An x-ray of the puma (*Puma concolor*) and its environment in Chilean Patagonia

A conservation narrative about puma diet, the meso and macro scavengers of the steppe and the livestock guardian dogs and their sheep

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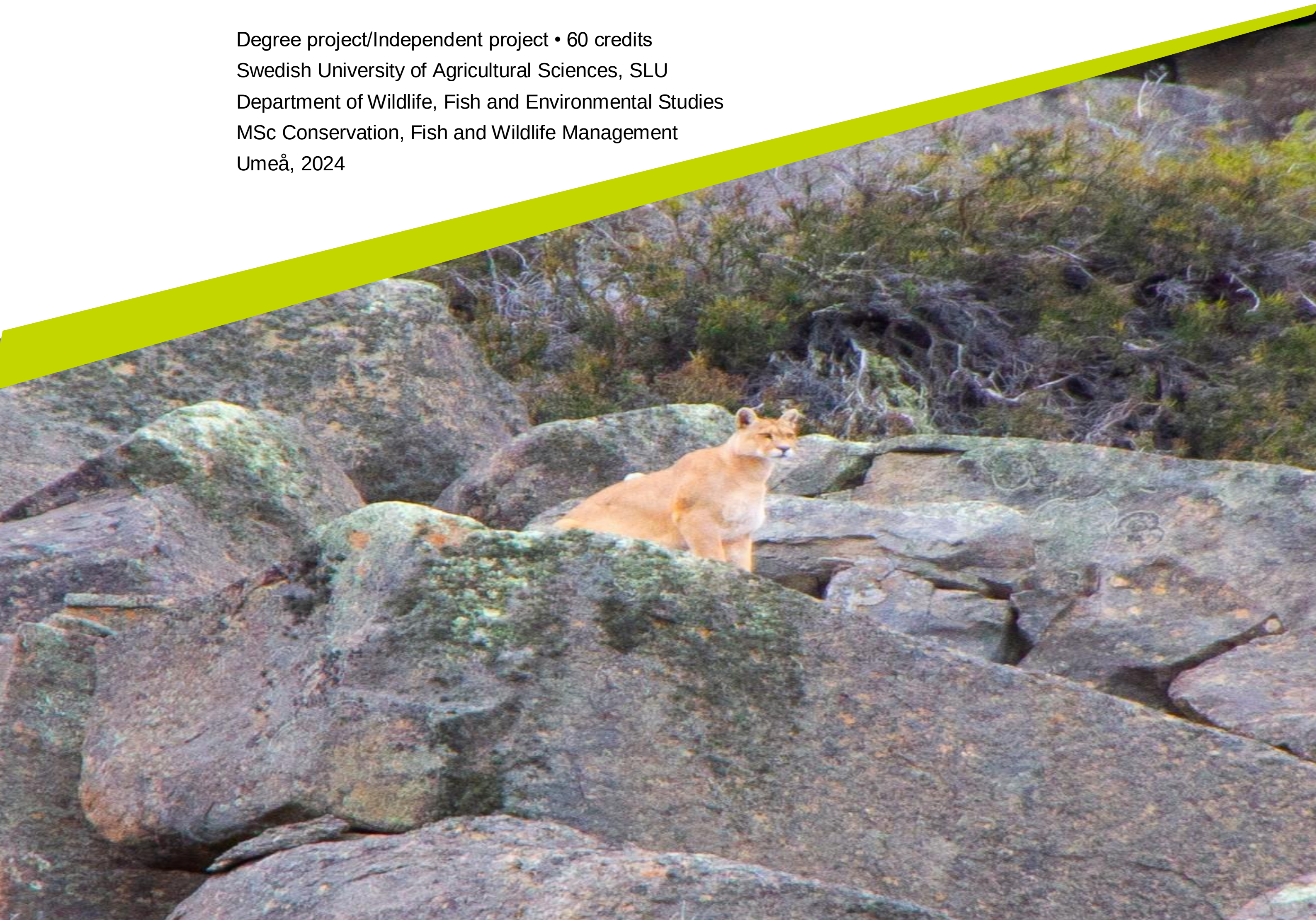

An x-ray of the puma (*Puma concolor*) and its environment in Chilean Patagonia. A conservation narrative about puma diet, the macro-scavengers of the steppe and livestock guardian dogs and their sheep.

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Keywords*:* *Puma concolor*, livestock guardian dogs, scavengers, Patagonia, puma diet, *Lama guanicoe*

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Abstract

This study provides insights into the predatory behaviour of pumas (*Puma concolor*), scavenger dynamics at puma-killed carcass sites, and the activity patterns of Livestock Guardian Dogs (*Canis lupus familiaris*) (LGDs) in the context of predator-livestock interactions in Chilean Patagonia. Using GPS collars, eight adult pumas were monitored for 16 months. I identified a predilection for targeting young guanacos (*Lama guanicoe*) (<1 year old) during the guanaco calving season (November-February), with predation extending up to four months post-calving. Young guanacos were most vulnerable between birth and seven months of age. Individual variations in hunting strategies were observed among pumas, emphasizing the complexity of predator behaviours. Pumas showed crepuscular hunting (n=170) and scavenging (n=51) preferences, and adult pumas were reported sharing prey's carcasses. Camouflaging of prey carcasses by pumas prolonged feeding opportunities, although the presence of scavenger signs did not have a significant impact on feeding duration. Scavenger communities at predation sites comprised a diverse array of meso and macro species. Using camera traps, pumas, grey foxes, and southern caracaras were identified as the main scavengers in the area, with pumas and grey foxes showing the highest degree of overlap in scavenging activities. The eight pumas from the study were reported scavenging. In contrast, LGDs, monitored with GPS collars, displayed similar activity levels throughout the day and night, suggesting no pronounced increase in activity during peak puma predation hours, dusk, and dawn, although different dogs showed varying activity patterns. My findings contribute new knowledge to our understanding of puma-guanaco dynamics and scavenger ecology in agricultural landscapes in Southern Chile. My results provide valuable insights into possible conservation strategies aimed at promoting coexistence between wildlife and livestock. Further research with larger sample sizes and standardized methodologies is warranted to validate and expand upon these findings, supporting effective wildlife management and conservation efforts in the region.

Keywords: *Puma concolor*, livestock guardian dogs, scavengers, Patagonia, puma diet, *Lama guanicoe*

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Abbreviations

SLU	Swedish University of Agricultural Sciences
LGD	Livestock Guardian Dog
ER	EarthRanger (software)
CT	Camera Trap

1. Introduction

In 2014, globally, 61% of large carnivore species were declared by the IUCN (International Union for Conservation of Nature) as threatened (Rostro-García et al. 2016). Carnivore populations are affected by persecution by humans, encouraged by reprisals due to attacks on humans or livestock, competition for game, or by the simple feeling of threat (Rostro-García et al. 2016). This human-wildlife conflict increases with intense human land use, intensified resource competition, and more rapidly regenerative predator populations (Lieb et al. 2021). The most common conflict between humans and carnivores arises from predation on livestock (Linnel et al. 1999; Gallo et al. 2020; Khorozyan & Waltert 2021). Throughout the world, ranchers and farmers from different production systems live in continuous conflict with large carnivores such as wolves, lynxes, tigers, lions, pumas and jaguars (Zarco-González et al. 2013, Amirkhiz et al. 2018, Kissling et al. 2009, Beattie et al. 2020, Miller et al. 2016). The reasons why predators might attack livestock are diverse, ranging from a shortage of natural prey due to the intense hunting of these by humans, to loss and invasion of habitat by infrastructures and human activities (Wilson et al. 2020; Brancatelli et al. 2017).

Many carnivore species have a large geographical range, covering multiple countries and even different continents that all provide all context-specific relationships between humans and predators. However, puma research in Central and South America is scarce and the available information comes mostly from North America (LaBarge et al. 2022; Chebez & Nigro 2010). Yet, socio-ecological preconditions may differ between continents, emphasizing the need to understand the dietary patterns and hunting behaviours of this wild apex predator within the South American system to comprehend their ecological roles and address conservation challenges. However, studies focusing on these aspects face logistical, practical, and financial hurdles, resulting in limited data compared to studies on smaller species or animals in captivity (Rowcliffe et al. 2014). Obtaining necessary data for wide-ranging and elusive large carnivores, such as pumas, can be particularly challenging, leading to gaps in our understanding of predation dynamics (Elbroch & Wittmer 2012b).

For 150 years, extensive sheep and cattle farming has been an important economic activity in the Torres del Paine National Park area in Chilean Patagonia, Southern Chile (Hernández et al. 2017). The arrival of cattle ranching in the area brought a large number of socio-ecological changes at many levels, from the conformation of the landscape to the culture and traditions of the local human population, but more importantly, it brought a new way of interacting with wildlife (Franklin et al. 1999; Anderson et al. 2011; Palacios, Walker & Novaro 2012). For example, within this system, the *Puma concolor*, a top/apex predator, is one of the species most threatened by human-wildlife conflicts caused by predation on livestock (Ohrens et al. 2021). Today, the puma is considered as 'vulnerable' in Southern Chile (Iriarte et al. 2013). Yet, the puma is also one of the most emblematic Patagonian species and has great economic importance for tourism, next to its ecological significance (LaBarge et al. 2022; Treves et al. 2011; Walker et al. 2010). Despite the fact that puma hunting is declared illegal in the Chilean state since 1980, today, the figure of the 'leonero' (puma hunter) still exists, whose function is to hunt those puma individuals that are a suspected threat to livestock. However, we are experiencing a paradigm shift worldwide, in which large carnivores are beginning to be perceived as an ally of human activity and considered as a precious natural asset instead of a threat (Chapron et al. 2014). Since many of the conservation costs are borne by locals, their acceptance and tolerance of large carnivore species like pumas in the landscape is fundamental to the success of in-situ conservation (Corcoran & Fisher 2022).

In the context of the ongoing puma-livestock conflict, this study aims to describe the puma diet in the area during one year and a half period (Cassaigne et al. 2016; Fernández & Baldi 2014; Iriarte, Johnson & Franklin 1991) and the occurrence of local scavenger species (culpeo fox (*Lycalopex culpaeus*), grey fox (*Lycalopex griseus*), Andean condor (*Vultur gryphus*), southern caracara (*Caracara plancus*) at puma-killed carcasses (Elbroch et al. 2017a; Elbroch & Wittmer 2013a) in order to quantify puma's relationship with wild species (i.e. mesopredators, scavengers and natural prey), and lift the focus beyond its predation of domestic livestock within the anthropogenic Patagonian ecosystem. Next to increasing our knowledge on prey-predator and scavenger interactions in the Patagonian ecosystem, I hope that the outcomes of my study will increase public awareness of the existing food web, and more specifically, of pumas' functional role in this system and its utilization of guanaco. Different stakeholders (e.g., conservation biologists, wildlife advocacy groups, and animal rights activists) are increasingly opposed to the lethal control of wild predators for being ineffective in the long-term (Saitone & Bruno 2020; Yusti-Muñoz & Simonetti 2021). To meet the request for alternative mitigation tools, this study also considers studying the behaviour of livestock guardian dogs (LGDs) in relation to high-risk times for puma predation. The application of LGDs as a prevention and mitigation tool might provide a non-lethal deterrent method for preventing puma attacks on sheep. In the long-term, LGDs might contribute to mitigate puma poaching levels and reduce the economic loses that the puma causes to the ranchers in this system and as observed in other systems (e.g., wolfs (*Canis lupus pallipes*) in Turkey (Akyazi et al. 2018); coyotes (*Canis latrans*), black bears (*Ursus americanus*) and pumas (*Puma concolor*) in USA (Andelt & Hopper 2000); dingoes (*Canis lupus dingo*), red foxes (*Vulpes vulpes*) and wild dogs (*Canis lupus familiaris*) in Australia (Van Bommel & Johnson 2012).

While the relationship between pumas and ungulate prey has been extensively studied in the North Hemisphere, their interactions with ungulate-camelid prey, such as guanaco, remain poorly understood (Donadio et al. 2010), asking for further research to elucidate puma-camelid dynamics and their implications for ecosystem dynamics and conservation. For example, in some contexts, farmers perceive pumas as a threat to livestock and guanacos as competitors for food resources with their cattle. In Canada, a study by Knopff et al. (2010), ungulate females comprised a greater proportion of puma diet during the spring, particularly leading up to and during the calving period, whereas the proportion of ungulate males increased significantly in autumn during the rutting season. This observation supports the idea that prey vulnerability plays a role in puma predation. Understanding the role of pumas in regulating guanaco populations during the breeding season and subsequent months is therefore crucial for managing wildlife-livestock conflicts.

