Understanding the influence of social and ecological components on the occupation of domestic dogs and wild mammals in rural landscapes of the temperate forests of southern Chile

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To Mother Earth, creator of nature, thank you for allowing us to be part of her...

“Soñando se me pasa
la pena del momento
pero tengo un lamento
que se ha vuelto mi casa

Manto de los abuelos
cubre esta vieja herida
haz que esta niña mía
vea el fruto en el suelo
y en la...

Rama del árbol vivo
que se quebró en la lucha
cuando el leñador no escucha
más que su propio ruido
pero el bosque nativo
sabe que el viento vuelve
que la barba del ñire cuelgue
no es señal de vejez
aunque se fue tu niñez
hoy tu risa aún me envuelve”

(Rama del árbol vivo, Savir Quintana, Cantautor, Coyhaique 2020)

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I want to thank all the living beings of the temperate forests of southern Chile. To the Pudú, for embracing me with their innocence. To the Kodkod for marveling at their beauty. To Darwin's fox for teaching me his strength. To the ancient native trees, bearers of wisdom. And to the people who opened their doors to us, shared a mate with us and showed us their experiences.

I want to thank my family for being the seedbed of my values and convictions, and my life partner, Matías, for being that sturdy oak that held me up in the storm.

I also want to thank those who believed in my ideas, Ariel and Marcelo, since without their guidance and constant support this would not have been possible.

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"La tierra no pertenece
al hombre sino al contrario
no basta el abecedario
si el verso es el que adolece
la cuna cuando se mece
disfruta del movimiento
el bosque y el padre viento
son hijos de la porfía
humanos en su agonía
no jueguen con el sustento"

(Savir Quintana, Cantautor, Coyhaique 2020)

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General Introduction

The magnitude, extent and speed of anthropogenic disturbances on the earth's surface are unprecedented in human history (Lambin et al., 2001). The exponential growth of the human population and our socio-economic system has led to dramatic changes in the Earth's landscapes (Giannecchini et al., 2007). Land use and land cover change (LULCC) and the introduction of alien species are considered the main drivers of global change, as they affect the functioning of ecosystems and cause biodiversity loss globally (Ojima et al., 1994; Vitousek et al., 1997; Wilcove et al., 1998; Sala et al., 2000; Lambin et al., 2001).

LULCC have a close relationship both with the physical and ecological characteristics of the landscape, and with the socio-economic context of an area or region, so that natural, cultural and economic forces interact to produce changes in the landscape structure (i.e. the spatial configuration of landscape patches in various sizes and shapes and the spatial relationships between them; Forman and Godron, 1986) (DeFries et al., 2004, 2006; Leitão et al., 2006; Fu et al., 2013).

Several studies on LULCC have demonstrated the close relationship between the formation of landscape structure and processes related to human activities (Echeverría et al., 2006; Gasparri and Grau, 2009; Geri et al., 2010; Echeverría et al., 2012). The loss and/or transformation of forest ecosystems into land suitable for agricultural, livestock, forestry and urban development has played the most important role in the formation of landscape structure (Medley et al., 1995; Sala et al., 2000), particularly in rural communities with subsistence economies (Kaeslin et al., 2013).

This modification of landscape structure affects not only the distribution of organisms, but the integrity of certain ecological processes, such as displacement and interaction between species (Turner, 1989; Wiens, 2002; August et al., 2002).

The replacement of natural cover by anthropic uses reduces the surface area of areas suitable for various species, both because of their direct transformation and because of the edge effect (Murcia, 1995; Davies et al., 2001). In this regard, the literature indicates that disturbed land cover is more susceptible to invasive alien species than native forests (Frigeri et al., 2014), and that anthropized land cover reduces the habitat, diversity, distribution and abundance of many wild species and modifies their activity patterns (Agetsuma et al., 2014; Ramesh and Down, 2015).

The most emblematic and globally known invasive alien species is the domestic dog (*Canis lupus familiaris*). The close connection that has been forged between dogs and humans throughout history has led to people taking their dogs with them wherever they go, resulting in the deliberate introduction of dogs to new landscapes around the world (Álvarez and Dominguez, 2001). This has resulted in the domestic dog being the most abundant and widely distributed carnivore in the world (Wandeler et al., 1993) with a population exceeding 900 million individuals (Gompper, 2014). Nearly 60% of this population would be found in rural areas, where agricultural land frequently comes into contact with protected areas and habitat remnants, and where households are more likely to own dogs (Franti et al., 1970; Knobel et al., 2008; Acosta-Jamett et al., 2010; Murray et al., 2010).

In rural areas, domestic dogs perform various functions according to their owners' socio-economic characteristics (Martínez et al., 2013; Sepúlveda et al., 2014), and are managed in various ways according to their level of integration with the human community. Free-ranging dogs are common and a significant proportion of them are inadequately fed (Gompper, 2014; Butler and Bingham, 2000; Kitala et al., 2001; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014). As a result, dogs may move away from human-dominated areas where they get food and shelter and are often found around or in protected areas (PA) and forest remnants (Butler et al., 2004; Srbek-Araujo and Chiarello, 2008; Lacerda et al., 2009; Soto and Palomares, 2014; Sepúlveda et al., 2015). This scenario is particularly important in developing countries such as Chile since rural communities, depending on the use of natural resources, expand into border areas by increasing their proximity to these areas (Wittemyer et al., 2008).

The creation of PAs has been one of the historical strategies to conserve wildlife in rural areas (Margules and Pressey, 2000); however, the replacement of forest cover by human land use has caused these PAs to be immersed in a matrix of hostile cover altered by humans, and exposed to external factors such as the presence of dogs (DeFries et al., 2007; Jones et al., 2009; Lacerda et al., 2009; Bailey et al., 2015). In addition, PAs may be too small to protect wild species in the long term, so their survival outside PAs could be influenced by contact with rural communities and their interaction with introduced animals such as domestic dogs (Ramesh and Down, 2015).

All these characteristics and risk factors present in rural areas have led to dogs being considered a major threat to species conservation worldwide as they can potentially interact with wildlife through predation, harassment, competition, disease transmission and hybridization (Young et al., 2011; Hughes and Macdonald, 2013; Doherty et al., 2017). The probability and type of dog-wildlife interaction, therefore, is a function of the space use of dogs, which varies with number of dogs, human-subsidized food, movement restriction, and proximity to homes (Vanak and Gompper, 2009; Gompper, 2014; Soto and Palomares, 2014; Alves et al., 2017; Ribeiro et al., 2019).

In Chile, negative effects of dogs on a significant number of wild species have been documented, many of them within the PA. There is evidence of dog predation on species with conservation problems such as pudu (*Pudu puda*) (Silva-Rodríguez et al., 2010), Darwin's fox (*Lycalopex fulvipes*) (D'Elía et al., 2013), Kodkod (*Leopardus guigna*) (Silva-Rodríguez et al., 2007) and huemul (*Hippocamelus bisulcus*) (Corti et al., 2010), among others. And transmission of diseases such as canine distemper virus to chilla and culpeo foxes have also been reported (Moreira and Stutzin, 2005; Acosta-Jamett et al., 2011). In addition, sublethal interactions such as harassment or competition for resources have been documented. These interactions can affect the patterns of space use of wildlife species due to the behavioural response of individuals to the threat imposed by dogs (Doherty et al., 2015, 2017; Banks y Bryant, 2007; Zapata-Ríos y Branch, 2016). Silva-Rodríguez et al. (2010) reported that domestic dogs restrict chilla fox space use through harassment. Silva-Rodríguez and Sieving (2012) found negative associations between dog and pudú distribution.

Moreira-Arce et al. (2015) showed that the occurrence of dogs had a negative effect on the occurrence of Darwin's foxes. Similar results have been reported in other regions of the world where the occurrence of various wild species is negatively associated with dog activity (Banks and Bryant, 2007; Lacerda et al., 2009; Vanak and Gompper, 2010; Zapata-Ríos and Branch, 2016).

Given the negative effect of dogs on various vertebrate species, in recent years there has been growing global interest in studying dog-wildlife interaction which has been reflected in a significant increase in the number of published scientific papers (Hughes and Macdonald, 2013; Doherty et al., 2016; 2017). Nevertheless, dog-wildlife interactions are only recently being documented. Very little is known about the ecological effects of free-range dogs on wildlife, despite evidence that dogs interact with native animals, especially in rural areas, and even less about the human dimension of this problem. A better understanding of the social and ecological factors that exacerbate the impacts of domestic dogs on wildlife is needed.

All published articles on dog-wildlife interaction have focused in isolation on the causes and immediate consequences of this interaction, without appreciating the general context in which it occurs or its underlying causes (but see Sepúlveda et al., 2014; Villatoro et al., 2016; Schuttler et al., 2018; Villatoro et al., 2019; Astorga et al., 2020). Among the various types of interaction that have been reported, the change in the spatial occupation patterns of wildlife has been one of the most widespread and studied in recent years (see Silva-Rodríguez et al., 2010; Vanak y Gompper, 2010; Silva-Rodríguez and Sieving, 2012; Vanak et al., 2014; Farris et al., 2015; Moreira-Arce et al., 2015; Zapata-Ríos and Branch, 2016; 2018). From these articles, it is evident that dog-wildlife interaction can be related to diverse components, both ecological (landscape structure, use of space by dogs and wildlife, interactions between species) and social (socio-economic characteristics of the population, trends in land use, dog management culture and dog ownership). Therefore, understanding the social and ecological dimension that can underlie this interaction will allow us to improve our understanding of this problem and will help to establish more effective management measures (Shackleton et al., 2019).

