lycalopex sp	7	0.13	1	0.02
Puma concolor	0	0.0	1	0.02
Lagomorpha				
*Lepus europeaus**	16	0.29	12	0.23
Rodentia*	31	0.33	29	0.36
Cricetidae	10	0.18	16	0.30
Abrothrix sp	4	0.07	2	0.04
Abrothrix xanthorinus	1	0.02	0	0.0
Abrothrix olivaceus	6	0.11	1	0.02
Abrothrix longipilis	0	0.0	4	0.07
Auliscomys micropus	3	0.05	1	0.02
Muridae				
Mus musculus	2	0.04	3	0.06
Rattus rattus	2	0.04	1	0.02
Myocastoridae				
Myocastor coypus	3	0.05	1	0.02
Birds*	5	0.09	6	0.11
Enicognathus ferrugineus	2	0.04	0	0.0
Unidentified birds	3	0.05	6	0.11
Insects*	29	0.36	21	0.28
Coleoptera				
Aegorhinus sp.[a]	1	0.02	5	0.09
Calydon submetallicum	1	0.02	1	0.02
Ceroglossus sp.[a]	2	0.04	1	0.02
Ceroglossus suturalis[a]	7	0.13	5	0.09
Coleoptera	1	0.02	1	0.02
Curculionidae	1	0.02	4	0.07

Erichius sp.	9	0.16	1	0.02
Erichius femoralis	4	0.07	1	0.02
Listroderes sp.[a]	9	0.16	10	0.19
Neopraocis sp.[a]	1	0.02	0	0.0
Oxyelitrum sp.[a]	8	0.15	0	0.0
Rhyphenes sp.[a]	1	0.02	0	0.0
Scarabidae	2	0.04	3	0.06
Diptera	2	0.04	1	0.02
Himenoptera				
Ichneumonoidea	0	0.0	1	0.02
Coleoptera and Diptera larvae	10	0.18	11	0.21
Unidentified insects	18	0.33	15	0.28
Plants	55	1	53	1
*Berberis microphylla**	46	0.84	29	0.55
Unidentified plants*[b]	38	0.69	45	0.85
Total scats	55		53	
Richness S	23		21	
Niche breadth	55.33		51.86	
Jackknife niche breadth estimates ± SD	52.66± 1.33		49.25± 1.52	
Niche overlap α	0.747			

[a] Insects >2 cm in length.

[b] Mainly Poaceae plants.

[*] Categories considered in chi squaredanalysis.

Overlap of culpeo fox niches between sites indicated high similarity (α=0.747). Niche breadth between LGD presence (*D*=52.66± 1.33) and LGD absence (*D*= 49.25± 1.52) were statistically different based on our jackknife estimates (Table 1) and Wilcoxon rank sum test (W=601; p<0.0001).

For chilla foxes, sheep (*Ovis aries*) was more frequent in feces with LGD absence (n=3, FO_{scat}=0.5) than in LGD presence (n=1, FO_{scat}=0.33) and it was only in this latter site that we identified large livestock remains (Appendix 1, Table 1). We found two livestock species, no carnivore remains, only two rodent species, four insects of prey and one bird remain (unidentified) (Appendix 1, Table 1). Plants, insects and rodents were most frequently encountered in chilla scats (Appendix 1, Table 1).

DISCUSSION

Livestock guarding dogs are used as an effective tool in reducing livestock losses (Moreira-Arce et al. 2018) and carnivore kills in retaliation (e.g. González et al. 2012). Considering LGDs main purpose is to protect livestock from predators, in other words to make livestock less available as prey, a reduction of livestock frequency in predators' diet analyses and an increase in the reliance of carnivores on wild prey is therefore expected.

Culpeo foxes in the Chilean and Argentine Patagonia have a generalist diet, composed by mammals, insects, plants, birds and reptiles (Jaksic et al. 1983, Johnson & Franklin 1994, Novaro et al. 2004, Palacios et al. 2012, Zapata et al. 2005). According to our results, culpeos are also generalists in Isla Riesco, consuming plants, mammals, birds and insects.

Sheep in our study were encountered in more than half of feces (56% in LGD presence and 64% in LGD absence), which contrasts with past studies of culpeo foxes' diets in Patagonia. In Neuquén, northwestern Argentine Patagonia, sheep remains were encountered in 25% of culpeo foxes' stomachs from sheep and cattle ranches (Novaro et al. 2000), half of what we encountered in our study. Novaro et al. (2004) hypothesized that domestic prey consumption, including sheep, in Patagonia may increase when hare densities are low. A previous study in our study area effectively found that hare occurrence and ovine kill rate in Isla Riesco are inversely related (Crespín 2019), therefore, evaluation of hare-relative-to-sheep densities in Isla Riesco could help ascertain if this is the cause for the high rates of sheep predation encountered.

Although we did not find statistical differences in livestock frequencies, frequency of occurrence of sheep in culpeo scats in LGD absence was 14% higher than in LGD presence which is what we expected and coincides with herder's perception in our study area: LGDs decrease livestock losses to carnivores (Peñaranda unpublished). Given that LGDs efficiency is context dependent, regarding, for example, predator species (Smith et al. 2000, Miller et al. 2016) and number of livestock per stock (van Bommel & Johnson 2012), and prey species availability is variable amongst localities and seasons, further analyses on carnivores' diet in LGD presence should be carried out.