Pumas play a significant role in regulating key ecological factors through population control and facilitation of resources, such as carrion (Elbroch & Wittmer 2012b). Coexistence among competitors can occur by minimizing resource use overlap, preventing interspecific competition (Zúñiga et al. 2017). The term activity level is described as the proportion of time that an animal spends active and it's used as a behavioural and ecological metric (Rowcliffe et al. 2014). However, understanding puma activity levels and the activity levels of the scavengers feeding on carcasses left by pumas in free-living conditions remains challenging due to the complexity of monitoring methods. Moreover, the role of pumas as scavengers themselves is still not enough documented and studied (Elbroch et al. 2017a; Elbroch and Wittmer 2013b). Most predators also scavenge at variable rates, but this has been traditionally ignored in food-web community ecology since predation and scavenging are classically understood as independent processes (Moleón et al. 2014).

Following the hypothesis that pumas hunt the most vulnerable prey, reducing sheep vulnerability, and making them more difficult to hunt than wild prey alternatives, puma-livestock conflicts might be decreased by the use of LGDs for protecting sheep. Although the use LGD has been a widespread practice in various parts of the world and ecosystems for centuries, the study of their effectiveness is relatively recent. LGDs, originating from Europe and Asia, are increasingly common in other regions such as Australia, the USA, Chile, and Argentina. However, while extensively studied in Western countries, our understanding of their performance in South America is still not well-documented. Therefore, to start with gathering new knowledge on LGDs functioning within the Chilean Patagonia and its relation to pumas, I will map dog activity in this pilot study during high-risk times for puma predation.

The overarching goal of Chilean puma conservation efforts is to reach a level of coexistence between livestock production and puma conservation. Findings of this study will aid information to the conservation work of the Patagonian ecosystem and local socio-economic development done by Fundación Cerro Guido Conservación and the international NGO Panthera.

Specifically, this study will cover three topics: (1) the description of the puma diet in the area, (2) the relevance and occurrence of scavengers at fresh carcasses hunted by puma and (3) a small pilot study to better understand the behaviour of livestock guardian dogs (LGD) in open rangeland with sheep.

Even though this study constitutes a small contribution to the hard work carried out over the years by many people in the fascinating south of Chile, I expect that the findings of this study can have a significant positive impact on the winding path towards coexistence and respect between the natural world and human society.

1.1 The puma (*Puma concolor*)

The puma, a species described by Linné in 1771, is an animal belonging to the Felidae family and a terrestrial mammal with a distribution across the entire American continent. Currently, it can be found in seven different biomes, from sea level to 5,800m high, from southern Canada to the Strait of Magellan in Chile (Iriarte et al. 1990). It is the carnivore species that has historically coexisted with the highest number of human colonies. Derived from this fact, it has come to receive more than 80 different names, although it is known more widely as puma, which in the ancient Quechua language means "powerful animal" (Barnes 1960). Based on molecular criteria, today, six subspecies of puma have been described with *Puma concolor puma* being the subspecies present in Chile (Culver et al. 2000).

Globally, the puma is categorized as Least Concern (LC) according to IUCN standards due to its wide range across the American Continent (Nielsen et al. 2015;

Barrera et al. 2010). In addition, it is included in the Appendix II of CITES (Iriarte et al. 2013; Chebez & Nigro 2010; Angelo et al. 2019; Barrera et al. 2010). In Chile, the Regulation of the Hunting Law (No. 19.473) considers the puma as a species “In Danger' in the northern and central regions of the country, and as 'Vulnerable' in the rest of the territory (Iriarte et al. 2013), which is why it cannot be hunted since the 1980s (Barrera et al. 2010). Like observed in many locations (e.g., pumas in the study area), large carnivore species are used as umbrella species for the conservation and protection of other species in a perimeter of hundreds of km^2 (Dickson & Beier 2006), which helps to envision a promising future for the Patagonian fauna and flora.

Puma activity patterns are variable, and although pumas are described mostly as a crepuscular species, many individuals have large peaks of diurnal activity and do not show specific diurnal patterns (Iriarte et al. 2013). Some studies describe them as crepuscular and nocturnal (Cepeda-Duque et al. 2021; Lucherini et al. 2009) while others documented that pumas showed activity levels during night and day with reduced activity during dusk and dawn, displaying a relatively homogeneous activity pattern throughout the day (Zúñiga, Jiménez & Ramírez de Arellano 2017).

1.1.1 The puma in Chilean Patagonia

In Patagonia, pumas are associated with open habitats with a large quantity of prey and reduced number of competitors (Elbroch & Wittmer 2012b). Pumas in Torres del Paine area, where this study is carried out, present the highest density in the world, 5,1 individuals/100km^2 versus the average 1,8 individuals/100km^2 in other areas (Elbroch et al. 2023). In its southernmost distribution, Patagonia, the puma has the largest average body size within its entire geographic distribution (Fernández & Baldi 2014). The flora of the Patagonian steppe, the main ecosystem of the puma in the study area, it is made up of muddy bush (*Mulinum spinosum*), black bush (*Mulguraea tridens*), paramela (*Adesmia boronoides*), calafate (*Berberis buxifolia*) and senecio (*Senecio patagonicus*) (Franklin et al. 1999). In forest environments, which are less extensive, the dominant plant species are the ñirre (*Nothofagus antarctica*) and the lenga (*N. pumilio*) (Franklin et al. 1999). Franklin et al. (1999) lists in his work the following mammals cohabiting with the puma in the territory: culpeo fox (*Lycalopex culpaeus*), grey fox (*L. griseus*), Humboldt’s hog-nosed skunk (*Conepatus humboldtii*) and Geoffroy's cat (*Leopardus geoffroyi*). Wild herbivores such as the guanaco (*Lama guanicoe*) and Darwin's rhea (*Rhea pennata pennata*) are abundant, as well as the omnivorous big hairy armadillo (*Chaetophractus villosus*) and the pichi (*Zaedyus pichiy*) or the scavengers like the Andean condor (*Vultur gryphus*) and the southern caracara (*Caracara plancus*) (Franklin et al. 1999).

1.1.2 Puma hunting and feeding habits

Due to its feeding habits, the puma is considered a generalist predator (Lagos 2021) as well as an opportunistic predator with flexible dietary habits over time (Fernández & Baldi 2014). Pumas have highly dietary flexibility, consuming at least 232 different species across their entire range (Karandikar et al. 2022). Pumas show a higher consumption of larger-bodied prey species as they moved farther from the equator, while the consumption of medium-sized species exhibits the opposite trend, influenced by competition from jaguars (Karandikar et al. 2022). In Chilean Patagonia, its main prey in absolute terms is the European hare (*Lepus capensis*), which makes up to 50% of its diet, while, in terms of biomass, the guanaco (*Lama guanicoe*), contributes up to 25% of the diet (Franklin et al. 1999, Fernández & Baldi 2014; Iriarte et al. 2013). In Torres del Paine National Park, the puma's diet is 92% based on mammals, while the remaining 8% corresponds to birds (Iriarte et al. 2013). Guanaco is the most important prey on puma’s diet in Patagonia, being puma predation the main cause of guanaco mortality (Fernández & Baldi 2014). Understanding prey use and selection it’s crucial for an effective management of the predator-prey system (Clark et al. 2014). Likewise, pumas can consume large amounts of carrion (Iriarte et al. 2013; Elbroch et al. 2017a; Knopff, Knopff & Boyce 2010; Bauer et al. 2005) by feeding on other puma’s prey. They are considered to be facultative scavengers (i.e., animals that are not exclusively dependent on carrion and primarily consume other types of food), which is a rare behaviour among predators (Pereira, Owen-Smith & Moleón 2014).

1.2 The scavengers from the Patagonian steppe

Animal carcasses, are trophically heterogeneous ephemeral energy-rich resources and play a crucial role in shaping the population dynamics of scavengers and decomposers (LaBarge et al. 2022). Moreover, they foster local biodiversity through nutrient deposition and enhance connections within food webs, facilitating energy flow and contributing to the stability and resilience of ecosystems (LaBarge et al. 2022). Animal carcasses are as well microbe-rich resources, representing a nexus for the macro and microbiome, linking predators, consumers, autotrophs and microbiota (Barceló et al. 2022).

Carnivores have a role in top-down control in terrestrial ecosystems, thus, their interactions with the other species are key to understand the community ecology (Zúñiga et al. 2017). Being an apex predator, the puma is a species considered as a modeler or ecosystem engineer. Ecosystem shapers are species that create physical changes both at biotic and abiotic levels, controlling through direct and indirect influences the resource availability for other species/organisms (Barry et al. 2019). In a synthesis, LaBarge et al. (2022) described 543 ecological interactions between pumas and 485 other species, including prey limitation, fear effects and ecosystem effects via carrion provisioning.

When a puma leaves a carcass, it’s creating a new habitat and food source for other species that are dependent on the carrion in all or some stages of their life cycle, thereby facilitating the transfer of energy among all trophic levels (Barry et al. 2019). Pumas lose or abandon on average 39% of their prey to competitors and scavengers (Elbroch et al. 2014). At least 65 vertebrate and 215 invertebrate scavengers are linked to carrion provided by pumas (LaBarge et al. 2022). Specifically, in a study in Patagonia, pumas provided more than 200kg of edible meat/month/100km^2 to a diverse scavenger community (Elbroch and Wittmer 2012b).

Pumas are considered to be solitary carnivores. However, Logan & Sweanor (2001) provided the first insights of interactions among pumas at food catches. Recent studies from the Grand Teton National Park, USA (Elbroch & Quigley 2016; Elbroch et al. 2017b) and a scientific note from Torres del Paine National Park, Chile (Lagos et al. 2017) documented social interactions in this species. Although it’s known by the locals that in the study area that adult pumas share carcasses with other pumas, this study aims to document this behaviour to contribute to the knowledge of the social interactions in pumas.

1.3 Livestock Guardian Dogs and their roll protecting sheep in Patagonia

Grazing animals, both wild and domestic species, have a large positive impact in preserving biodiversity of permanent meadows, keeping and developing a variety of plants and animals associated to those (Rochon, Duval & Goby 2009). In Patagonia, there are two wild grazers, the guanaco (native) and the European hare (introduced). The main domestic grazers are sheep and cows. However, in areas with carnivores and grazing animals, carnivore predation on livestock triggers their persecution and killing and can even encourage retaliation killing (Yusti-Muñoz & Simonetti 2021). Predators can affect their prey directly (by killing it) and indirectly (so called non-consumptive effects) by creating a ‘landscape of fear’. The landscape of fear describes the phenome of altered prey behaviour in relation to predator activity and the corresponding risk of predation (i.e., avoiding risky places at risky times) (Moll et al. 2017; Gaynor et al. 2019), affecting their ability to survive and breed successfully (Gingold et al. 2009; Yusti-Muñoz & Simonetti 2021). The time a prey spends avoiding predators can result in deterioration of body condition due to insufficient time spent feeding (Gingold et al. 2009; Webber et al. 2015), affecting the fitness of the animal.

In systems with large carnivores, LGDs are considered one of the most effective and valuable tools to prevent predation on livestock (Webber et al. 2015; Zingaroa et al. 2018). These dogs have a history of more than 2000 years in Europe and Asia protecting domestic animals from natural predators and thieves (Lieb et al. 2021; Van Bommel & Johnson 2012; Van Bommel & Johnson 2016; Vercauteren et al. 2008; Gehring, VerCauteran & Landry 2010). Nowadays, there are at least 40 breeds of LGDs (Gehring, VerCauteran & Landry 2010), each of them with unique characteristics to defend livestock.