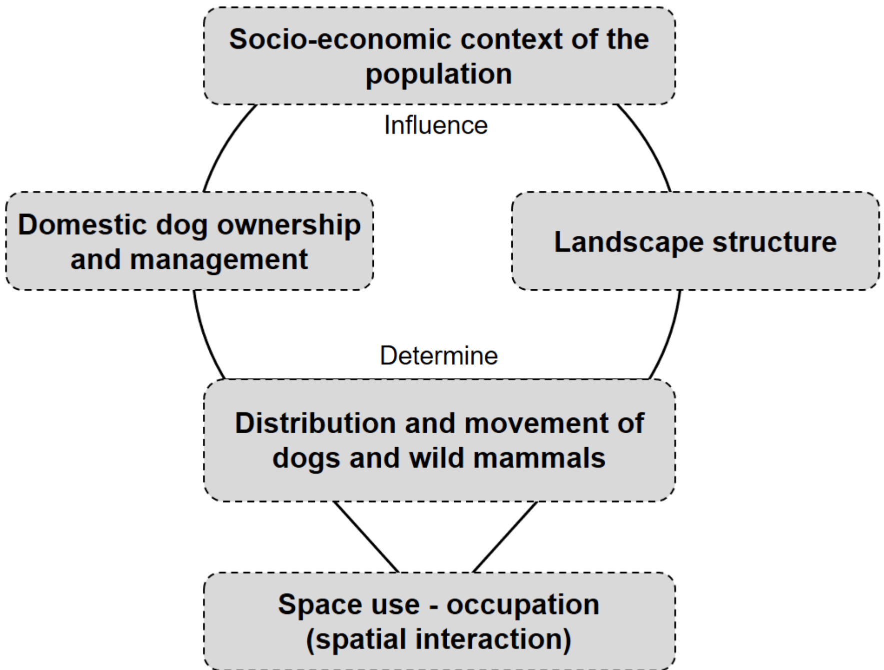
From the literature, certain unexplored questions emerge: Is it correct to study the dog-wildlife interaction as an isolated process considering the close association of the domestic dog with the human? How do the various social and ecological components, underlying the dog-wildlife interaction, relate to each other and to this process? Considering the dog-wildlife interaction as an isolated process and not in its systemic context, resulting from the interaction of diverse components that are interconnected, may lead to the generation of inefficient management strategies and cause greater problems to the conservation of species.

This approach implies that research should integrate social and ecological dimensions given the fundamental role of humans in modifying terrestrial ecosystems (Carpenter et al., 2009; Liu et al., 2007; Anderson et al., 2015; Shackleton et al., 2019). Improving our understanding of the human and ecological dimensions is imperative for improving our understanding and management of invasive alien species in the future. This will enable us to resolve environmental conflicts that will facilitate the reconciliation of social and ecological interests in the future, through the development of more efficient and effective management strategies for both human well-being and wildlife conservation.

Because forest ecosystems are one of the most vulnerable and least resilient to anthropogenic disturbances (e.g., Williams, 2003), our study was conducted in rural areas of the Southern Chilean Temperate Rainforest Ecoregion, which has experienced a long history of intense landscape modification through land cover changes and the introduction of invasive alien species (including domestic dogs, European wild boar, red deer, and American mink) (Armesto et al., 1992, 1994, 1998). Due to their prolonged isolation, the species of these forests shows high levels of endemism which makes them important objects of conservation worldwide (Armesto et al., 1992, 1998; Olson and Dinerstein, 1998; Myers et al., 2000). Our study focused on the interaction of the domestic dog with three medium-sized wild mammal species with conservation problems and which are representative of the temperate forests of southern Chile: The Pudu, Kodkod and Darwin's Fox. According to the IUCN Red List of Threatened Species (IUCN, 2020), the Darwin' s fox is endangered, the Kodkod is vulnerable and the Pudu is near threatened.

This research studied the patterns of spatial occupation of domestic dogs and these three medium-sized wild mammals from a socio-ecological perspective, integrating various social and ecological components that may be influencing this interaction. Not only were the immediate causes of this interaction and its effect on wildlife studied, but also the underlying causes, where the ultimate cause of this system is the socio-economic context of the rural population (Figure 1).

Fig. 1. Theoretical scheme of the systemic relationship where the dog-wildlife interaction resulting from the interaction of social and ecological components is contextualized. The ultimate cause of dog-wildlife interaction is the socio-economic context of the population, which influences the landscape structure and the domestic dog ownership and management. These in turn determine the distribution and movement of dogs and wild mammals, and thus their patterns of occupation (spatial interaction). Own elaboration.



We hypothesize that dog-wildlife interaction in protected areas and forest remnants is influenced by a combination of effects of the socio-economic context of surrounding rural communities on landscape structure and domestic dog ownership and management, which in turn influence the occupation patterns of domestic dogs and wild mammals in these areas. Therefore, our general objective was to determine the role that the socio-economic context of 14 rural communities has in the configuration of the landscape structure and in domestic dog ownership and management, and the influence of this on the occupation patterns of dogs and wild mammals as an indicator of the intensity of the interaction between them. And, our specific objectives were (1) to associate the socio-economic context of 14 rural communities with the domestic dog ownership and management, (2) to associate the socio-economic context of 14 rural communities with the current landscape structure, (3) to model the dog-wildlife interaction through species occupation, and (4) to explore how the interaction between domestic dogs and wild mammals in protected areas and forest remnants varies with the influence of the social and ecological context of the surrounding rural communities. To achieve our goal, we integrate different approaches and methodologies from ecological and social disciplines to collect, analyze and integrate data.

Chapter 1

One or more rural dogs? Understanding the association of community socioeconomic factors with the domestic dog ownership and management among rural households in the temperate forests of southern Chile

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One or more rural dogs? Understanding the association of community socioeconomic factors with the domestic dog ownership and management among rural households in the temperate forests of southern Chile

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Abstract

The presence of dogs in rural areas has provided many benefits for their owners, but negative impacts to wildlife. In these areas, dogs are usually work animals, and often show signs of inadequate feeding, insufficient veterinary care, and little to no restrictions on movement. Since human-dog associations vary regionally and among social units, ownership and management are expected to vary with the socioeconomic (SE) characteristics of owners. To explore this association, we regionally evaluate the relationship between the SE context and dog ownership and management for 218 households in 14 different rural communities in southern Chile. We conducted semi-structured open interviews with households in areas differing in their dominant economic activities, and the collected information was analyzed using backward logistic regression and partial least squares regression (PLSR). We found that 85.8% of households owned dogs, and that the probability of dog possession was negatively associated with years of schooling of the head of household and positively associated with number of people living in the household. The PLSR showed a gradient between two well-differentiated SE contexts, reflected in dog ownership and management. In general, livestock/agroforestry contexts were associated with more dogs per household, poor food quality, lower feeding frequency, insufficient veterinary care, work functions in animal herding and care, and a lack of confinement. Service/marine species extraction contexts were associated with fewer dogs per household, greater feeding frequency, sufficient or optimal veterinary care, companionship function, and some degree of confinement. Our results show that the dog ownership and management in the study area varies according their owners' SE conditions, suggesting a gradient between two different domestic dog profiles found in the rural landscapes of the temperate forests of southern Chile. Since the number and management of dogs can influence how they interact with wildlife, our results suggest the need to contextualize dog-wildlife interactions according to the SE characteristics of their owners and to prioritize research in communities and homes with traditional lifestyles and strong livestock activities, which is where dog-wildlife interactions would be more likely to occur as a result of greater numbers of dogs present and worse dog management. Our findings

will help develop more effective dog-management strategies for rural areas and reconcile economic interests of rural residents and wildlife conservation interests.

Key words: Domestic dog (*Canis lupus familiaris*); socioeconomic factors; dog ownership and management; rural communities; interviews; temperate forests.

1. Introduction

More than 15,000 years ago, domestic dogs (*Canis lupus familiaris*) and humans started a mutually beneficial relationship by sharing living spaces and food sources (Savolainen et al., 2002; Larson et al., 2012; Thalmann et al., 2013; Miller et al., 2014; Frantz et al., 2016; Serpell, 2017). Currently the dog is ubiquitous in human society and has become the most abundant and widely spread carnivore globally (Wandeler et al., 1993), with a population larger than 900 million individuals (Gompper, 2014a). Roughly 60% live in rural areas (Gompper, 2014a), where agricultural lands frequently contact protected areas and forest remnants, and where households are more likely to own dogs (Franti et al., 1974; Knobel et al., 2008; Acosta-Jamett et al., 2010; Murray et al., 2010).