We found that culpeo foxes' diet differed between the ranch that uses LGDs and the ranch that does not use LGDs, according to our measures of diet niche breadth. As we predicted, foxes' niche breadth in the LGD present site was significantly more diverse than foxes' niche breadth in the LGD absent site (W=601; p=2.104e-8), indicating foxes are probably broadening their diet in response to sheep being less accesible. This could be due to *Berberis microphylla*, which presented a higher frequency of occurrence in the LGD present site (FO_{scat} =0.84) as compared to the LGD absent site (FO_{scat}=0.55), and to some prey items that were consumed only in the LGD present site: *Abrothrix* *xanthorinus, Enicognathus ferrugineus, Neopraocis sp., Oxyelitrum sp.* and *Rhyphenes sp.*

The difference in *Berberis microphylla* ("Calafate") occurrence in foxes' diets could be due to calafate's availability in each site. Anita Beatriz ranch (LGD-present site) contains greater calafate abundance as compared to Ankel ranch (LGD-absent site) (pers. obs.), which could lead to greater fox consumption of this berry. Additionally, feces recollection was done during the spring-summer period, which corresponds to calafate fruiting season (Arena & Curvetto 2008). This probably explains why calafate was the most consumed item in both ranches. The prey items encountered exclusively in the LGD present site could suggest this site holds greater diversity, a result of its holistic management (Crespín 2019).

Similarly to culpeos' diets in Tierra del Fuego (TF) (Jaksic et al. 1983), culpeo foxes in Isla Riesco consumed plants in high frequencies of occurrence. Regarding specifically *Berberis microphylla* berries, these were consumed by foxes in the Monumento Natural Bosques Petrificados, Argentine Patagonia, albeit in much lower frequencies (36.7 in spring-summer) compared to our results and considered with other fruits (Zapata et al. 2005) which are not present in Isla Riesco (Pisano 1971). Among vegetable remains, we found a high frequency occurrence of Poaceae plants (Unidentified plants) in fox feces. Even though seldom considered in past diet analyses, these plants could be consumed intentionally by culpeos, as they are by other fox species (e.g. Jedrzejewski & Jedrzejewska 1992), thus being relevant to consider in diet analyses.

Albeit we did not statistically analyze fox hair frequency of occurrence in scats, fox hair was qualitatively more frequent in culpeo's scats in LGD presence compared to LGD absence (Table 1). This could be due to foxes' licking their wounds, which could be evidence for livestock guarding dogs' attacks on culpeos. Anita Beatriz's owner has occasionally observed wounds and blood on LGDs' snouts. Nonetheless, it is not possible to ascertain if these hairs resulted from scavenging or self-grooming.

To our knowledge this is the first study to analyze LGDs' efficiency in diminishing livestock losses by means of predators' diets, contributing quantitative evidence on LGD performance. Although we did not find statistical support for the differences in sheep consumption between the site with LGD and the site without LGD, the tendency suggests it is possible to diminish sheep predation with this management tool. Thus, considering this tendency towards fewer sheep consumed, we further validate livestock guarding dogs as an effective method for the carnivore livestock conflict, which can help us attain sustainable agriculture and thus accomplish Aichi Target 7 (Convention on Biological Diversity 2010).

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APPENDIX 1

Frequency of occurrence data for chilla fox (*Lycalopex griseus).*

	LGD presence		LGD absence	
Food category	n	FO	n	FO
Mammalia				
Artiodactyla				
Large livestock	0	0.0	2	0.33
Equus caballus	0	0.0	2	0.33
Ovis aries	1	0.33	3	0.5
Lagomorpha				
Lepus europeaus	1	0.33	0	0.0
Rodentia	1	0.33	6	1.0
Cricetidae	0	0.0	3	0.50
Abrothrix sp	1	0.33	1	0.16
Abrothrix longipilis	0	0.0	1	0.16
Auliscomys micropus	0	0.0	1	0.16
Birds	0	0.0	1	0.33
Unidentified birds	0	0.0	1	0.33
Insects	0	0.0	9	1.5
Aegorhinus sp.[a]	0	0.0	2	0.33
Ceroglossus suturalis[a]	0	0.0	1	0.16
Coleoptera and Diptera larvae	0	0.0	3	0.5
Erichius sp.	0	0.0	1	0.16
Listroderes sp.[a]	0	0.0	3	0.5
Scarabidae	0	0.0	1	0.16
Unidentified insects	1	0.33	3	0.5

Plants	4	1.33	6	1
Berberis microphylla	3	1	2	0.33
Unidentified plants	1	0.33	4	0.66
Total scats	3		6	

GENERAL DISCUSSION

We found that livestock guarding dogs interact with both target and non-target wildlife, however articles in which this statement is based upon are scarce and lack analyses on the effects LGDs interactions could have on species persistence. Despite the lack of evidence, LGDs effects on wildlife seem negligible in magnitude (number of individuals affected) and mostly influenced by training. Thus, we recommend further studies addressing population aspects of species affected to ascertain the magnitude of LGDs interactions with wildlife and we emphasize the relevance of a responsible training and management of LGDs to enhance carnivore conservation and livestock loss mitigation.

Regarding livestock guarding dogs' effect on foxes' trophic niche, we found the expected result: decrease in sheep consumption and increase in wildlife consumption by foxes in LGD presence, as compared to LGD absence. However, the decrease in sheep's frequency of occurrence when in presence of LGDs was not statistically significant, so we believe further studies should be carried out in Isla Riesco to determine if LGD's performance can be enhanced. To our knowledge, this is the first study to analyze LGD's efficiency by means of predator diet analyses, and we believe its replication around the world should be carried out, to better understand how LGDs operate, and to analyze and gather more evidence regarding these dogs' efficiency in reducing livestock losses and aiding in the livestock-carnivore conflict.

Apparently, LGDs are effective in diminishing livestock losses and they currently are the most environmentally friendly method available as compared to other methods, especially lethal ones. We thus support and promote the use of LGDs in carnivore-livestock conflict scenarios.