LGDs can effectively protect a wide range of livestock species from several types of predators in intensive or extensive systems (Van Bommel & Johnson 2016; Van Bommel & Johnson 2012). For example, LDGs are used in Namibia to protect livestock from cheetahs, in France and Switzerland to protect livestock from wolfs, lynx, and bear, or in the USA to protect livestock from wolves and pumas (Van Bommel & Johnson 2012). They are also used for the same purpose in Romania, Spain, Finland, South Africa (Lieb et al. 2021). Traditionally, shepherds keep the flock together and provide backup for a group of LGDs (Van Bommel & Johnson 2012). In Chile, dogs must work unsupervised in bast areas. As is the case in Australia (Van Bommel & Johnson 2012), flocks or herds are managed with low input, and low-intensity monitoring is effective in predator control, which makes livestock more vulnerable to predation.

In my study, LGDs were a mix of two breeds: Great Pyrenees (Spain and France) and Maremma (Italy). Both Great Pyrenees and Maremma are valued for being effective in protecting livestock, being an economic asset, showing no aggression towards people, being less likely to harm livestock than other breeds and exhibiting behavioural maturity at an early age (Vercauteren et al. 2008; Bellini et al. 2022).

2. Research Objectives and Hypothesis

2.1 Research Objectives

1. Conduct a detailed description of puma hunting habits and diet focussing on guanaco, using observations of eight GPS collared puma adults (five females and three males).

2. Quantify the diurnal and nocturnal occurrence of macro and meso scavengers at fresh carcasses hunted by pumas using camera traps and acknowledge the roll of pumas as facultative scavengers.

3. Describe livestock guardian dogs’ spatial-temporal behaviour in open rangeland in the presence of sheep, in a landscape dominated by puma, conducting a small pilot study.

2.2 Research Questions and Hypotheses

Identification and quantification of puma predation events and dietary habits

a) Pumas are targeting young guanacos (<1 year old) during the guanaco calving season (November-February).
b) Pumas prefer hunting at crepuscular hours (dusk and dawn).
c) When a puma hides a carcass, the food lasts longer and therefore the puma can feed on its prey for more days. When there are signs of the presence of scavengers in a carcass, this will result in the puma feeding on its prey for fewer days.

Scavengers at predation sites

a) Different scavenger species utilize the carcass at different times of the day, following their main feeding times.
b) Pumas have a preference for scavenging at crepuscular hours (dusk and dawn).

Livestock Guardian Dogs

a) LGDs express different spatial-temporal behaviour during the peak of puma activity, dusk and dawn, compared to the rest of the day.

3. Material and methods

3.1 Study area

The data collection for the research objectives of this study mainly took place at the ranch Estancia Cerro Guido and adjacent ranching properties. This ranch, is located in the commune of Torres del Paine (51°03’54’’S/72°32’46’’W), province of Última Esperanza, Magallanes and the Chilean Antarctica Region. It is bordering to the west with Torres del Paine National Park and other ranches, and to the east with Argentina, on a distance of 12km to each reference point (*see Figure 1*). Estancia Cerro Guido is the largest livestock ranch in the region, comprising 100.000ha. In Estancia Cerro Guido, extensive sheep farming, tourism and conservation activities take place simultaneously, making it a good case to study different aspects of puma ecology and typical interests in local land use. In the area, there are two population settlements, one smaller 'Entre Lagos' and another larger 'Villa Cerro Guido', of 60 inhabitants, which is the center of the tourist activities due to the location of an hotel. Most of the data collection took place between Toro Lake and Sarmiento Lake, in Sierra del Toro (100 m.a.s.l). The habitat is Patagonian steppe, dominated by xerophytic vegetation, including *Mulguraea tridens* and *Festuca spp*. (Maynard 2014), with cold steppe climate (cold to very cold winters, and temperate to warm summers).

Figure 1. Location of the study area in Chilean Patagonia, southern South America.

3.2 Puma captures

Puma captures took place in July 2022 and March 2023 (*see Table 1*). During July, seven pumas where captured (four females and three males) while in March, only one puma (female) was captured. Four collars from pumas captured in July (one female and three males) stopped working eventually before the end of the battery life length for unknow reasons. Captures were led by the specialized Panthera Puma Project team under the recommendations of the American Society of Mammalogists (Sikes, R.S. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97(3): 663-688.). The GPS collar device chosen was Lotek Litetrack Iridium HD (*see Figure 2*), with a drop-off system that automatically release the collar after 2 years of installation. The GPS is programmed to calculate positions every 1hour intervals and sending the information every 8 hours.

Figure 2. Female adult puma, Camila, with a GPS collar resting. Torres del Paine National Park area, south Chile (Ana Reverter 2023).

All animal handling and captures were approved by the Chilean Agricultural and Livestock Service SAG (DNR 7325/2022). Captures took place using between two and three trained hounds. Dogs helped to pack pumas in places such as rocky caves, bushes or ravines, where those were immobilized with a O_2-powered dart gun that injected a dart with a mixture of Butorphanol, Azaperone and Medetomidine (BAM). Immobilization was reversed with a mixture of Atipamezole and Naltrexone.

Table 1. Information on the eight GPS-marked adult pumas that have been monitored during the study in Torres del Paine, Patagonia, south Chile, 2022-2023.

Puma ID	**Name**	**Sex**	**Age*(years)**	**GPS Collar ID**	**Monitored days**	**Nr of identified predation events**
P1	Cami	F	+8	150181	517	70
P2	Limia	F	+2	150188	515	37
P3	Cuevas	M	5-6	89222	144	5
P4	Lenga	F	2	150714	509	20
P5	Caitlin	F	4	150712	58	2
P6	Juan José	M	2	150708	329	13
P7	Toro	M	6-7	150707	310	16
P8	Aoni	F	2	150709	248	9

*At the time of capture

3.3 Data collection

3.3.1 Identification and quantification of puma predation events and dietary habits

The data was collected between early June 2022 and late November 2023 by the Panthera Puma Project team, the Fundación Cerro Guido Conservación team and myself (period September-November 2023) (*see Figure 3*). The collection of data associated with identified predation and puma scavenging events was conducted through a protocol linked to the EarthRanger platform (EarthRanger, 2024). EarthRanger managed and stored the collected GPS data. The GPS collars calculated individual's position every hour, and sent the locations in near real-time (i.e., every eight hours) to EarthRanger. Among other functions, EarthRanger mapped individuals' locations chronologically and automatically generated clusters where two or more GPS locations occurred within a 150m radius over a 4-hour period or longer (Anderson & Lindzey 2003). Puma diet was determined by GPS kill sites in many studies (Knopff et al. 2010; Knopff et al. 2009; Clark et al. 2014; Cassaigne et al. 2016; Anderson & Lindzey 2003). The appearance of a cluster in the program indicated the potential occurrence of a predation or scavenging event by the collared puma, a den (in the case of females), or a resting site. After 24 hours of inactivity by the puma in that specific delimited area, EarthRanger automatically closed the cluster. In simpler terms, the puma had to stay in the same area for at least 4 hours, and the cluster ended when the puma did not visit it for a day.

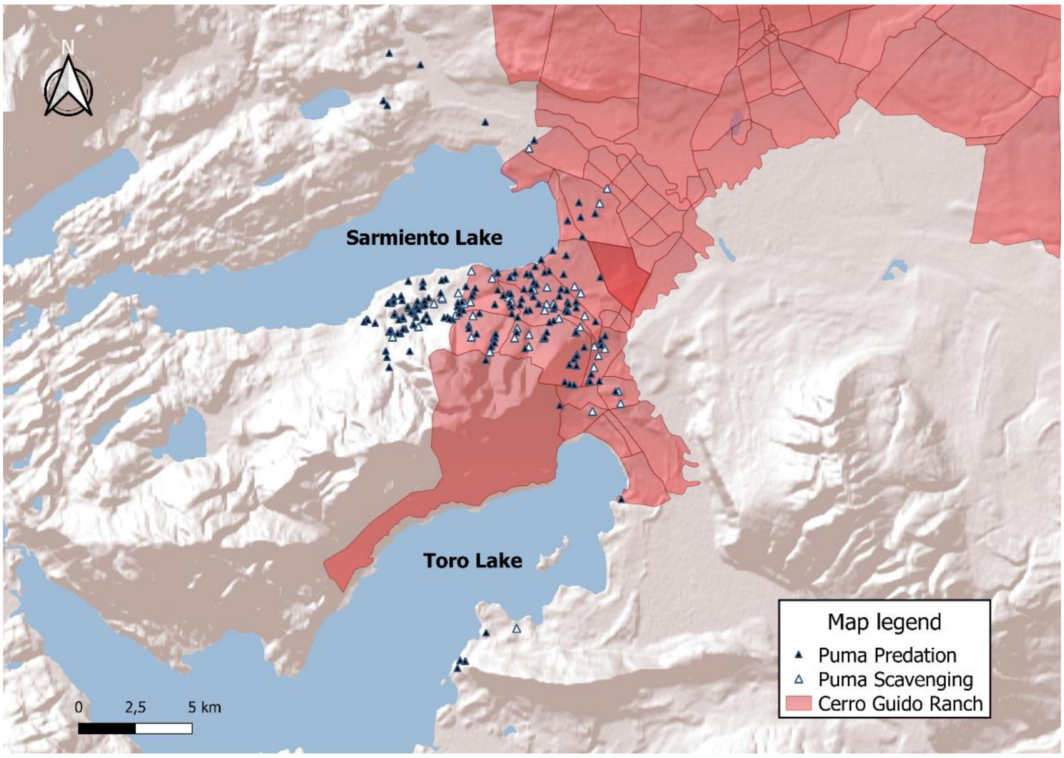

Figure 3. Map from the detected puma predation and scavenging events analysed on this study inside and outside Cerro Guido Ranch. The predation events were detected using the EarthRanger software. Location Torres del Paine, Patagonia, south Chile.

The protocol for detecting predation and scavenging events and subsequent data collection involves several steps. First, EarthRanger sends users a daily file containing the point cloud forming each cluster from the past weeks, including various points associated with the same event and thus sharing the same code. Second, this file is imported into the Garmin BaseCamp app to transfer the information to the Garmin GPS device used in the field. Additionally, this file must be imported into the GaiaGPS mobile application. Third, using the GPS and GaiaGPS support from the mobile device, the cluster is located in the field, and the corresponding data is collected if it is a predation event or a scavenging event (e.g., type of prey, prey sex, prey age, georeferenced location, date and time, habitat type, scavenger signs, and if the carcass is hidden or not). All locations forming the point cloud of the cluster must be visited in search of as many clues as possible (e.g., sometimes the puma or a scavenger moves the prey's skull, which is crucial for age or sex determination, as in the case of guanacos).

It is essential to clarify that clusters are visited once closed by the app, as visiting them while still open could result in changes to their characteristics, rendering the data collection unreliable (for the placement of camera traps in fresh carcasses in the next section, active clusters will be visited). Through practical experience, it has been observed that clusters with a relatively low number of fixes, between five and

13, are often associated with puma resting sites, while those exceeding 35 fixes may indicate a predation event. Dens typically consist of a larger number of fixes.

Once all the information associated with each predation and scavenging event is collected in the form of a report, it is downloaded from EarthRanger to a spreadsheet for initial screening. For this study, reports lacking essential information, such as the puma ID associated with the event or its coordinates, were excluded. Additionally, only reports where the reporting individual had a certainty level between 75% and 100% that the GPS-collared puma killed the animal were referred as predation event (*see Table 2*), otherwise, the event was referred as scavenging. Because I focused on predation events for this part of the study, I did not considered reports believed to be associated with scavenging by the puma in for this analysis.

Table 2. Puma prey species registered in the on-field predation reports (n=170) and the share (%) of reports per species. Data taken between July 2022 and November 2023 in Torres del Paine, Patagonia, south Chile.

Species	**Share (%)**
Guanaco	78,2%
European hare	7%
Domestic cow	5,2%
Rhea	3,5%
Domestic sheep	3,5%
Domestic horse	1,2%
Andean condor	0,6%
Upland goose	0,6%

I focused my analysis on the prey species guanaco, because it is the main puma prey item next to hare in Patagonia. Moreover, it is the prey species that was most detected in predation reports. To test my hypothesis that pumas will target young guanacos (<1 year old) during the guanaco calving season (November-February), I grouped guanacos using the following age classification: young (< 1 year) (*see Figure 4*), juvenile (1-2 years) and adult (> 2 years). During field-work, guanaco age was determined based on dentition and body size.