Dogs play an important role in rural areas, performing various functions, according to their owners' socioeconomic (SE) contexts (Martínez et al., 2013; Sepúlveda et al., 2014). These mainly include companionship, home protection, and livestock care and herding (Silva-Rodríguez and Sieving, 2011; Miller et al., 2014; Sepúlveda et al., 2014). Owners handle their dogs in various ways, ranging from complete control (dogs live inside houses and receive all basic care) to dogs living freely and without necessary care (Vanak and Gompper, 2009; Hughes and Macdonald, 2013). In rural areas, dogs bred with no controls are common and a significant proportion receive inadequate feeding (Gompper, 2014a; Butler and Bingham, 2000; Kitala et al., 2001; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014). As a result, dogs can move between human-dominated areas, where they receive food and shelter, and protected areas and forest remnants, where they interact with wildlife (Butler et al., 2004; Srbek-Araujo and Chiarello, 2008; Torres and Prado, 2010) via predation (Manor and Saltz, 2004; Silva-Rodríguez and Sieving, 2011; Ritchie et al., 2014; Wierzbowska et al., 2016), harassment (Silva-Rodríguez et al., 2010; Silva-Rodríguez and Sieving, 2012), competition (Banks and Bryant, 2007; Whiteman et al., 2007; Lacerda et al., 2009; Vanak and Gompper, 2010; Newsome et al., 2014; Zapata-Ríos and Branch, 2016), disease transmission (Randall et al., 2006; Moreira and Stutzin, 2005; Acosta-Jamett et al., 2011), and hybridization (Vilà and Wayne, 1999; Godinho et al., 2011; Khosravi et al., 2013). The probability and type of dog-wildlife interaction is a function of the dog's use of space, which varies based on the availability of human-food subsidies, movement restrictions, and proximity to houses (Vanak and Gompper, 2009; Gompper, 2014a; Soto and Palomares, 2014; Alves et al., 2017; Ribeiro et al., 2019). In rural areas of Chile, Silva-Rodríguez and Sieving (2011) found that poorly fed dogs preyed more on wild mammals than well-fed dogs. Sepúlveda et al. (2014) concluded that the dog-wildlife interactions were a function of the number of dogs per household and their confinement, and they reported that livestock ownership and food provision were significant predictors of dog-wildlife interaction. Silva-Rodríguez and Sieving (2012) also observed that distance-to-home was a significant variable to predict dog presence. Sepúlveda et al. (2015) indicated that most dogs were close to homes (<200 m) but could show excursion patterns with an average range of 0.5 to 1.9 km. These findings suggest the important role that humans have in facilitating or reducing dog-wildlife interaction in rural systems.

Although the biology and ecology of dog-wildlife interactions is a common research focus, studies along the human dimension (i.e., studies of attitudes, beliefs, values, and underlying behaviors of people; Bath, 1998) remain scarce (Miller et al., 2014). Addressing this topic requires an interdisciplinary approach including ecological, cultural, social, and economic perspectives (White and Ward, 2010; Hughes and Macdonald, 2013; Anderson et al., 2015; Doherty et al., 2017). Since the domestic dog management occurs within complex SE systems, a better understanding of the human factors exacerbating the impact of domestic dogs on wildlife is needed (Doherty et al., 2017). To understand the role of human beings in dog-wildlife interactions, it is necessary to understand what SE factors of human populations relate to the ownership and management of dogs (Wandeler et al., 1993). Several studies have associated human SE factors with dog ownership (i.e., possession and number of dogs per household), however, the evaluated variables and associations differ greatly. Age, gender, educational level, occupation, number of people in the household, rurality, and ownership of livestock are all shown to be associated with dog ownership (Franti et al., 1974; Leslie et al., 1994; Westgarth et al., 2007; Knobel et al., 2008; Slater et al., 2008; Downes et al., 2009; Murray et al., 2010; Marinelli et al., 2013; Ortega-Pacheco et al., 2015). Most of these studies were conducted in urban areas of developed countries, with less emphasis on rural areas and developing countries, where human populations continue to increase in proximity to protected areas (Wittemyer et al., 2008), and where owners provide lower quality food, shelter, and veterinary care to their dogs (Ortega-Pacheco et al., 2015). What's more, no study has associated SE factors with dog management (i.e., feeding, function, veterinary care, and confinement) in rural areas, save for a few studies (Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Astorga et al., 2015; Ortega-Pacheco et al., 2015) that have done it locally, disjointedly, and indirectly. There still are no studies that have regionally documented the variability of SE factors and their relationship with dog ownership and management in rural households in southern Chile. Understanding this association can be important in addressing production and conservation interests in this region, given the important utilitarian role of dogs in rural areas and their potential for harming wildlife.

Values towards wildlife, which contribute to human-wildlife interaction, vary between households (Clark et al., 2017), and attitudes towards dogs and human-dog associations vary regionally and between social units (i.e., communities and households) (Knobel et al., 2008), thus establishing different levels of dependence on human care (Wandeler et al., 1993). We therefore hypothesize that demographic, educational, cultural, and other factors associated with the economic and subsistence activities of rural populations will influence the types of human-dog relationships. In other words, behaviors related to dog ownership and management will be associated with the SE characteristics of the owners and will differ between households. To explore this association, we evaluated the relationship between population SE factors and dog ownership and management in 218 households in 14 rural communities, covering geographical areas with different land-use histories in order to consider existing SE heterogeneity at a regional level.

In particular, the objective of this study is to determine whether the heterogeneity in the SE characteristics of owners (i.e., the variation age, years of schooling, the number of people in the household, years of residence in the home, economic activities, and the ownership of farm animals) relates to the ownership and management of their domestic dogs.

2. Materials and Methods

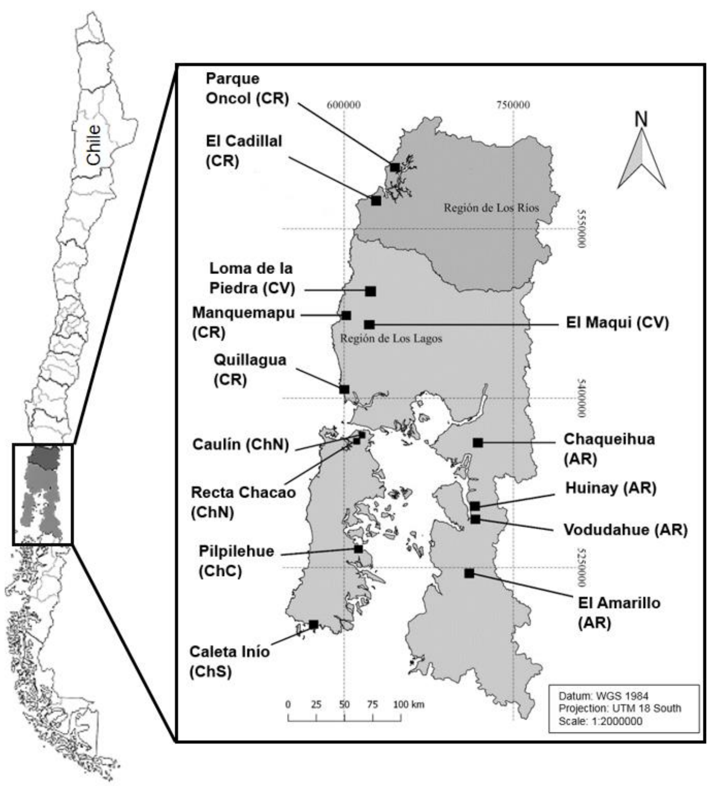
2.1 Ethics Statement

Before each interview, we obtained informed consent from each participant of legal age by reading a printed statement explaining the project objectives, interview duration, that it would not be recorded, the possibility of omitting questions, and that the interview was anonymous, confidential, and voluntary. Participants who agreed signed a copy of the informed consent form and another copy was given to them. Interview papers and their digital transcripts were stored anonymously. The Comité Ético Científico de Ciencias Sociales, Artes y Humanidades ("Scientific Ethics Committee of Social Sciences, Arts, and Humanities") of the Pontificia Universidad Católica de Chile approved the informed consent and the study.

2.2 Study Area

The study was conducted in 14 rural communities in Southern Chile, in Los Ríos and Los Lagos administrative regions (39° 40' S to 43° 23' S) (Figure 1). The climate of the area is temperate rainy, with an average temperature of 10.6 °C, with precipitation occurring throughout the year, decreasing from the mountains to the central valley (2,500 to 1,200 mm/year) (Rioseco and Tesser, nd). The dominant vegetation cover is temperate rain forest and the Valdivian temperate rainforest (Luerbert and Pliscoff, 2004), found mainly within protected areas and high-elevation areas.

Figure 1. Rural communities visited during the study and the number of interviews conducted per community and geographic zone.



Geographic Zone		Community	Number of interviews
Coast Range (CR)		Parque Oncol	23
		El Cadillal	11
		Manquemapu	16
		Quillagua	14
Andes Range (AR)		Chaqueihua	12
		Huinay	6
		Vodudahue	7
		El Amarillo	18
Central Valley (CV)		Loma de la Piedra	21
		El Maqui	21
Chiloé Island	North (ChN)	Caulín	20
		Recta Chacao	16
	Center (ChC)	Pilpilehue	19
	South (ChS)	Caleta Inío	14
Number of total interviews			218

All study sites were within the Temperate Rainforest Ecoregion, considered a hotspot for biodiversity conservation (Myers et al., 2000), due to its unique species assembly with a high degree of endemism (Armesto et al., 1992). The intense exploitation and fragmentation of the native forest over the last 150 years (Armesto et al., 1994; Echeverría et al. 2006), together human settlement, and exotic species introduction (including domestic dogs, European wild boar, red deer, and American mink) that interact with native fauna (Armesto et al., 1992) all influence the endangered forest remnants. Domestic dogs are common in the study area, and potentially interact with various species of medium-sized wild mammals, such as the pudu (*Pudu puda*), Kodkod (*Leopardus guigna*), and Darwin's Fox (*Lycalopex fulvipes*) (Silva-Rodríguez and Sieving, 2012; Farías et al., 2014; Sepúlveda et al., 2014; Silva-Rodríguez et al., 2018). Darwin's fox is in danger of extinction, the Kodkod is vulnerable and the pudú is near threatened (IUCN, 2019).

This study focused on areas where the consequences of dog ownership on dog-wildlife interactions would more likely be significant. Since the ecotone between anthropogenic environments and remnants of forest is where dog-wildlife interactions are most likely to occur (Vanak and Gompper, 2010; Lacerda et al., 2009; Soto and Palomares, 2014), communities were selected adjacent to protected areas or large remnants of native forest, within a buffer that would cover the range of distances usually travelled by free-roaming dogs (i.e. <2 km; Sepúlveda et al., 2015). Note that protected areas in Southern Chile do not contain significant human rural populations within them; most populations are settled in buffer zones and on their periphery.

All communities were characterized by low, rural human population densities. Economic activities varied between communities and within them, and were mainly associated with livestock (cows, sheep, and poultry), agriculture, marine species extraction, the use of forest resources (timber) and services (e.g., tourism, business services, personal services) (OLR, 2018a; OLR, 2018b). The selected communities were in four geographical areas with different land-use and human disturbance histories (Armesto et al., 1994): Coast Range, Andes Range, Central Valley, and Chiloé Island (Figure 1). The communities located in the Coast and Andes Ranges had large tracts of native forest and small rural subsistence areas within different management regimes (e.g., animal husbandry, small-scale agriculture, timber extraction). The coast locations were associated with marine species extraction and the Andes Range pursued service activities, like tourism. Central Valley communities had large deforested tracts associated with livestock and agriculture, and large plantations of introduced forest species. The communities in Chiloé Island vary in human disturbance from north to south. The north zone had large deforested areas associated with wood extraction, livestock, and agriculture, like the Central Valley. The central zone had large tracts of native forest with rural subsistence areas associated with agriculture and animal husbandry. The southern zone had rural areas linked mainly to marine species extraction, surrounded by large areas of native forest. Although these activities continue to characterize rural communities of southern Chile, service activities have increased in importance in some communities and rural households.

2.3 Interview Protocol

Between December of 2016 and August of 2017, we conducted open-ended, semi-structured interviews (Newing et al., 2011) with one person of legal age per household (n = 218 households). We conducted an average of 15.7 interviews per community (Figure 1). The number of interviews per community was related to the density of inhabited houses; we conducted interviews in all households that wanted to participate in the study in communities with fewer than 30 houses; in those with more than 30, we used random and snowball sampling (see Newing et al., 2011). We first used images from Google Earth™ (Google Inc., 2016) in order to identify the location of houses (i.e., roofs) and confirmed their location in the field. Before field visits, we calculated the representative population sample with a confidence level of 95% and an error margin of 5%, using the number of roofs observed in Google Earth for the 14 communities (650 observed roofs). The interview design and the selection of dog ownership and management data were based on prior questionnaires (Silva-Rodríguez and Sieving, 2011, 2012; Sepúlveda et al., 2014). To test the interview design and adapt the questions to the study objectives, we conducted a pilot study in two communities (Pilpilehue and Caleta Inío) in March 2016. The interviews were conducted face-to-face, in Spanish, in the homes of the interviewees. Each interview lasted between 15 minutes and 4 hours.

To complete our objective, the information from each interview included participant SE variables that prior studies have shown significant association with dog ownership (Franti et al., 1974; Leslie et al., 1994; Westgarth et al., 2007; Knobel et al., 2008; Slater et al., 2008; Downes et al., 2009; Murray et al., 2010; Marinelli et al., 2013) and dog ownership and management in Chile (Acosta-Jamett et al., 2010; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Astorga et al., 2015; Sepúlveda et al., 2015; Schüttler et al., 2018; Villatoro et al., 2019) and abroad (Butler and Bingham, 2000; Kitala et al., 2001; Ortega-Pacheco et al., 2015). SE data included gender, age, years of schooling, number of people living in the home, economic activity in which they were engaged, and whether they owned farm animals, for what and which. In addition, we include the variable years of residence in the sector because in our pilot study some households reported not owning dogs due to the short residence time. Regarding the ownership of dogs, we asked whether or not they owned dogs, the number of dogs per household, the age and sex of each of them. In the dog-management section we ask about feeding (type of food and frequency of feeding), veterinary care delivered (if they were sterilized, vaccinated, dewormed or if they had been seen by a veterinarian), the role played by the dog in the household, and the degree of confinement (i.e., completely free or restricted movements to some degree) (Table 1) (see Questionnaire S1 in Supplementary Material). All these variables provided us with information on the ownership and management of dogs relevant to our study and future plans for dog management, and socio-economic information on rural households that allowed us to characterize them and better explain their relationship with the ownership and management of dogs.

Table 1. SE and dog ownership and management variables used for modeling. Obtained from the 218 interviews in 14 rural communities of the temperate forests of southern Chile.

SE Variables	**Type**	**Coding**	**Description**
IG	Dummy	1,2	Female interviewee (1), male interviewee (2)
IA	Numeric	-	Age of the interviewee
IYS	Numeric	-	Years of schooling of the interviewee
HG	Dummy	1,2	Head of household female (1), male (2)
HA	Numeric	-	Age of head of household
HYS	Numeric	-	Years of schooling of the head of household
PpH	Numeric	-	Number of people living in the household
YRs	Numeric	-	Years of residence in the sector
AfA	Dummy	0,1	Household dedicated (1) or not (0) to agroforestry activities
LvA	Dummy	0,1	Household dedicated (1) or not (0) to livestock activities
MrA	Dummy	0,1	Household dedicated (1) or not (0) to marine species extraction activities
SrA	Dummy	0,1	Household dedicated (1) or not (0) to service activities
LvPos	Polytomics	0	No possession of farm animals
		1	Possession of farm animals for subsistence
		2	Possession of farm animals for sale
LvQa	Numeric	-	Number of farm animals
NSp	Polytomics	0	No possession of farm animals
		1	Possession of a species of farm animal
		2	Possession of multiple species of farm animals
Pou	Dummy	0,1	Possession (1) or not (0) of poultry

She	Dummy	0,1	Possession (1) or not (0) of sheep
Cow	Dummy	0,1	Possession (1) or not (0) of cows
Pig	Dummy	0,1	Possession (1) or not (0) of pigs
Dog Ownership and management variables	**Type**	**Coding**	**Description**
ND	Numeric	-	Number of dogs in the household
SxD	Dummy	0,1	Female dog (0), Male dog (1)
AgD	Numeric	-	Age of dog
WbF	Dummy	0,1	Feeding (1) or not (0) with wheat bran
LoF	Dummy	0,1	Feeding (1) or not (0) with leftovers
CfF	Dummy	0,1	Feeding (1) or not (0) with commercial food
FA	Polytomics	1	Fed 1 time/day
		2	Fed 2 times/day
		3	Fed 3+ times/day
VC	Polytomics	1	Insufficient veterinary care
		2	Sufficient veterinary care
		3	Optimum veterinary care
Cmp	Dummy	0,1	Companionship function (1) or not (0)
HPr	Dummy	0,1	Home protection function (1) or not (0)
AHc	Dummy	0,1	Animal herding and care function (1) or not (0)
Cfm	Polytomic	1	No movement restriction
		2	Partial movement restriction
		3	Full movement restriction

2.4 Data analysis

Given the nature of the data derived from the interviews, each qualitative variable in our analysis was categorized as either dichotomous or polytomous variables (Table 1). Note categories in type of food provided, function of dog, economic activity, and species of farm animals present were categorized as dichotomous ‘dummy’ variables, since the options were not mutually exclusive. The Polytomic variable Veterinary care (VC) was evaluated by weighting each of the four criteria covered in the interview (sterilization, deworming, vaccination, and veterinarian visits), according to their importance in dog-wildlife interactions, with deworming and vaccination having greater weights (3 points), given their impacts on disease transmission to native wildlife. Next, the scores were summed and categorized, with "insufficient" having 0 to 3 points, "sufficient" having 4 to 6 points, and "optimal" having 7 to 9 points. The vaccination criterion included both anti-rabies within the last two years and either the sextuple or octuple vaccine.

We evaluated the probability of dog possession, based on the SE factors of the community using multivariate, binary, backward logistic regression (i.e., generalized linear models with binomial error distributions and logit link functions) (Agresti, 2019). This analysis was performed with household level data (n = 218). Given the high collinearity between the variables "possession of farm animals" and "number of a species of livestock" (variance inflation factor >10 and tolerance <0.1), we excluded the first variable from this analysis. The selection of variables was carried out using likelihood ratio tests (α = 0.05) to determine the final predictive models. Model selection was made using the Akaike Information Criterion (AIC), ensuring the selection of the most parsimonious model (i.e. smaller AIC) each time a variable was deleted. The goodness of fit of the model was examined using the Hosmer-Lemeshow test.