Figure 4. Three young guanacos (<1 year old), Lama guanicoe, in the study area, Torres del Paine, Patagonia, south Chile (Ana Reverter 2023).

The predation reports were also utilized to determinate the time period where pumas hunt and scavenge the most (day, dusk and dawn or night). The average duration of the daytime during the study, understood as the period between sunrise and sunset, was 12,15 hours ± 2,89 hours. On the other hand, the average during of the twilight period, understood as the dawn period plus the dusk period, was 4,49 hours ± 1,08 hours. The night period had an average duration of 7,39 hours ± 3,80 hours.

3.3.2 Scavengers at predation sites

To address this research question, two different data sets were taken into account. Data came from installing camera traps at fresh carcasses of puma prey and from scavenging events reports (see section 3.3.1). Within the events, for this part of the analysis, those considered as 'scavenging events' were taken into account, that is, those in which it was considered that the puma had not hunted its prey, but was scavenging in that carcass hunted by another puma. This was determined by the confidence interval with which the puma hunted the animal. If this interval was from 0 to 50%, both inclusive, the event was considered a 'scavenging event' and not a 'predation event'.

Camera Trap dataset

Data on scavenger occurrence at predation sites derived from camera traps recordings at fresh puma preys' carcasses. A total of eight camera traps where deployed, recording during a total period of 69 camera trapping days. To quantify which species scavenged on puma-killed carcasses over time, camera traps (CT) were installed on fresh carcasses as soon as possible after detecting a predation event (*see Table 3*). I used CTs brand Browning, models Strike Force PRO DCL BTC-5DCL and Dark Ops XD BTC-6PXD (*see Figure 5*). The Earth Ranger app was checked daily, multiple times a day, to identify the formation of new clusters, since the goal was to identify active clusters as soon as possible. A cluster could be primarily associated with a resting site, a predation event, or a den (for females). Once there was minimal certainty that it could be a predation event (for instance, if there were indications that the GPS-collared puma visited the location on more than one occasion or spent extended periods there), and weather conditions allowed, the site was visited to confirm a predation event and deploy a CT. On average, the CT units were placed between 21.5 and 76 hours after the onset of the predation event.

Regular field checks were conducted on the CT units to ensure they had not been displaced or damaged, and to verify the proper functioning of the rechargeable 3000mAh battery and memory cards. The devices were left in place, recording activity around the carcass in 20-seconds videos, with 30-second intervals (*see Appendix 1* to visualize all the CT settings) for a minimum of one day and a maximum of 12 days. The variability in recording days was primarily influenced by the feasibility of capturing the activity around the carcass, as it was sometimes moved by the puma or scavengers over considerable distances, making it challenging to relocate.

Table 3. Information regarding the eight Camera Traps (CTs) installed in this study at fresh carcasses from puma preys: CT code, number of days that the CT was installed at each site (camera trappings days), type of prey and habitat type where the carcass was found. The carcasses were found using the EarthRanger platform (CTXXXX) for pumas with GPS collar or spontaneously during field-work (NC CTXXX). Torres del Paine, south Chile, 2022-2023.

CT code	Camera trapping days	Prey	Habitat
CT4355	11,71	Guanaco	Steppe
NC CT001	0,79	Guanaco	Steppe
NC CT002	5,03	Lesser rhea	Steppe
CT4485	12,03	Guanaco	Steppe
CT4521	12,25	Guanaco	Native Forest
CT4675	9,16	Guanaco	Steppe
NC CT003	10,93	Guanaco	Steppe
CT4690	6,61	Guanaco	Steppe

The total of camera trapping days was 69 days. CT were classified as being located at collared-puma carcasses (CTX, as identified by EarthRanger, see section 3.3.1) and non-collared-puma carcasses (NC CTX, i.e., carcasses hunted by pumas found spontaneously).

Figure 5. Camera trap from the study, pointing a guanaco carcass, Lama guanicoe, in a steppe-like habitat (Browning Dark Ops XD BTC-6PXD). Torres del Paine National Park area, south Chile (Ana Reverter 2023).

Additionally, three CT units (NC CT 0001, NC CT 002, and NC CT 003) were opportunistically deployed when fresh carcasses were encountered in the study area. When encountered a fresh carcass, the interpretation of the scene was key to make sure that the predator was a puma. Some specific indicators for puma predation on this region, where there are no other predators of a similar size, are the following: open sternum with consumption of the surrounding cartilage, absence of red viscera, fang marks on the nape or trachea, highly localized hematomas under the skin only in the bite area, removed stomach, and prey dragged towards a shrub area. The CT units were positioned approximately 3 meters away from the carcass when terrain and vegetation allowed it.

Puma scavenging reports dataset

When visiting a predation site (following the methods outlined in the previous section, 3.3.1), the designated data collector assigns a value reflecting the certainty percentage for a given predation event (0, 25, 50, 75, 100%, where 0%

unequivocally corresponds to scavenging, and 100% corresponds to absolute certainty that the GPS-collared puma hunted the animal). The certainty percentage is determined based on the judgment of the individual filing the report, taking into consideration factors such as the time the GPS-collared puma spent at the predation event according to the EarthRanger monitoring app, CT images if available, on-site observations, and other field observations. To quantify the usage of carcasses by pumas (i.e., scavenging), I considered reports with 0, 25, and 50% certainty that the given puma had killed the animal (scavenging events), since this low certainty can be interpreted as scavenging behaviour instead of hunting behaviour (*see Table 4*).

Table 4. Species registered in the puma scavenging reports (n=51) as share (%) of reports per species. Data taken between July 2022 and November 2023 in Torres del Paine, Patagonia, south Chile.

Species	**Share (%)**
Guanaco	80%
Domestic cow	7,8%
Lesser rhea	2,1%
Domestic sheep	5,9%
Big hairy armadillo	2,1%
Humboldt’s hog-nosed skunk	2,1%

3.3.3 Livestock guardian dog behaviour in open rangeland with sheep

To study the behaviour of LGDs in open rangeland with sheep, three GPS collars from the DigitAnimal company were acquired and rotated on seven dogs (five males and two females) (*see Table 5*). The data was gathered between early October and late November 2023. These collars, equipped with long-lasting batteries, operate on SigFox coverage and calculated the dog's position, ideally every half an hour. This data was stored in the DigitAnimal application and the specialized EarthRanger software, and it can be near real-time visualized using either of these two platforms. For data analysis, the information associated with each collar was downloaded through EarthRanger.

Table 5. Information regarding the seven GPS-marked adult LGD that have been monitored during the study in Torres del Paine, Patagonia, Southern Chile, 2022-2023.

Name	**Sex**	**Age**	**Monitored days**	**Number GPS points**
China	F	+8	19	258
Coigüe	M	2	53	422
Goliat	M	4	6	163
Igore	M	3	8	74
Membrillo	M	2	4	94
Paloma	F	4	14	242
Punto	M	3	30	113

Initially, a one-week test of collar functionality (local time zone settings and correct geographical location) and the applications functionality was conducted. To test the performance of the collars, they were installed on a car that was driven through different areas of the study area. Once their effectiveness was confirmed, three adult dogs working in fields with sheep at that time were selected. For this pilot study, it should be noted that the management of LGDs is closely related to the sheep herding practices on the ranch, which was prioritised. Thus, the location and number of dogs assigned to a field depended on the needs of the ranchers. The collars were rotated among a total of seven dogs according to these needs, as dogs were sometimes moved from one field to areas without coverage or sent to kennels for a shorter or longer period, so collars were change to other individuals.

Collar installation was straightforward as the dogs were perfectly accustomed to people. A person would fit the collar to the dog, ensuring that the compartment with the GPS and battery was centered to the left of the animal's neck, and the counterweight hanging from the neck. It was also checked that the length of the collar and the counterweight did not hinder the animal and that the dog could move freely (*see Figure 6*).

Figure 6. Male livestock guardian dog (LGD) from the pilot study, Membrillo, wearing a GPS collar from Digit Animal. Torres del Paine National Park area, south Chile (Ana Reverter 2023).

The DigitAnimal application and/or EarthRanger software were checked several times a day by myself and the field technicians to verify the proper functioning of the collars and the location of the dogs, detecting any anomalies. For example, if a dog was detected outside the assigned field in an area without sheep for more than a day, it was picked up by a car and returned to its original position. In addition, the dogs were visited several times a week to check their well-being, feed them with food and water and ensure that the collars were correctly placed.

3.4 Data analysis

3.4.1 Identification and quantification of puma predation events and dietary habits

The analysis of predation reports generated during field-work had three different purposes (*see Table 6*). In first place, to explore the consumption of young guanaco (< 1 year) by pumas along the annual cycle and to test for predation patterns linked to the guanaco calving season (November – February). Secondly, predation reports were used to map the relationship between that a carcass was hidden by the puma and the days a given puma took to consume it as well as to study the relationship between the presence of scavenger signs around the carcass and the days that the puma took to consume it as well. Thirdly, timestamps of the reports were used to investigate if pumas had a preference for hunting during the crepuscular hours, dusk and dawn.

To better understand the predation patterns on guanaco, a dataset of 133 predation events was categorized based on whether they occurred inside or outside the guanaco calving season (i.e., November to February; Bas and González 2000), resulting in a binary variable (0 for outside, 1 for inside). Additionally, to discriminate young guanacos from older guanacos, while accounting for repeated measures and temporal autocorrelation (i.e., considering several predation events from the same puma), I added Puma_ID and the month of each specific predation event as predictor variables. Rows with missing values were removed. To allow a non-linear relationship between the month and the odds of targeting young guanacos, I applied a smooth term on 'month' using a *Generalized Additive Mixed Model* (GAMM, R package 'gamm4', (Wood and Wood 2017)) with a binomial error distribution (presence or absence young guanacos), whereas I added 'Puma_ID' as a factor variable. The model assesses the relationship between the binary response variable (Young) and smoothed terms for the month and the individual pumas.

To test the hypothesis that puma usage time of a given carcasses depends on hidden carcasses and scavenger signs at the carcass, I applied a *Multiple Linear Regression Model* (MLRM**,** R package 'lme4', (Bates et al. 2015). Initially, both predictor variables had three levels (Yes/No/Unknow), but the 'Unknow' values were removed to perform the model and to address my hypotheses. To account for possible differences among puma individuals but to avoid zero variance, the individual pumas (Puma_ID) were taken into account as a predictor variable. I first applied Puma_ID as a random effect but this model structure resulted in an estimated value of variance that was zero. Thus, the predictor variables were 'hidden_carcass' (Yes/No) and 'scavenger_signs' (Yes/No) and Puma_ID. The response variable (puma residence time at a given carcass) was 'log-transformed' to ensure normality.

In order to associate the time that a puma predation event had taken place within the different times of the day, I categorized predation events into three groups according to their timestamp using the R package 'suncalc' (Thieurmel, Elmarhraoui & Thieurmel 2019): 'day' (spanning between sunrise and sunset), 'dusk/dawn' (dusk, understood as the period between sunset and night and dawn, defined as the period between nightEnd and sunrise) and everything else was classified as 'night'. The 'suncalc' function takes into account the geographical location, in this case, 'America/Punta_Arenas', to adjust variables based on changes in day length for each date at a given location.

Moreover, frequencies of predation events for each time category were calculated using the following formula ($n_{\text{predation events}}$=170):

$$Frequency_{predation\ time\ category} = \frac{Nº\ predation\ events\ per\ predation\ time\ category}{Total\ predation\ events} \times 100$$

Using the formula ($Frequency_{predation\ time\ category} / nhours\ per\ time\ category$) the frequency with which a puma hunts in each time category weighted by the duration of that category in hours was obtained.

Table 6. Summary of the models (Generalized Additive Mixed Model, Multiple Linear Regression Model and Linear Mixed-Effects model) used to test three different hypotheses including the specific data source linked to each one for the study.