To understand and predict the relationship between the community SE factors with the ownership and management of domestic dogs, we use Partial Least Squares Regression (PLSR). This covariance-based multivariate technique generalizes and combines features of principal component analysis and multiple linear regression. In PLSR, the general objective is to use factors to predict population responses. This is achieved indirectly by extracting the latent variables T and U from the sampled factors (predictor variables) and responses, respectively. The extracted factors T (also called X-scores) are used to predict the Y-scores U, and then the predicted Y-scores are used to construct predictions for the responses (Tobias, 2003). These latent factors are defined as linear combinations built between the predictor and response variables, so that the original multidimensionality is reduced to a smaller number of orthogonal factors to detect the structure in the relationships between the predictor variables and between these latent factors and the response variables (Hubert and Branden, 2003, Carrascal et al., 2009). PLSR is particularly suitable when the predictors are highly correlated (i.e. there is strong collinearity) and/or the number of predictor variables is similar to or greater than the number of observations (i.e. overfitting) (Abdi, 2007; Carrascal et al., 2009). Although this type of data is quite common in ecological studies, the use of PLSR remains rare (Carrascal et al., 2009).

Therefore, the PLSR model used has the following structure,

$$X = TP^T + E$$
$$Y = UQ^T + F,$$

where X is a matrix of $n \times m$ predictors, Y is a matrix of $n \times p$ responses; T and U are $n \times l$ matrices which are projections of X (X-scores) and projections of Y (Y-scores), respectively; P and Q are $n \times l$ and $p \times l$ matrices of orthogonal charges, respectively; and the E and F matrices are the error terms. The decompositions of X and Y are done to maximize the covariance of T and U.

The data set used for the PLSR analysis included only those interviewees who owned dogs, and the regression was performed with data at the dog level (n = 435) and their respective owners.

The statistical analysis was performed using the "ade4" package (see Bougeard and Dray, 2018) in the R software (R Development Core Team 2018). The optimal model and predictive ability was evaluated by double cross-validation (Stone, 1974). The optimal number of dimensions (or mutlivariate axes) sufficient to describe the main gradients of covariation between the variables was determined through the trade-off between good fit (minimizing the square root mean square error of the calibration, RMSECC) and good predictive ability (minimizing the validation mean square error, RMSECV) (Bougeard and Dray, 2018). To identify significant relationships between predictive and dependent variables, 1000 Bootstrapping simulations were performed to provide confidence intervals, calculated by the non-Studentized pivotal method (Carpenter and Bithell, 2000). The regression coefficients of the optimal model measure the links between each explanatory and dependent variable. A coefficient is considered significant if the 95% bootstrap confidence interval did not contain the threshold value 0.

3. Results

3.1 SE and dog ownership and management characteristics

Table 2 presents the socioeconomic characteristics of the 218 households interviewed, separated by households with dog ownership and households without dog ownership. Of all the interviewed households, 187 (85.8%) reported owning at least one domestic dog and provided basic information related with the ownership and management of their dogs (Table 3).

Table 2. Social and economic characteristics of 218 households with and without dog ownership in 14 rural communities in southern Chile.

		Households with dog ownership		Households without dog ownership	
Social characteristics					
Total number of households (%)			187 (85.8)		31 (14.2)
Gender of interviewees: Male (%); Female (%)			88 (47.1); 99 (52.9)		11 (35.5); 20 (64.5)
Average age of interviewees (SD)			51.5 (16.0)		49.3 (15.7)
Average years of schooling of interviewees (SD)			8.4 (4.1)		10 (4.8)
Gender of head of household: Male (%); Female (%)			129 (69.0); 58 (31.0)		20 (64.5); 11 (35.5)
Average age of head of household (SD)			54.1 (14.6)		49.9 (15.5)
Average years of schooling of the head of household (SD)			8.0 (3.9)		9.8 (4.8)
Average number of people per household (SD)			3.2 (1.6)		2.6 (1.4)
Average years of residence in the sector (SD)			33.9 (22.5)		33.6 (23.4)
Economic characteristics					
Households dedicated to agroforestry activity (%)			105 (56.2)		12 (38.7)
Households dedicated to livestock activity (%)			81 (43.3)		10 (32.3)
Households dedicated to marine species extraction activity (%)			31 (16.6)		5 (16.1)
Households dedicated to service activity (%)			96 (51.3)		21 (67.7)
Total number of households with possession of farm animals (%)	For subsistence (%)	150 (80.2)	70 (37.4)	23 (74.2)	13 (41.9)
	For sale (%)		80 (42.8)		10 (32.3)
	With a species (%)		55 (29.4)		9 (29.0)
	With 2 or more species (%)		95 (50.8)		14 (45.2)
Average number of farm animals per household (SD)			34.1 (34.9)		26.7 (29.4)
No. of households with poultry (%)			108 (57.8)		18 (58.1)
No. of households with sheep (%)			88 (47.1)		11 (35.5)
No. of households with cows (%)			80 (42.8)		11 (35.5)
No. of households with pigs (%)			49 (26.2)		6 (19.4)

Table 3. Ownership (number, sex, age) and management (feeding, veterinary care, function, and confinement) of 435 domestic dogs in 218 households from 14 rural communities of southern Chile.

Ownership		**Response**
Number of households interviewed		218
Number of households owning dogs (%)		187 (85.8)
Total number of dogs		435
Average number of dogs per household (SD; range)		2.3 (1.4; 1–8)
Average age of dogs in years (SD)		4.5 (3.7)
Number of males; Number of females (Proportion male:female)		335; 100 (3.4:1)
Feeding		**Response**
Wheat bran (%)		101 (23.2)
Commercial food (%)		320 (73.6)
Leftovers (%)		351 (80.7)
Feeding frequency (times/day)	1 (%)	59 (13.6)
	2 (%)	330 (75.8)
	3+ (%)	46 (10.6)
Veterinary Care		**Response**
Total sterilized dogs (%): males (%); females (%)		63 (14.5): 16 (4.8); 47 (47)
Vaccinated (%)		119 (27.4)
De-parasitized (%)		159 (36.6)

Veterinary visitation (%)	97 (22.3)
Insufficient care (%)	306 (70.3)
Sufficient care (%)	52 (12.0)
Optimal care (%)	77 (17.7)
Function in the home	**Response**
Companionship (%)	173 (39.8)
House protection (%)	306 (70.3)
Animal herding and care (%)	120 (27.6)
Restriction on movement	**Response**
Free-ranging (%)	324 (74.5)
Tethered (%)	66 (15.2)
Free-ranging and tethered (%)	45 (10.3)

The binary logistic regression model to assess the relationship between dog possession and SE variables that obtained the lowest AIC value includes the variables years of schooling of the head of household and number of people per household (Table 4). The variable years of schooling of the head of household is negatively related to dog ownership ($p < 0.05$), while the number of people per household is positively related to dog ownership ($p > 0.05$) (Table 4.1).

Table 4. Model selection by AIC (Akaike Information Criterion). Binary multiple logistic regression model with backward stepwise selection (link function = logit) used to evaluate the relationship between dog possession and SE variables in each household (n = 218).

Binary multiple logistic regression model with backward stepwise selection	**AIC**
IG+IA+IYS+HG+HA+HYS+PpH+YRs+AfA+LvA+MrA+SrA+LvQa+NSp+Pou+She+Cow+Pig	201.73
IG+IA+IYS+HG+HA+HYS+PpH+YRs+AfA+LvA+MrA+SrA+LvQa+Pou+She+Cow+Pig	197.76
IG+IA+IYS+HG+HA+HYS+PpH+YRs+AfA+LvA+MrA+SrA+LvQa+Pou+She+Cow	195.76
IG+IA+IYS+HG+HA+HYS+PpH+YRs+AfA+MrA+SrA+LvQa+Pou+She+Cow	193.78
IG+IA+HG+HA+HYS+PpH+YRs+AfA+MrA+SrA+LvQa+Pou+She+Cow	191.81
IG+IA+HG+HA+HYS+PpH+YRs+AfA+SrA+LvQa+Pou+She+Cow	189.88
IG+IA+HG+HA+HYS+PpH+YRs+AfA+SrA+LvQa+Pou+She	187.96
IG+IA+HG+HA+HYS+PpH+YRs+AfA+LvQa+Pou+She	186.08
IG+IA+HG+HA+HYS+PpH+YRs+AfA+LvQa+Pou	184.28
IG+HG+HA+HYS+PpH+YRs+AfA+LvQa+Pou	182.71
IG+HA+HYS+PpH+YRs+AfA+LvQa+Pou	181.13
IG+HA+HYS+PpH+YRs+AfA+Pou	180.1
IG+HYS+PpH+YRs+AfA+Pou	179.44
IG+HYS+PpH+AfA+Pou	178.01
HYS+PpH+AfA+Pou	177.42
HYS+PpH+AfA	176.87
HYS+PpH	176.74

See the description of variables in Table 1.

Table 4.1. Final binary logistic regression model (link function = logit) used to evaluate the relationship between dog possession and SE variables in each household (n = 218).

SE Variables (Y)	Estimate coeff.	95% CI	Std. Error	P value
Intercept	1.908	0.759 - 3.144	0.606	0.00163 **
Years of schooling of the head of household	-0.098	-0.190 - -0.008	0.046	0.03255 *
Number of people per household	0.257	-0.017 - 0.566	0.148	0.08312 .

Aikake Information Criterion (AIC)= 176.74
Signif. codes: '**' 0.01, '*' 0.05, '.' 0.1
P-value < 0.05 is significant
Hosmer and Lemeshow goodness-of-fit: X2 = 218, df = 8, p < 0.0001

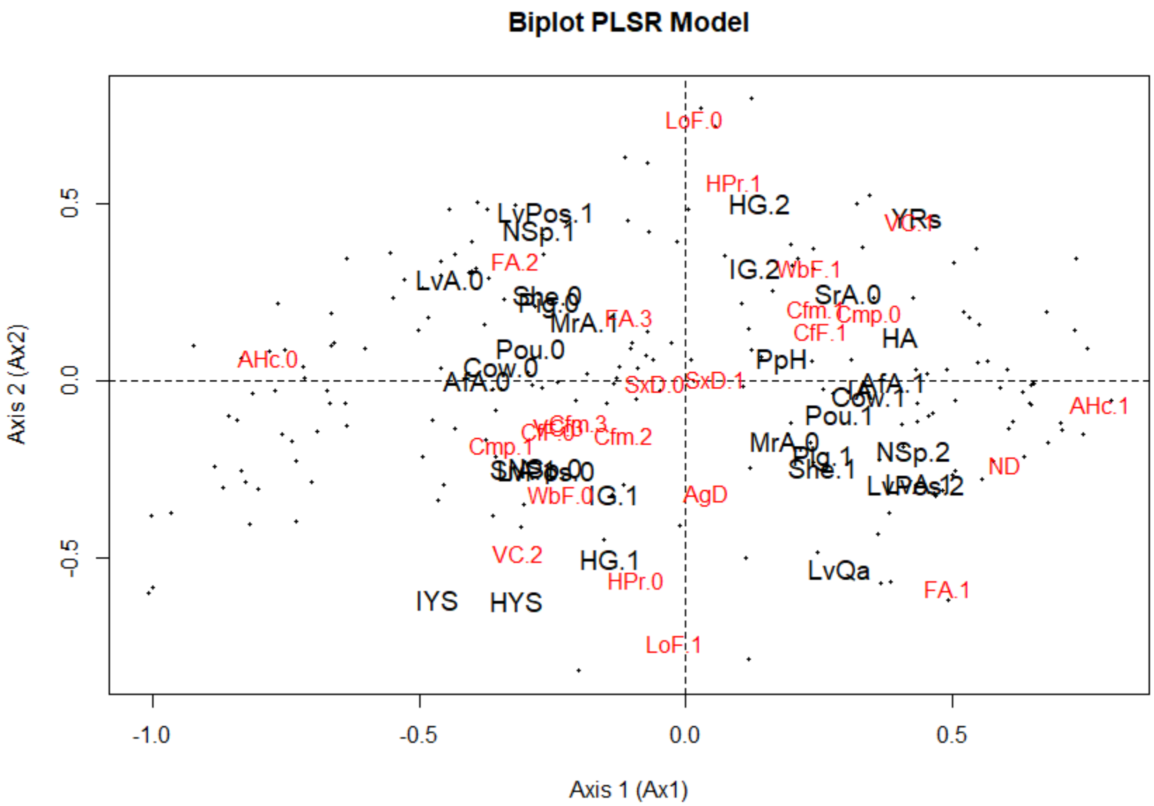
3.2 SE factors associated with domestic dog ownership and management in rural areas

The PLSR analysis showed the second dimension as having the lowest RMSECV (Ax2; Table 5). The addition of more dimensions increased the explained cumulative variance, but the corresponding RMSECV was not significantly changed, and did not provide additional relevant information. Thus, two latent variables are sufficient to describe the main covariation patterns between variables. The results of the PLSR are shown in Figure 2, and the main gradient found (Ax1) that explains 25.6% of the variation of the predictor variables and 16.1% of the variation of the explained variables is synthesized in Figure 3.

Table 5. PLSR analysis of SE factors (x) and domestic dog ownership and management (y), with cross-validation and 1000 replications. Only the first 10 (Ax10) of 20 axes are shown.

Number of latent PLSR variables	Percent of explained variance				Root mean squared error cross validation (RMSECV)		
	Variance X	Acum. Var. X	Variance Y	Acum. Var. Y	Mean	2.5%	97.5%
Ax1	25.6361	25.6	16.128	16.1	1.6358	1.6136	1.6580
Ax2	**9.4845**	**35.1**	**15.067**	**31.2**	**1.6354**	**1.6148**	**1.6577**
Ax3	7.7891	42.9	11.195	42.4	1.6374	1.6160	1.6598
Ax4	6.7712	49.7	8.335	50.7	1.6397	1.6175	1.6615
Ax5	6.5493	56.2	7.434	58.2	1.6400	1.6182	1.6622
Ax6	5.8649	62.1	6.423	64.6	1.6416	1.6197	1.6636
Ax7	5.2754	67.4	4.936	69.5	1.6450	1.6226	1.6670
Ax8	3.4144	70.8	5.735	75.3	1.6471	1.6239	1.6695
Ax9	3.6716	74.5	3.927	79.2	1.6489	1.6266	1.6712
Ax10	4.8704	79.3	2.000	81.2	1.6496	1.6267	1.6721

Figure 2. Biplot summarizing the PLSR analysis results along the first (Ax1) and second (Ax2) dimensions. The sign and relative contribution of each explanatory variable (i.e., SE aspects of the rural population) on each axis are shown in black. The projection of the response variables (i.e., ownership and management of domestic dogs) on the multivariate plane are shown in red. See variables in table 1.



The biplot summarizing the PLSR analysis results (Fig. 2) shows a major gradient on axis 1 (Ax1) between two rural landscape types that differ in their dominant economic activities. At the positive end are, cases associated with a primarily livestock and/or agroforestry economic context, which are characterized by the ownership of a greater number and variety of farm animals, and where the head of household and/or interviewee were older and had fewer years of schooling and more years of residence in the area. On the negative side are cases linked to service activities and marine species extraction, which are characterized by not owning livestock or possessing only one species for subsistence purposes, and whose head of household and/or interviewee were younger and had more years of schooling, and fewer years of residence. Axis 2 (Ax2) shows two subgroups, differentiated by years of schooling. On the positive end is a group with low schooling, linked to male heads of household, with more years of residence and ownership of a single livestock species for subsistence, while the inverse characteristics are found at the negative end.

This SE gradient is reflected in the ownership and management of domestic dogs, which vary simultaneously in all evaluated aspects (ownership, feeding, veterinary care, function, confinement) (Fig. 2). Those engaged in livestock and agroforestry activities have a greater number of dogs per household that tend to show low food quality, lower feeding frequency, insufficient veterinary care, activity linked to animal herding and care, and being free-ranging. Those engaged service and marine species extraction have fewer dogs per household, greater frequency of feeding and sufficient or optimal veterinary care, fulfil mainly companionship functions, and have some degree of confinement.

The results of the multiple bootstrapping procedure with two optimal dimensions (Ax2) and their associated regression coefficients (b) are shown in Table 6. Only those variables that were significant are shown.

Figure 3. Schematic of the relationship between explanatory (domestic dog ownership and management) and predictive (SE aspects of the rural population) variables, elaborated from the biplot of the PLSR analysis. Source: Own elaboration.

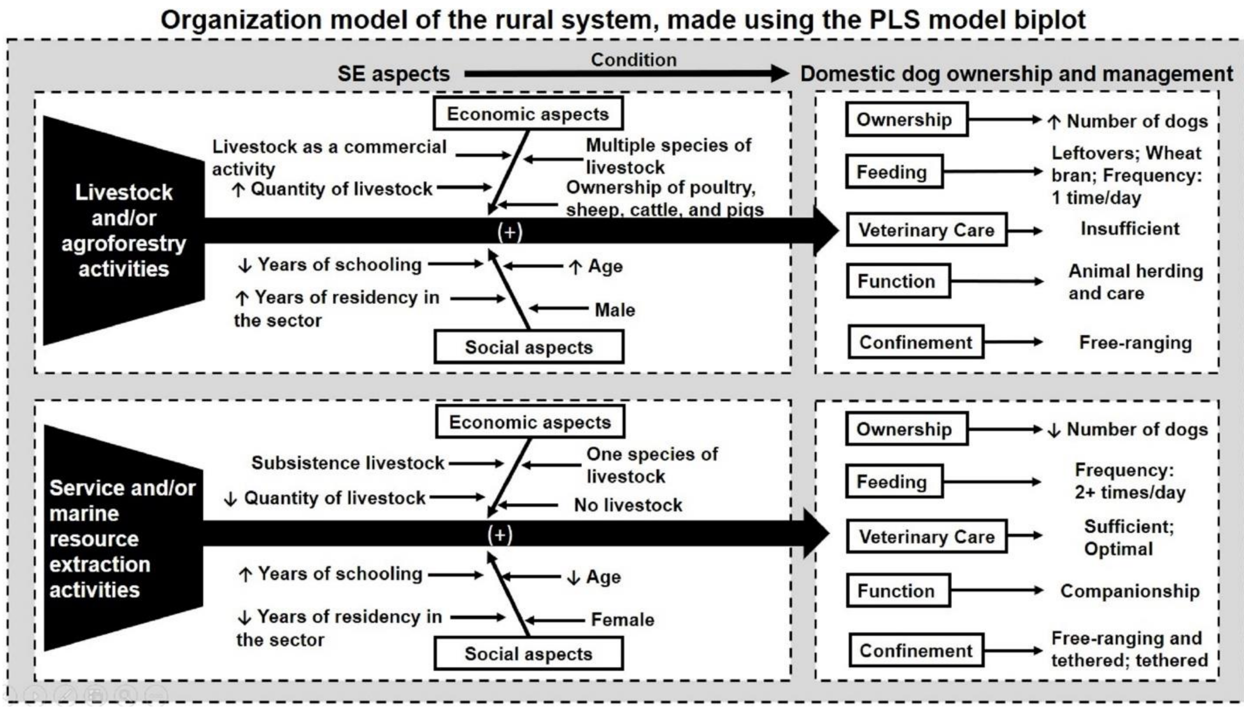


Table 6. Results of the multiple bootstrapping procedure of the PLSR model with 2 optimal dimensions and 1000 repetitions. Only the explanatory variables that were significant on each response variable are shown. The + (positive) and - (negative) signs are associated with the regression coefficients (b) and indicate the type of relationship between each SE variable and each variable of the dog ownership and management. n = 435