Hypothesis	Model structure	Model	Dataset
Pumas target <1 years old guanacos (Nov-Feb)	Young[a] ~ s(month[b]) + as.factor(Puma_ID[c])	*Generalized Additive Mixed Model with* binomial error structure	Information derived from puma predation on-field reports on guanaco collected using Earth Ranger (n=133)
Puma carcass usage time depends on if the hidden carcass and scavenger signs	log (hours_difference + 1[d]) ~ as.factor(hidden_carcass[e]) * as.factor(scavengers_signs[f]) + as.factor(Puma_ID[c])	Linear regression	Information derived from puma predation on-field reports collected using Earth Ranger (n=170)

LGD are more active during dusk and dawn	log (stepmhr + 1[g]) ~ as.factor(dog_activity[h]), random = ~1|Dog_ID	Linear mixed model	Seven LGD equipped with GPS collars from Digit Animal

[a]Young guanaco (1) or not young guanaco (0)

[b]Month where the predation occurred

[c]Different pumas from the study

[d]Hours that the puma spent at a given carcass (log-transformed)

[e]Hidden carcass by puma (Yes or No)

[f]Scavenger signs at the carcass (Yes or No)

[g]Speed (m/h) (log-transformed)

[h]Three levels Night/Dusk and Dawn and Day

[i]Different LGD from the pilot study

3.4.2 Scavengers at predation sites

The videos from the eight camera traps placed at fresh carcasses were viewed for data extraction. Species were identified using ‘A Wildlife Guide to Chile. Continental Chile, Chilean Antarctica, Easter Island, Juan Fernández Archipelago’, by Sharon Chester (2008).

The objective of viewing the videos was to record the occurrence of the different species of scavengers at different times of the day (*see Appendix 2*). In a spreadsheet, any active individuals were counted in 15-minute time intervals taking into account the species. This task was carried out cumulatively during all the days in which observations were made. Subsequently, using the R ‘camtrapR’ package (Niedballa et al. 2016), the species activity plots (scavenging activity) and the two-species activity plots overlap coefficient (Dhat1) were calculated for the main three scavenger species: puma, grey fox and southern caracara. The overlap coefficient, is a measure of similarity or overlap between two probability distributions. It is calculated as the minimum of the proportions of the two distributions in the overlapping region. It ranges from 0 to 1 where 0 indicates no overlap and 1 indicates complete overlap between the distributions.

In order to associate the time that a puma scavenging event had taken place within the different times of the day, I categorized events as for the predation events into three groups (see section 3.4.1): 'day', 'dusk/dawn' and 'night'.

Frequencies of scavenging events for each time category were calculated using the following formula ($n_{scavenging\ events}$= 51):

$$Frequency_{scavenging\ time\ category} = \frac{N^{o}\ scavenging\ events\ per\ scavenging\ time\ category}{Total\ scavenging\ events} \times 100$$

Using the formula ($^{Frequency_{scavenging\ time\ category}}/_{nhours\ per\ time\ category}$) the frequency with which a puma scavenges in each time category weighted by the duration of that category in hours was obtained.

3.4.3 LGD behaviour in open rangeland with sheep

To map the activity levels of LGDs during the peak activity hours of pumas, specifically dusk and dawn (i.e., periods with a higher risk of attacks on livestock) and to detect possible differences, as well as to compare LGD activity with the rest of the day (*see Table 6*), I associated dog activity patterns with different times of the day. As before, I classified GPS positions into three categories (see section 3.4.1): 'day' 'dusk and dawn' and 'night'. Activity was measured using the calculated speed (m/h) between consecutive locations using the R package 'adehabitatHR' (Calenge 2016).

To test for higher dog activity during high risk for puma predation, I applied a *Linear mixed-effects model* (LMM, R package 'nlme', (Pinheiro et al. 2021)) *fitted using the Restricted Maximum Likehood (REML) method*. To ensure normality, the response variable was log-transformed. The predictor variable was categorical (i.e., "as.factor (dog_activity)" with three levels 'day', 'night', and 'dusk_dawn'). Dog_ID was assigned as random effect to acknowledge that there might be variability in the baseline probability of the outcome across different LGDs as well as for repeated measures.

To quantify the average daily movement of LGDs, the mean Euclidean distance travelled in meters between consecutive positions was calculated for each of the seven dogs using the R package 'geosphere' (Hijmans et al., 2017).

For all data analysis, RStudio version 4.2.1 was used.

4. Results

4.1 Identification and quantification of puma predation events and dietary habits

Pumas targeted more young guanacos during the guanaco calving season (i.e., November to February) and even until May (t (3.014) = 4.1, p = 0.0017) (*see Figure 7*). The results also suggest that some pumas such as 'Juan José' (t (3.014) = -2.1, p = 0.0390) and 'Lenga' (t (3.014) = -2.3, p = 0.0239) have a higher impact compared to Caitlin and other pumas, acknowledging individual dietary preferences and hunting strategies.

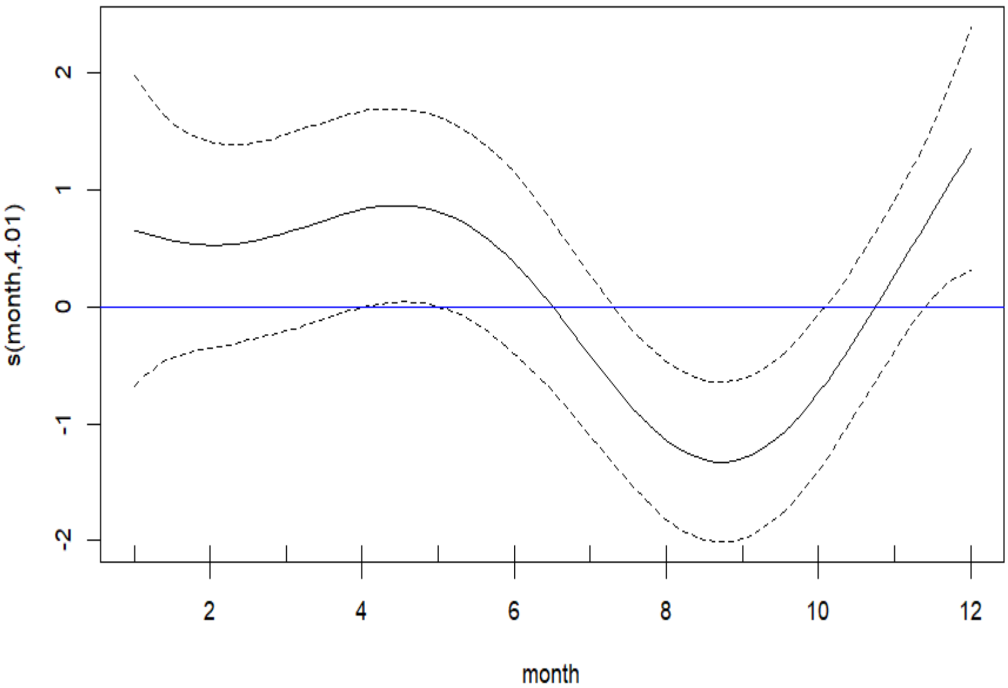

Figure 7. Likelihood of targeting young guanacos by GPS-collared pumas (n=8) in relation to the month of the year as predicted by the generalized additive mixed model (GAMM) in the area Torres del Paine, south Chile, 2022-2023. Values above zero (blue line) indicate higher likelihood, values below zero lower.

Derived from the predation reports (n=170), I found that puma predation frequency was relatively higher at night in relation to other times of the day (*see Table 7*). Nevertheless, taking into account that most of the predation events happened at the verge of dusk and dawn (within half an hour around the astronomic calculation of dusk and dawn), I extended the dusk and dawn period with a half an hour margin (extended dusk and dawn). Using extended dusk and dawn periods, results shifted towards pumas hunting predominantly during dusk and dawn (see calculations in section 3.4.1).

Table 7. Frequency of recorded puma predation events during a given time period (day, dusk/dusk or night) given as number of attacks divided by the average number of hours a given category last (f/nh). Extended frequencies describe frequencies including 30 minutes from the astronomic dusk and dawn. Torres del Paine National Park, south Chile, 2022-2023.

Predation time category	**f/nh**	**f/nh$_{(extended)}$**
Day	2,12	1,28
Dusk and Dawn	5,50	12,05
Night	6,68	4,07

For both scenarios, all pumas varied in their attack's frequencies for the three-time categories. For all pumas, attacks occurred less often during the day (*see Figure 8*).

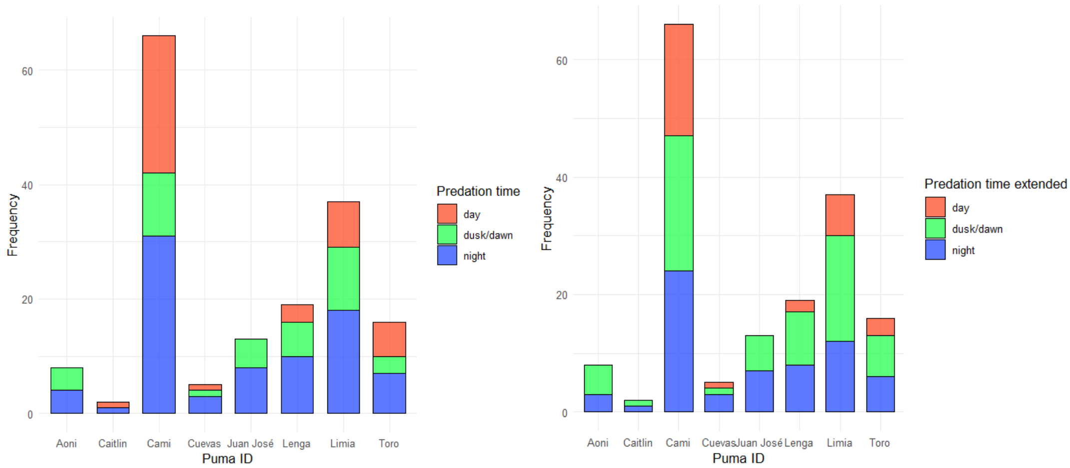

Figure 8. Puma predation events (n=170) classified depending when they had place into three different time categories: day (from sunrise to sunset), dusk and dawn (from sunset to night and from nightEnd to sunrise) and night for the rest of the time, according to the R package suncalc (on the left). Same graph on the right but using an extended version of periods dusk and dawn with half an hour margin. The 'x' axis shows different puma individuals (Puma_ID) and the 'y' axis the frequency with which these attacks took place in the different temporal categories. Area of Torres del Paine National Park, south Chile, 2022-2023.

In the first scenario, pumas Aoni and Juan José did not carry out attacks during daylight hours. In the second scenario, including the extended dusk and dawn periods, in addition to Aoni and Juan José, the puma Caitlin also did not make attacks during the day.

A puma spent on average 41,8 hours ± 26,9 hours feeding on a carcass (n=170). When a carcass was hidden by a puma (with plant cover, soil, leaves...), the animal spent more time feeding on it (t (163) =3.2, p=0.002). From the 170 detected predation events, in 30% of the cases, the carcass was hidden by the puma (*see Appendix 3*).

Conversely, I did not find any evidence that the presence of scavenger signs around the carcass, affected the number of the days that a puma fed on the carcass (t (163) =1.7, p=0.098) (*see Figure 9*).

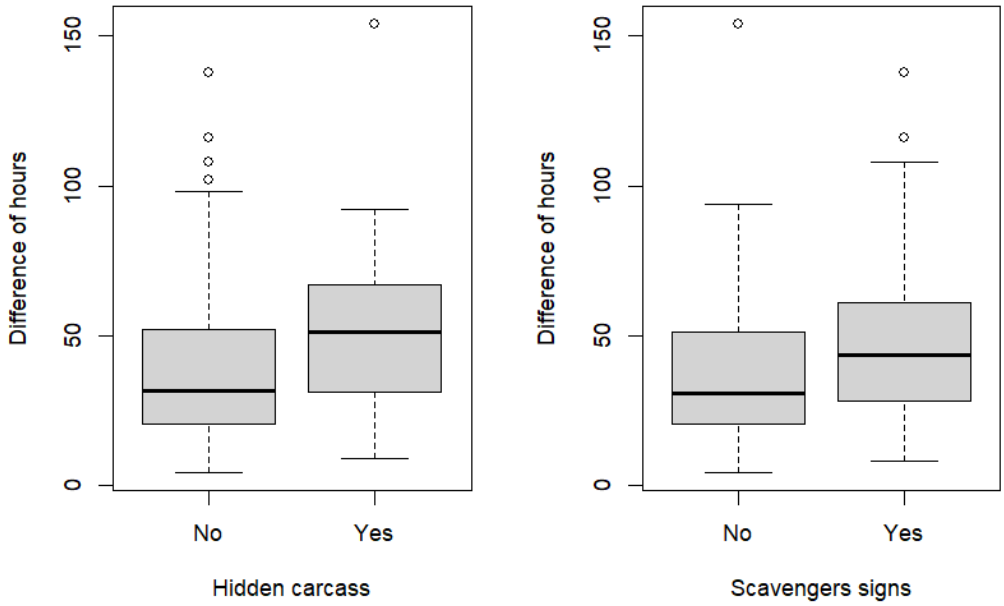

Figure 9. Relationship between the fact that a fresh carcass hunted by a puma was hidden and the hours that the puma spent feeding on it (left) and relationship between the presence of scavenger signs at the carcass and the hours that the pumas fed on it (right) (n=170) as predicted by a Multiple Linear Regression Model (MLRM) model, Torres del Paine, south Chile, 2022-2023.

4.2 Scavengers at predation sites

The scavenger species detected in both camera traps at fresh carcasses and predation reports were almost coincident. Both methods registered grey fox, big hairy armadillo, southern caracara, chimango caracara, black-chested buzzard-eagle, white-throated caracara, Andean condor, culpeo fox and puma. However, the predation reports, also detected Humboldt's hog-nosed skunk and austral blackbird.

On the camera trap recordings, adult pumas where registered sharing carcasses (*See Figure 10*). The eight pumas from this study, were reported scavenging.

Figure 10. Three adult pumas (Puma concolor) sharing a guanaco (Lama guanicoe) carcass that was hidden under plant material. The guanaco was hunted by a GPS collared-female on the left (Camila) and was being shared with a male (middle) and another female (right). The two un-collared pumas were scavenging from the collared puma prey. The image was capture by a camera trap in Torres del Paine National Park area, south Chile (Ana Reverter 2023).

Out of nine scavenger species, only three, the puma, the grey fox and the southern caracara exceed the 100 registers in the camera traps, while the other six species, had less than 20. Therefore, the data exploration was focussed on the three main scavenger species (*see Appendix 4*). Interference behaviour is critical to determine the structure of biological communities, as dominant species can displace subordinate species and model their interaction with the environment (Zúñiga et al. 2017).

Pumas showed a crepuscular and nocturnal scavenger activity, with no diurnal activity. Grey foxes had a crepuscular and nocturnal behaviour but with diurnal activity as well and southern caracaras showed mainly diurnal behaviour with some crepuscular activity. The overlap index (Dhat1), percentage of hours that two species share scavenging, showed that pumas and grey foxes had an overlap of 72% with the overlap in carcass utilization taking place mainly between 18:00 and 8:00 (*see Figure 11*). The overlap index between pumas and southern caracara was of 25%, with the overlap taking place mainly between 05:00 and 09:00 and 17:00 and 24:00 (*see Figure 12*). The overlap index showed that grey foxes and southern caracara had an overlap of 25%, with the overlap taking place between 05:00 and 24:00 (*see Figure 13*).

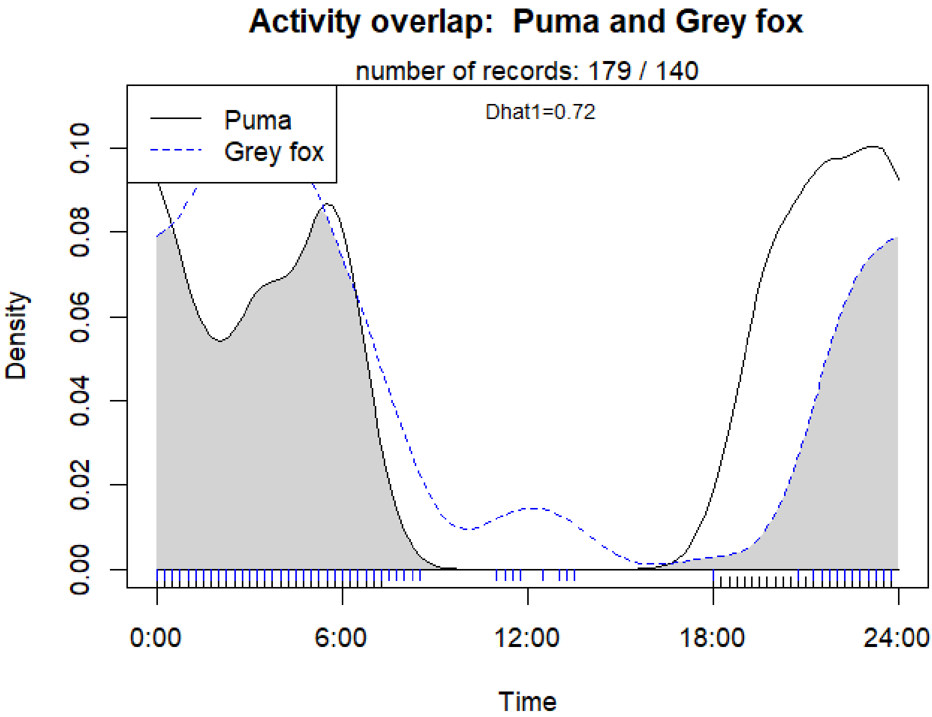

Figure 11. Puma (Puma concolor) and grey fox (Lycalopex griseus) scavenging activity plot over time and activity overlap (Dhat1) between both species. Overlapping time slots are shown shaded in grey. The data was extracted from camara trap videos and the species observation were registered each 15 minutes. Torres del Paine area, south Chile, 2022-2023.

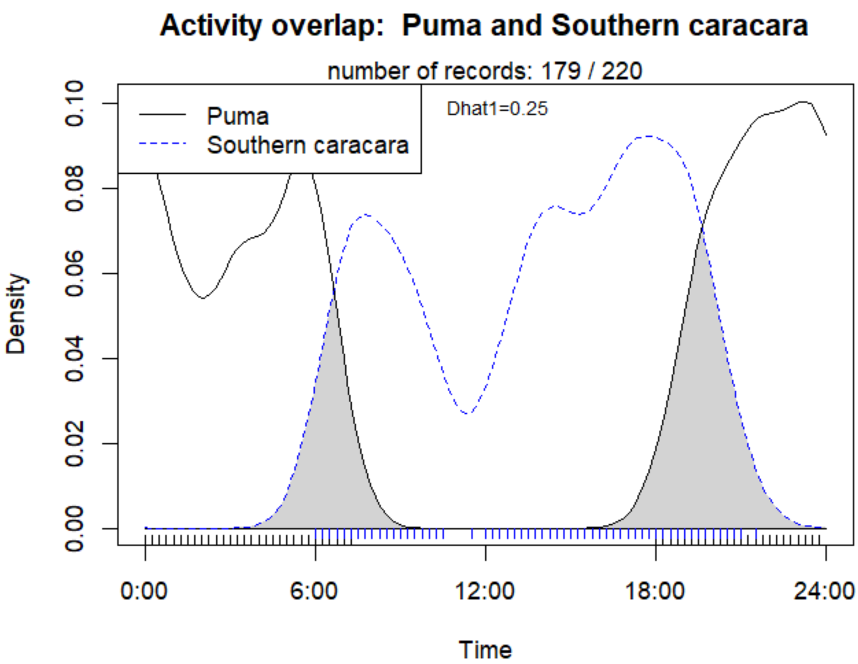

Figure 12. Puma (Puma concolor) and southern caracara (Caracara plancus) scavenging activity plot over time and activity overlap (Dhat1) between both species. Overlapping time slots are shown shaded in grey. The data was extracted from camera trap videos and the species observation were registered each 15 minutes. Torres del Paine area, south Chile, 2022-2023.

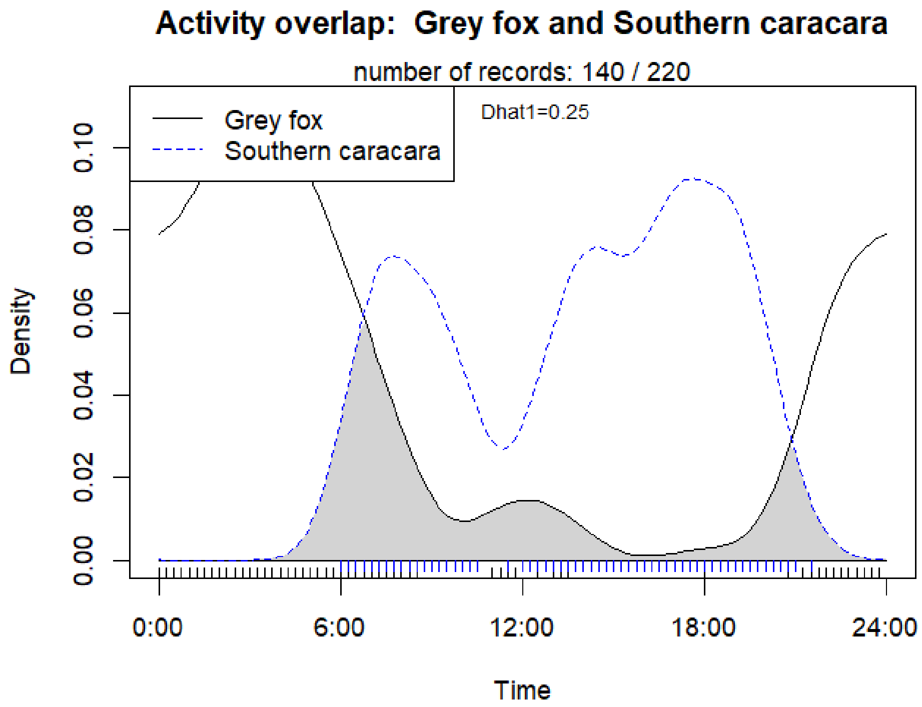

Figure 13. Grey fox (Lycalopex griseus) and southern caracara (Caracara plancus) scavenging activity plot over time and activity overlap (Dhat1) between both species. Overlapping time slots are shown shaded in grey. The data was extracted from camera trap videos and the species observation were registered each 15 minutes. Data obtained with camera traps in Torres del Paine area, Southern Chile, 2022-2023.

A puma spent on average 30 hours ± 22 hours scavenging on a carcass and scavenged commonly at night (n=51) (*Table 8*). Nevertheless, taking into account that most of these events happened at the verge of dusk and dawn (within half an hour around the astronomic calculation of dusk and dawn), I extended the dusk and dawn period with a half an hour margin (extended dusk and dawn). Using extended dusk and dawn periods results shifted the frequency towards pumas scavenging predominantly during dusk and dawn (see calculations in section 3.4.2).

Table 8. Frequency of recorded puma scavenging events during a given time period (day, dusk/dusk or night) (n=51) given as number of scavenging events divided by the average number of hours a given category last (f/nh). Extended frequencies describe frequencies including 30 minutes from the astronomic dusk and dawn. Torres del Paine National Park, south Chile, 2022-2023.

Scavenging time category	**f/nh**	**$f/nh_{(extended)}$**
Day	2,09	0,96
Dusk and Dawn	5,44	10,46
Night	6,63	5,56

As in the previous section (see 4.1), for both scenarios, all pumas presented different composition in their attack's frequencies for the three-time categories. For all pumas, attacks occurred least often during the day (*see Figure 14*).