Dog ownership and management variables (y)	SE variables (x)																					
	IG (1)	IA	IYS	HG (1)	HA	HYS	PpH	YRs	AfA	LvA	MrA	SrA	LvPos (0)	LvPos (1)	LvPos (2)	LvQa	Nps (1)	Nps (2)	Pou	She	Cow	Pig
ND		0.024 (+)			0.023 (+)				0.027 (+)	0.043 (+)				0.039 (-)	0.043 (+)	0.043 (+)	0.037 (-)	0.039 (+)	0.024 (+)	0.028 (+)	0.026 (+)	
SxD (0,1)																						
AgD			0.036 (+)			0.036 (+)		0.027 (-)						0.029 (-)	0.018 (+)	0.032 (+)	0.025 (-)					
WbF (1)			0.051 (-)			0.046 (-)		0.041 (+)				0.024 (-)	0.023 (-)									
LoF (1)																						
CfF (1)	0.045 (+)		0.089 (+)	0.070 (+)		0.088 (+)		0.067 (-)		0.035 (+)		0.037 (+)	0.037 (+)	0.063 (-)	0.036 (+)	0.070 (+)	0.055 (-)			0.030 (+)		
FA (1)	0.027 (+)			0.046 (+)					0.021 (+)	0.055 (+)				0.066 (-)	0.055 (+)	0.073 (+)	0.060 (-)	0.045 (+)	0.026 (+)	0.040 (+)		0.037 (+)
FA (2)									0.014 (-)								0.036 (+)	0.028 (-)				
FA (3)																						
VC (1)	0.034 (-)		0.077 (-)	0.050 (-)	0.033 (+)	0.069 (-)		0.063 (+)				0.037 (-)	0.035 (-)									
VC (2)			0.075 (+)	0.051 (+)		0.069 (+)		0.060 (-)				0.035 (+)	0.034 (+)	0.031 (-)		0.035 (+)						
VC (3)																						
Cmp (1)								0.035 (-)				0.022 (+)										
HPr (1)			0.072 (-)	0.054 (-)		0.070 (-)		0.055 (+)		0.022 (-)		0.031 (-)	0.030 (-)	0.045 (+)	0.023 (-)	0.050 (-)	0.039 (+)					
AHc (1)		0.031 (+)			0.036 (+)			0.035 (+)	0.037 (+)	0.045 (+)	0.019 (-)	0.025 (-)	0.021 (-)	0.030 (-)	0.044 (+)	0.033 (+)	0.030 (-)	0.043 (+)	0.028 (+)	0.027 (+)	0.033 (+)	0.027 (+)
Cfm (1)					0.017 (+)			0.031 (+)				0.019 (-)										
Cfm (2)																						
Cfm (3)																						

IG (1)= Interviewee female, IA = Interviewee age, IYS = Interviewee years-of-schooling, HG (1) = Head of household female, HA = Head of household age, HYS = Head of household years of schooling, PpH = People per household, YRs = Years of residence, AfA.1 = Agroforestry activity, LvA.1 = Livestock activity, MrA.1 = Marine species extraction activity, SrA.1 = Service Activity, LvPos.0 = No ownership of livestock, LvPos.1 = Subsistence livestock, LvPos.2 = Livestock for sale, NSp.1 = 1 species of livestock, NSp.2 = More than 1 species of livestock, LvQa = Livestock quantity, Pou.1 = Ownership of poultry, She.1 = Ownership of sheep, Cow.1 = Ownership of cows, Pig.1 = Ownership of pigs. In red, ND = Number of dogs, SxD.0 = Female dog, SxD.1 = Male dog, AgD = Age of dog, WbF.1 = Feeding with wheat bran, LoF.1 = Feeding with leftovers, CfF.1 = Feeding with commercial food, FA.1 = Fed 1 time/day, FA.2 = Fed 2 times/day, FA.3 = Fed 3+ times/day, VC.1 = Insufficient veterinary care, VC.2 = Sufficient veterinary care, VC.3 = Optimum veterinary care, Cmp.1 = Companionship function, HPr.1 = Home protection, AHc.1 = Animal herding and care, Cfm.1 = No movement restriction, Cfm.2 = Partial movement restriction, Cfm.3 = Full movement restriction.

4. Discussion

The urgent need to control the impact of domestic dogs on wildlife has meant that this problem has begun to attract more research attention (Young et al., 2011; Hughes and Macdonald, 2013; Gompper, 2014b; Doherty et al., 2017; Twardek et al., 2017). Our study is the first that characterizes, at a regional scale, the variability of SE factors of the rural human population, and documents the impact that this variability has on the ownership and management of domestic dogs in 218 households, covering 14 different rural communities, located across different geographic areas of southern Chile. Our study design allowed us to address much of the SE heterogeneity in the region, in contrast to other domestic dog studies in southern Chile, which generally focused on a single landscape (Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014, Sepúlveda et al., 2015; Schüttler et al., 2018).

The results of this study support our hypothesis and suggest a gradient between two contrasting profiles of domestic dogs found in southern Chile's rural landscapes. These differ in the ownership (i.e., number and age of dogs) and the management of dogs (i.e., food, veterinary care, function, and confinement) in relation to the SE characteristics of their owners. Our results contrast with the generalizations that are commonly made in other studies (Butler and Bingham 2000; Kitala et al. 2001; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014, Ortega-Pacheco et al., 2015; Sepúlveda et al., 2015; Schüttler et al., 2018; Villatoro et al., 2018), where "rural dogs" are mentioned as a homogeneous entity or in relation to average characteristics (i.e., a working dog, with inadequate feeding, insufficient veterinary care, and no restrictions of movement), suggesting the existence of a single "rural dog” profile, whose management is generalized within rural systems. Our findings invite us to rethink the way we study dogs and their interaction with wildlife in rural systems, and highlight the need to contextualize the dog ownership and management and the dog-wildlife interaction according to the SE characteristics of each household.

The results of the PLSR analysis (Figure 2) indicate two well-differentiated rural contexts, reflecting the current condition of rural southern Chile (Berdegué et al., 2010a, 2010b; CASEN, 2015) and Latin America in general (Muñoz, 2000; Giarracca, 2001), and they are consistent with the current transition to a new rurality (Giarracca, 2001; Berdegué et al., 2010a, 2010b). This transition is expressed in this gradient of well-differentiated SE characteristics, where on the one side there are households following traditional ways-of-life associated with livestock, forestry and agricultural activities, and on the other side that are households characterized by the disaggregation of rural spaces, the revalorization of the rural and the economic pluriactivity with activities linked to the service such as tourism (Pérez, 2001; OLR, 2018a; OLR, 2018b). This transition would be caused by globalized rural development (Pérez, 2001) and social changes that incentivize the arrival of younger families with more years of schooling in rural areas (Berdegué et al., 2010b; CASEN, 2015; Zunino et al., 2016). According to Teel et al. (2010), this modernization of rural systems, including economic development, urbanization, and increasing income and education, has predictable effects on social values, contributing to an intergenerational change in values towards wildlife and environmental perception, from a perspective of domination towards one of mutualism (Manfredo et al., 2009).

This change in values orientation may be explaining why the two rural SE contexts of dog-owning households found in our study expressed different patterns of dog ownership and management. Our findings lay the foundation for future research on changes in attitudes and values from this perspective.

Domestic dogs are very popular in Chile, and it has one of the highest number of dogs per capita in rural areas (see Gompper, 2014a). The proportion of rural households with dogs reported in our study (85.8%, Table 3) was similar to that reported in other studies conducted in rural southern Chile (Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Schüttler et al., 2018; Villatoro et al., 2018), suggesting a general pattern for the region. The probability of dog possession was negatively associated with years of schooling of the head of household ($p < 0.05$) and positively associated with number of people living in the household ($p > 0.05$) (Table 4). The number of people per household has been reported to be positively related to dog ownership in other parts of the world (see Franti et al., 1974; Westgarth et al., 2007; Murray et al., 2010). Our findings could be due to the fact that larger families may be made up of younger members, whose presence has been reported to be positively related to dog ownership (see Westgarth et al., 2007; Murray et al., 2010). On the other side, a higher likelihood of dog possession in households with fewer years of schooling is consistent with the study by Murray et al., (2010), who reported that urban and rural United Kingdom households with higher educational degrees were much less likely to own a dog, possibly because occupations requiring higher levels of education are associated with jobs outside the household and therefore less time available for dog care. In addition, as observed in the results, traditional rural households of southern Chile are characterized by fewer years of schooling and are dedicated to livestock activities, so the presence of dogs in these households, more than an option, is a utilitarian necessity and a deeply rooted cultural tradition (Valadez and Mendoza, 2005).