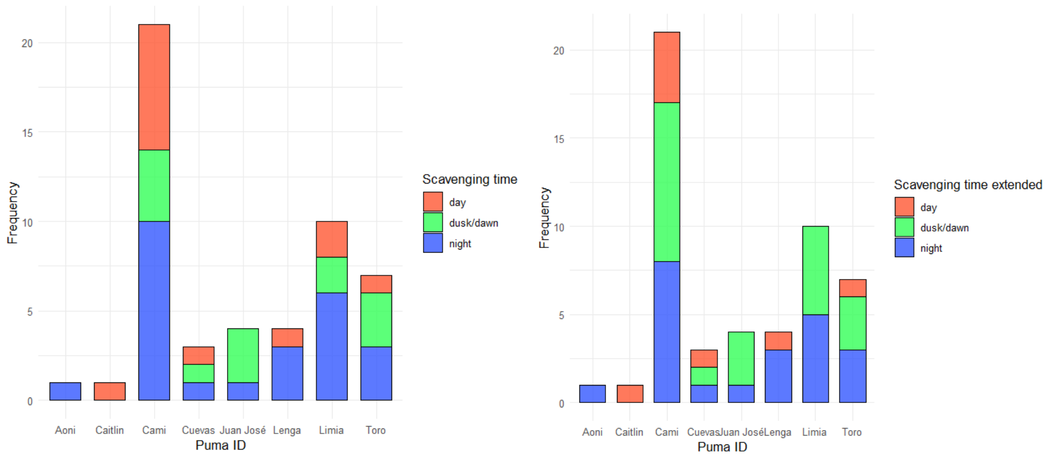

Figure 14. Puma scavenging events (n=51) classified depending when they had taken place: day (from sunrise to sunset), dusk and dawn (from sunset to night and from nightEnd to sunrise) and night for the rest of the time, according to the R package suncalc (on the left). Same graph on the right but using an extended version of periods dusk and dawn with half an hour margin. The 'x' axis shows different puma individuals (Puma_ID) and the 'y' axis the frequency with which these attacks took place in the different temporal categories. Area of Torres del Paine National Park, south Chile, 2022-2023.

In the first scenario, pumas Aoni and Juan José did not scavenge during daylight hours, while Caitlin only scavenged during the day and Aoni at night. In the second scenario, the one included extended dusk and dawn, the pumas Aoni, Juan José and Limia did not scavenged during the day while Cami presented the highest frequency of scavenging events during the day.

4.3 LGD behaviour in open rangeland with sheep

On average, the crossbred Maremma-Pyrenees LGD covered a distance of 5.900 m ± 2608, equivalent to approximately 3.3 to 8.5 km, on a daily basis. However, no evidence was found during this pilot study that LGD behave differently during the reference level 'day' and the 'dusk/dawn' (t (1357) =-0.4, p=0.707) and 'night' (t (1357) =-0.4, p=0.711)) levels, which indicates that LGD have similar activity levels at any time of the day.

5. Discussion

Identification and quantification of puma predation events and dietary habits

The results from this study shown that pumas targeted young guanacos (<1 year) during guanaco calving season (November-February) until June. This means that pumas target young guanacos from the age of zero to seven months. This presumably could indicate that guanacos older than seven months are not an attractive prey anymore, potentially due to a decrease on their vulnerability. Guanacos are weaned and expelled from their family group on average at seven months of age (Sarasqueta 2001). At this age, their mobility and defensive behaviour presumably increase, making them suitable for survival away from the group of adults. The results account also for significant differences among individual pumas, since some individuals contribute more to this predation pattern than others, indicating differences in personality and hunting strategies. However, it is important to be careful when interpreting results based on individual choices since depending on the home-range of each puma and the point of the specific predation or scavenging event, it is more or less easy to access it and report it.

Comparable information from specific puma-guanaco systems is scarce. However, Sarno et al. (1999), obtained similar results in the same area in Southern Chile, stating that "most [guanacos] deaths occurred between birth and 7 months of age". Taraborelli et al. (2014) found that in guanaco groups with at least one young among their members, the flee response is more predominant, acknowledging young guanacos' vulnerability because of their lower mobility and defensive behaviour. Previous studies from the Torres del Paine National Park area also shown that pumas selectively killed young guanacos (Bank et al. 2002; Franklin et al. 1999). Young guanacos were preyed up to four times as much as adults by pumas, relative to their availability (Franklin et al. 1999). Future research should focus its attention on puma-guanaco systems and on how climate change affects guanaco calving season and the possible implications for puma diet and both puma and guanaco management. There is a need as well for doing research on the implications of sheep vulnerability if accessibility to guanaco changes. The results from this study show a similar tendence from those obtained in other studies in North America, in puma-north American ungulate systems where Laundré (2008) and Clark et al. (2014) found that pumas kill more frequently in summer, when juvenile ungulates are more available.

The interaction between time of the day and habitat use greatly influences kill probability by puma (Smith et al. 2020). Pumas hunt most frequently during twilight hours, that is, at dawn and dusk. Although the results in absolute terms indicated that pumas hunt predominantly at night. Yet, when comparing the number of predation events in each period with the average duration in hours of the same, i.e., estimating the frequency of predation events, showed that twilight was the period with the highest number of attacks. These results align with those stating that pumas are crepuscular animals (Sweanor et al. 2008; Cepeda–Duque et al. 2021; Smith et al. 2019). Contrary to these results, a study from Smith et al. (2020) in a puma-vicuña system in Argentina found that the proportion of kills did not vary across the diel cycle. This suggests that puma hunting habits could greatly vary across ranges an even populations.

According to my own observations on the field, some pumas hide the carcasses of their prey, especially if the prey is large, such as guanaco, as they feed on them for several days. Pumas hide the carcasses by covering them with plant material available in the surroundings. According to my findings, pumas fed on hidden carcass for more days than on unhidden carcasses. Thus, this behaviour could potentially be a good strategy to preserve the resource for longer. Further research is need to verify that the fact that a carcass is hidden could mean that other scavengers have greater difficulty accessing it, and therefore cannot take advantage of the food provided by puma predation, especially bird species that scout for carcasses from the air.

Furthermore, evaluating the relationship between the presence of scavenger's signs (feathers, hair, feces...) at the carcasses and the number of days that the puma fed on them, I presumed that pumas would feed on its prey for fewer days if scavengers signs were present, since that means the same resource for more consumers. However, the results from the analysis were not statistically significant, but indicated a trend ($p=0.098$). Finding scavengers signs in the field is challenging since local weather conditions (strong winds, rain and snow) can affect their presence. No research studies were found that studied this aspect of the puma's ecology in order to compare my results with previous research, neither in North or South America.

Although my results meet my expectations, this study has some limitations, which is mainly due to that my study objectives had to be incorporated within a larger study infrastructure, for example, the design was not uniform because the field-work was organized randomly, mainly depending on the climate conditions, the availability of a field-technician and the distance between clusters. This may have resulted in undetected or delayed identification of scavenging or predation events, particularly when data collection was impeded by the advanced deterioration of organic matter. Consequently, certain valuable indexes, crucial for dietary studies, such as predation rate, could not be calculated.

In a study from Chilean Patagonia, by Elbroch and Wittmer (2013)b, pumas displayed differences in prey selection at both individual and population level. Many species, as the puma, have been recognized as an aggregation of individual dietary specialists, instead of generalist predators (Lowrey, Elbroch & Broberg 2016; Elbroch & Wittmer 2013b). Due to the small sample size (five female pumas and three male pumas) in my study, my findings might be influenced because of undetected differences due to individual personality that might have led to the different dietary preferences I found among the eight pumas.

Some predation events might have been undetected by the cluster method. There are several prey species with a weight less than or near 8kg, such as the European hare, the big haired armadillo, the culpeo and grey fox or the upland goose (Elbroch and Wittmer 2013b). These prey, according to Bacon et al. (2011) are difficult to detect using the clusters method since the handling time might be shorter than one hour. Thus using 1-hour intervals applied in this study, the GPS positions calculated would not generate a cluster, and thus would not be associated with a predation event. To address this issue, it is feasible to integrate this approach with scat analysis or diminish the interval duration for GPS points fixation. However, such actions may impact the battery longevity of GPS collar. To solve the battery issue, it would be necessary in many cases to increase its size and weight of the battery to provide it more capacity, which could be detrimental to the animal.

Meso and macro scavengers at predation sites

Different scavenger species feed on carrion provided by puma at different times of the day. Results from this study shown that pumas, grey foxes and southern caracaras are the main three scavengers in Torres del Paine National Park area.

In my study area, pumas fed on carrion provided by other pumas mainly at twilight but also at night. Grey foxes fed on carrion mainly at twilight and night but also during the day while southern caracara only during day hours. The activity overlap at the carcasses was high between pumas and grey foxes but low between pumas and southern caracaras and southern caracaras and grey foxes, aligning with the results from Olea, Igleasias & Mateo-Tomás (2022), since birds and mammals had contrasting activity patters. While pumas avoid feeding on carcasses during the day and southern caracara only fed on them during daylight, grey foxes proved to have a more opportunistic behaviour. These results align with the findings by Perrig et al. (2023), Olea, Iglesias & Mateo-Tomás (2022) and Elbroch & Wittmer (2013)a, concluding that subordinate scavengers are vulnerable while foraging and adjust their strategies based on risk management, (e.g., size difference, with or without offspring, vegetation cover in the area…), modifying their activity patterns at carcasses used by apex predators, reducing the temporal overlap.

Puma roll as facultative scavenger has been documented in other systems (e.g., puma-north American ungulates in Canada Knopff, Knopff & Boyce 2010; puma-mule deer in the USA Bauer et al. 2005; puma-guanaco in Chilean Patagonia (Elbroch & Wittmer 2012b) although scientific literature on this topic is scarce. In this study, 51 scavenging events by puma were registered (compared to 170 predation events), indicating that scavenging behaviour might be not unusual in this species in this study system.

Adult pumas were also registered by camera traps sharing carrion with other adult pumas, which so far has been rarely documented. Even though the pumas have been historically defined by the scientific community as solitary species, recent research has shown that pumas exhibit social behaviour not necessarily linked to kinship (Elbrock et al. 2017b), as it might be the case for findings of this study. Future research is needed to redefine the concept of social and solitary animals and to better understand the role of pumas as a social species. It is also of great importance to understand what drives pumas to share their food, such as a high abundance of prey. Camera trap records can be valuable allies for such studies, but for first-hand information, these studies should rely on the analysis of spatiotemporal patterns of collared pumas and on genetic analysis of individuals to determine their degree of kinship.

As mentioned in the methods section, camera traps were regularly checked to ensure proper functioning. While this practice is initially beneficial for data collection, as cameras may run out of battery or shift from the focal point of interest, it could also have influenced the behaviour of the animals being monitored. Some animals may have left the area due to human presence or become more hesitant to visit it. Therefore, for future research, it is essential to assess the cost-benefit of frequenting camera traps during a study.

Livestock Guardian Dogs

My results indicate that the activity levels (meters/h) of seven LGDs during the peak risk hours of puma attacks on sheep, dusk and dawn, are similar to their activity during the rest of the day and night. This indicates that LGDs do not present a peak of activity when there is a higher risk of puma attacks.

My results are in contrast with findings from similar studies. Gipson et al. (2012) reported that both sheep and dogs travel significantly more during the day than at night in a predator system with sheep and goats in the USA. Next, Van Bommel & Johnson (2014) suggest that LGDs exhibit a distinct peak in activity during early morning and late afternoon, coinciding with twilight hours in a predator system with sheep in grazing properties in Australia. Additionally, movements away from the sheep, characterized by high-speed travel on relatively straight paths, occurred mainly at night (Van Bommel & Johnson 2014), which might indicate a defensive behaviour towards predators in the area. Young, Draper & Kinka (2019) observed that dogs stay closer to sheep during the early morning hours in a system with sheep in the USA. Tomeček et al. (2019), in a study with a small sample size similar to this one, found that three out of four dogs exhibited a clearly crepuscular daily cycle, while the fourth dog showed a different daily pattern.

These findings from other studies, indicating that LGDs exhibit varying levels of activity throughout the day, are in disagreement with those obtained in my pilot study. However, it is important to note that this is a pilot study in the area, and therefore, it is understandable that the results may have limitations. In this study, for instance, the sample size was relatively small. Only three GPS collars were available, which were rotated among the seven LGDs participating in the pilot study. Additionally, the small sample size prevented the study of the impact of dogs' age on their activity levels even tough according to Zingaroa et al (2008), older dogs usually remain closer to sheep than younger individuals (while sex seems not to affect their behaviour on this regard).

The effectiveness of livestock protection increases when there is a group of LGDs working in the same area, as they work independently and occupy a larger area than a single dog, distributing themselves across the assigned territory (Van Bommel & Johnson 2014; Tomeček et al. 2019; Roddick et al. 2022). During this pilot-study, the LGDs worked usually in groups of two to four individuals, although the number of dogs working together was not controlled or uniform, which could have led to variability in the results.

Due to livestock management considerations, as the study was tailored to the ranch work with sheep and the needs of the workers, some dogs wore the GPS collar intermittently or for fewer days compared to other individuals, making the periods that each dog wore the collar incomparable and perhaps, in some cases, insufficient.

Managing the dogs proved to be challenging at times, necessitating their removal from the field and temporary placement in kennels before reintroduction.

Additionally, many areas lacked SigFox coverage as it is a remote and isolated area with complex topography, characterized by plains, mountains, and ravines. The collars transmitted the GPS positions every 30 minutes, but if this information couldn't be transmitted due to lack of coverage, the information with the LDG position wasn't stored. This resulted in significant data losses. Other studies in this area should take into account the limitations of coverage when storing data and explore other types of GPS collars that work with systems more suitable for the topography in the region, or perhaps, combine the use of SigFox coverage with the installation of signal-boosting antennas. For further research, it could be of great interest to use accelerometer devices together with GPS collars, since the dog might not be moving more during dusk and dawn but could display more head movements or other types of behaviours that could have been overlooked.

Landscape also has an influence. LGDs and sheep tend to separate more in pastures with a high percentage of trees and shrubs while they stay closer in pastures nearby inhabited areas (Zingaroa et al. 2018). When comparing studies, it is essential to consider that the environmental context, especially the topography and also the types of predators present in the area, may affect the specific behaviour of LGDs. In my pilot study, topography and important aspect such as land cover type were not taken into account due to an increasing of the analysis's complexity.

The results of the LGDs' activity analysis do suggest significant differences in activity among the seven individuals studied. Different dogs have different personalities (Van Bommel and Johnson 2015). Some personality traits make LGDs more suitable for livestock protection (Zingaroa et al. 2018). An effective LGD presents a balance between three behaviours: trustworthiness, attentiveness, and protection of livestock (Vercauteren et al. 2008). Within studies, it is imperative to consider the individual personality of each subject as a variable. In this pilot study, dogs were not uniformly trained, and their individual personalities, sensitivity, and intelligence may contribute to divergent attitudes and capabilities towards work. Therefore, it is important for future research to examine specific interactions between LGDs and pumas in Patagonia taking into account LGDs personalities and then compare them with other studies to assess to which extent the data can be extrapolated to other systems.

During my data collection, some dogs left the designated sheep perimeters. However, in Australia, unsupervised Maremma LGDs in open range spent 90% of their time with the flock, according to Van Bommel & Jonhson (2016). Although spatial proximity between dogs and sheep is significantly important when preventing attacks on livestock, some roaming is expected since dogs create territorial boundaries, which might help them protect their animals (Zingaroa et al. 2018). The movement of LGDs in open range is sequential, with a low overlap percentage between areas used by the same dog on consecutive days (Van Bommel & Johnson 2014). Therefore, these events are considered sporadic and may not have a significant impact on livestock management.

The benefits of having LGDs with sheep go beyond reducing predator attacks on livestock. Although no differences in LGDs' activity levels throughout the day were found in my pilot study, this does not imply that LGDs are not having a positive impact on sheep protection. LGDs perform territorial signalling, such as regular barking, boundary patrolling, and scent-marking (Van Bommel & Johnson 2014). Ewes in companionship with LGDs travel greater distances every day than those that are not, which can result in improved fitness and, therefore, economic revenues (Webber et al. 2015). All of this suggests that the presence of LGDs with the sheep entails an additional advantage beyond mere prevention of puma attacks. LGDs' presence in an area could potentially enhance the fitness of the sheep and their offspring, leading to heightened levels of animal welfare and augmented profits for the ranchers. In the future, it would be of great interest for livestock managers to compare the fitness of sheep and their offspring in the presence of LGDs with those without LGDs.

6. Conclusions

Using different types of data and approaches to improve our knowledge on puma ecology (intra- and inter-specific interactions) and possible tools to mitigate puma-livestock conflicts (LGD), my findings emphasize that:

1. Pumas targeted young guanacos (<1 year) not only during the guanaco calving season (November to February) but also up to four months after it, until June. This suggests a higher vulnerability of young guanacos between birth and seven months of age, underscoring the importance of protecting this age group for both puma and guanaco conservation efforts. Presumably, applying management measures for protecting young guanacos and keeping this age group in good conditions, could allow pumas to have access to its natural food resource, contributing to reduce the number of attacks on livestock. Moreover, these findings contribute to understand the puma-guanaco system in South America.

2. Predation events by pumas predominantly occurred during dusk and dawn, indicating the significance of these temporal periods for prey species' predation risk, including livestock. While daytime attacks were observed, they were less frequent compared to those during crepuscular and nocturnal hours. This highlights the importance of protecting livestock from puma attacks specially during these critical periods with strategies such as rounding of livestock at dusk, using light and sound deterrent devices or keeping the livestock at closed enclosures from dusk until dawn.

3. When pumas hid their prey's carcasses with vegetation, the feeding time (understood as hours spend at the carcass) was prolonged, suggesting that hiding carcasses is a valuable survival strategy to access food for an extended period (i.e., lower need to kill a new prey). However, the presence of scavenger signs around a carcass did not significantly affect the duration of puma presence at the carcass, although this may still have practical relevance despite not being statistically significant.

4. Scavenging activity at puma predation sites involved at least 10 species of meso and macro scavengers, including the puma itself, reinforcing the idea of the puma as a facultative scavenger. Pumas were reported to scavenged mainly at dusk and dawn. This highlights the ecological importance of puma-killed carcasses as a food resource for various wildlife species and the contributes to creating new knowledge of the puma roll in food-webs in

South America. Pumas and grey foxes exhibited the highest overlap in scavenging activity, indicating strong temporal competition between these species as scavengers.

5. Results from this study, regarding puma hunting and scavenging strategies acknowledged differences among the eight pumas that participated in the study, revealing the different personalities of these individuals. Together with the fact that adult pumas were recorded sharing food during this study, these findings contribute to the study of puma behaviour in South America.

6. Livestock Guardian Dogs (LGD) exhibited similar activity levels throughout the daily cycle, without showing increased activity during the critical hours for puma predation on livestock, dusk and dawn. Although this pilot study intended to contribute to the study of LGDs behaviour in Chile, which is scarce and recent compared to other countries such as Australia or the USA, these findings should not necessarily be interpreted as indicating that LGDs are ineffective in mitigating puma-livestock conflicts. The observed results could be attributed to technical issues related to GPS collar coverage and data storage, both crucial aspects in such studies. However, variations in activity levels among individual dogs were noted, underscoring the notion that different dogs exhibit distinct personalities and work capabilities.

Table 9. Summary of the conclusions from the study.

Research Objective	Research Question	Fulfilment	Why not?
Identification and quantification of puma predation events and dietary habits	Pumas target <1-year guanacos during calving season	Yes	✓
	Pumas hunt at crepuscular hours	Yes	✓
	When a carcass is hidden food last longer / When there are scavenger signs food last less	Yes / No	✓ / No evidence was found
Scavengers at predation sites	Different scavenger species different feeding times	Yes	✓
	Pumas scavenge at crepuscular hours	Yes	✓
Livestock Guardian Dogs	LGDs have different spatial-temporal behaviour at dusk and dawn	No	LGDs show similar spatial-temporal behaviour at any time of the day

Overall, these findings contribute to our understanding of puma ecology and its interactions with prey and scavenger species in South America. It emphasizes the vulnerability of young guanacos to puma predation and underscores the importance of conservation measures for this age group. Additionally, the crepuscular patterns of puma predation highlight the need for key strategies for livestock protection, while insights into puma scavenging behaviour contribute to our knowledge of species ecology and their roll in food webs. Lastly, the examination of Livestock Guardian Dogs' activity patterns offers valuable insights into their potential role in mitigating puma-livestock conflicts.

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Popular science summary

Through the various themes encompassed in this study—such as the diet and hunting habits of the puma, macro- and meso-scavengers in the area, and livestock-guarding dogs—a comprehensive analysis of the puma and its environment in the Chilean Patagonia was intended. Specifically, the focus is on the Torres del Paine region, home to the renowned national park of the same name.

First and foremost, delving into the hunting and dietary habits of the puma yields information on its ecology and its relationship with prey species. Subsequently, by studying the scavenger animals associated with the puma, a broad perspective is gained on the various levels at which it interacts with other species and the nature of these interactions. Lastly, it is crucial not to overlook that the puma's diet includes domestic and production animals such as sheep and cows. This engenders a significant conflict in the area between ranchers and pumas, occasionally resulting in retaliatory actions against the puma, such as illegal hunting. To mitigate this conflict, an increasingly widespread tool in the region is the use of livestock-guarding dogs. This study aims to provide a brief glimpse into their activity patterns when protecting sheep from pumas.

The results of this study are as diverse as the topics it addresses. Nevertheless, there are some key points to highlight. Regarding the puma's diet, it was observed that the dominant prey was the guanaco. Additionally, the results indicated that pumas fed on young guanacos (< 1 year old), from the beginning of the guanaco breeding season in November until the animals were seven months old. Therefore, this may lead us to think that the period when the guanacos were most vulnerable was between zero and seven months of age. On the other hand, this study revealed that when a puma hide carcass, the resource lasts for more days, highlighting the success of this characteristic puma technique for protecting food. Through data analysis, it was also found that pumas tend to hunt and scavenge predominantly at crepuscular hours, dusk and dawn.

The community of meso and macro scavengers associated with the puma is diverse, ranging from other pumas to condors and small armadillos. Thanks to the use of camera traps, it has been possible to verify that different scavenger species feed at different times of the day. Some with marked patterns like pumas that scavenge at dusk, dawn and night or southern caracara that fed during the day.

Livestock guardian dogs are a widely recognized and employed tool for preventing and mitigating conflicts between predators and livestock. However, in this pilot study done using GPS collars, no marked activity patterns of these dogs could be observed when they are protecting sheep in open spaces. Although initially it was expected that these dogs would be more active during the hours when there is a greater risk of puma attacks on sheep, dusk and dawn. Which does not necessarily mean that its presence in the field does not keep predators away.

The results from this study emphasize the vulnerability of young guanacos to puma predation and underscore the importance of implementing conservation measures for this age group, benefiting both guanaco and puma conservation efforts. Additionally, the temporal patterns of puma predation highlight essential strategies for livestock protection at twilight and night, while insights into the behaviour of Patagonia's scavenger community contribute to our understanding of interspecies competition and food webs. Examination of Livestock Guardian Dogs' activity patterns offers valuable insights into their potential role in mitigating puma-livestock conflicts, thereby aiding puma conservation efforts in South America.

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Lorenzo and Mirko walking with their dogs at Cerro Guido Ranch: Ron, Solito and Paisano

This master's thesis was a collaborative effort involving the Swedish University of Agricultural Sciences, Universidad de Chile, Panthera, and Fundación Cerro Guido Conservación.

Appendix 1

Settings Camera Traps

Date	DD-MM-YY
Time	hh:mm:ss
Mode Video	Video
Capture Delay	Delay 30s
PicSize Medium	10MP
MultiShot	Off
Cap Start	12:00 AM
Cap End	12:00 AM
Video Quality	High
Video Length	20s
Smart IR	On
Night Exp	Pwr Save
TL Frequency	10s
TL Period	3Hr
Temp Unit	C
Info Strip	On
SD Management	Off
Motion Detect	Normal
Motion Test	OK
Language	English
Name	Cluster ID
Default Setting	OK
Delete All	OK
SW Upgrade	OK

Appendix 2

Example of the raw data extracted from visualizing the CT videos.

Species	0:00				1:00			
	0:00	**0:15**	**0:30**	**0:45**	**1:00**	**1:15**	**1:30**	**1:45**
Grey fox	4	2	1	3	3	2	4	5
Puma	4	4	4	4	2	2	3	2
Southern caracara	0	0	0	0	0	0	0	0
White-throated caracara	0	0	0	0	0	0	0	0
Chimango caracara	0	0	0	0	0	0	0	0
Andean Condor	0	0	0	0	0	0	0	0
Big hairy armadillo	0	0	0	0	0	0	0	0
Black-chested buzzard-eagle	0	0	0	0	0	0	0	0
Culpeo fox	1	1	1	0	0	0	0	0

Appendix 3

Adult puma hiding a guanaco carcass with surrounding vegetation

Appendix 4

Southern caracara (top) and grey fox (bottom) scavenging on a guanaco carcass

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