Although almost all interviewed rural households had dogs, the number of dogs per household varied markedly and, together with the density of houses, could determine the frequency of the dog presence in rural areas and remnant-forest (Silva-Rodríguez and Sieving, 2012; Sepúlveda et al., 2015; Ribeiro et al., 2019). The average number of dogs per household in our study (2.3 dogs, Table 3) was similar to that reported in prior studies from other rural areas of Chile (Acosta-Jamett et al., 2010; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Schüttler et al., 2018; Villatoro et al., 2018). This variable was positively influenced by livestock/agroforestry contexts and negatively by the possession of livestock of a species as a subsistence activity (Figure 2, Table 6). Previous studies report a greater probability of dog ownership and a greater number of them in households with livestock activities (Knobel et al., 2008), which would be associated with their utilitarian role in animal herding and care (Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Schüttler et al., 2018). In addition, the number of dogs per household was directly related to the age of the head of household and the interviewee. These results coincide with Marinelli et al. (2013), who found that as the age of household members increased, the number of dogs increased, but their study was conducted in urban areas of Brazil, where the integration and management of dogs in a home is different. Contrasting results were found in Westgarth et al. (2007)

and Murray et al. (2010), who studied urban and rural areas of the United Kingdom, and reported that younger households were more likely to own more than one dog. Our results could be explained by the isolation of traditional rural families, where a greater number of dogs would facilitate rural labor, particularly for households whose main income is associated with the ownership of several livestock species, and the advanced average age of these adults.

As in other studies of rural Chile (Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Schüttler et al., 2018; Villatoro et al., 2018), we found an average age of rural dogs biased towards adults (4.5 years, Table 3), which could be due to the high mortality rate of puppies, due to the elimination of unwanted litters and previously reported diseases (Sepúlveda et al., 2014; Villatoro et al., 2018). Using PLSR, we showed that the age of the dogs was positively influenced by the years of schooling of the owner, the number of farm animals, and the ownership of livestock meant for sale. These results suggest that dog owners with more schooling could be more informed on issues of responsible pet ownership, which would result in lower mortality risk factors, and some households told us that more adult dogs would be better trained for animal herding and care than juvenile dogs.

We found no significant associations with the dog sex variable, given the strong bias of the owners when selecting male dogs (male: female 3.4: 1 ratio, Table 3). This bias would be due to the reproductive behavior of females, where coming into heat would be problematic, because it attracts male dogs and is associated with a decrease in the body condition of working dogs (Sepúlveda et al., 2014).

Although we found general dog management (Table 3) similar to that reported in other studies in rural areas of developing countries (Butler and Bingham 2000; Kitala et al. 2001; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al. , 2014, Ortega-Pacheco et al., 2015; Sepúlveda et al., 2015; Schüttler et al., 2018; Villatoro et al., 2018), incorporating the socio-economic heterogeneity of 218 households from different geographical areas allowed us to define a gradient between two rural dog management profiles that varied according to the SE characteristics of their owners (Figure 2; Table 6).

In general terms, livestock SE contexts were associated with free-ranging dogs fed wheat bran once a day, with insufficient veterinary care, and with functions linked mainly to the animal herding and care. This association could be caused by the geographic isolation of these homes and the tendency of reduced physical condition of aging owners, which would make access to urban and veterinary centers difficult. In addition, poor access to education in these traditional rural families (Berdegué et al., 2010a, 2010b; Castro, 2012; CASEN, 2015) could be associated with misinformation regarding responsible pet ownership and the increased risks to wildlife associated with free-ranging dogs. However, the value orientations related with wildlife and dogs in these contexts could be more related to materialistic perspectives, and a utilitarian role for dogs (Teel et al., 2007), so more studies about the human dimension are needed.

Socio-economic contexts linked to service activities were, in contrast, associated with dogs being fed commercial food and twice a day, with sufficient or optimal veterinary care, and with main function of companionship. This association, according to Teel et al. (2007), could be caused by urbanization of the population and the change to a service economy changing the materialist perspective towards that of a post-materialist one linked with mutualistic values, in which people see animals as something more "human" and deserving of concomitant rights and care. This change in assessment would be due to the upbringing of young people in very different environments from previous generations, where learning would take place largely through indirect means (e.g., television, social interaction, formal education and internet) (Teel et al., 2010). The greater access these households have to information and veterinary centers, along with younger families with higher levels of education (Berdegué et al., 2010b; Castro, 2012; CASEN, 2015), is associated with a new form of thinking about wildlife and a change in the concern of the state of dogs and the risks associated with their presence in rural areas (Teel et al., 2007, 2010).

Neither the provision of leftovers as food, found in the vast majority of households (80.7%), nor high frequency feeding (3+ times/day), found in a minority of households (10.6%) (Table 3), were associated with SE factors (Table 6). This could be due, in part, to the low variability shown by these indicators, affecting the power of statistical analyses, as well as cultural factors. In other words, the declared feeding frequency could be biased, with interviewees assuming that declaring a higher frequency is synonymous with demonstrating better care for their dogs. We also found no significant associations between SE variables and the degree of movement restriction of dogs (Table 6). Various households mentioned during the interviews that attacks on cattle, getting run over by cars, and aggressiveness of the dog were reasons to tether or lock up their dogs, which would indicate that external factors more strongly influence the decision to restrict the movement of their dogs.

5. Conclusion

This article presents the results of the first study that documents the regional SE heterogeneity of various households located in different geographic areas and associated this variability with dog ownership and management in rural landscapes of southern Chile. Our study reveals that there is no single "rural dog", but in fact various types of rural dogs, with ownership and management varied according to the SE characteristics of their owners.

Since dog and human populations are expected to grow and expand over the coming decades, work with rural people and their dogs is critical. Local commitment and support by residents are key to implementing successful dog management plans that educate the population on issues of responsible pet ownership and also control the risks that dogs represent near protected areas or forest remnants. The success of these management programs will be more effective if the SE reality of dog owners is considered and if both the interests and needs of rural communities and species under conservation are integrated, which will permit the reconciliation of social and ecological interests. This is especially important in rural areas where dogs play a fundamental role as workers.

We propose to prioritize research and educational work in homes with traditional lifestyles and strong livestock activities, which is where dog-wildlife interactions would be more likely to occur as a result of greater numbers of dogs present and worse dog management. We suggest that future research relate the findings of this study to the intensity of dog-wildlife interactions, in order to identify areas of greatest potential conflict. The low variance explained by the PLSR model on the Ax2 axis (Acum. Var. X = 35.1%; Acum. Var. Y = 31.2%; Table 5) show that other factors could be affecting the association of SE variables with the dog ownership and management, so more research should be conducted.

It should be noted that rural communities, especially traditional small-scale ones, are direct users of ecosystems through agriculture, livestock, and forestry activities, which makes them central decision makers in their management (Castillo et al., 2018). Therefore, rural residents and dog owners should be seen as key stakeholders for conservation, since their actions will determine the course and resolution of dog-wildlife interactions, allowing for the well-being of the residents and the conservation of endangered species.

Conflict of interest statement

The authors of the study declare that there is no conflict of interest.

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Appendix. Supplementary Material

Questionnaire S1. Interview conducted with rural populations.

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Chapter 2

Understanding the relationship between socio-economic factors of the population and current landscape metrics in rural communities of the Temperate Rainforest Ecoregion of southern Chile

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Abstract

The way in which anthropogenic pressures change the landscape structure is strongly linked to the historical development of society and to socio-cultural and economic aspects of the population. Socio-economic (SE) forces are one of the main drivers of landscape change so understanding their influence on landscape structure in rural areas is paramount for biodiversity conservation. The objective of this study was to investigate the local SE factors, from 14 rural communities located in different geographical zones of the Temperate Rainforest Ecoregion of southern Chile, that predict and relate to the metrics of current landscape structure. For this purpose, (1) metrics of configuration and composition of the current landscape were calculated at the level of native forest, grassland, scrubland and exotic plantation classes (total area (CA), percentage of landscape (PLAND), patch density (PD), edge density

(ED), largest patch index (LPI), average area of all patches (AREA) and proximity index (PROX)), (2) the rural communities was characterized socio-economically through the application of interviews to households, and (3) the relationship between the metrics of the current landscape structure of all classes as a whole and the local SE variables was modeled by partial least squares regression (PLSR). PLSR models indicated significant relationships between local SE factors and current landscape structure metrics. The SE variable that had the most weight in all models was the geographic area, which suggests two different SE contexts reflected in current landscape metrics. On the one side, landscapes with greater coverage and representation of the grassland, scrubland and exotic plantation classes (higher values of CA, PLAND, LPI, AREA, PD, ED and PROX metrics) and greater fragmentation of the native forest cover (higher values of PD and ED metrics) were observed, which are characterized by belonging to the Central Valley, possessing a higher number of dogs and farm animals, engaging in livestock activities and owning livestock for sale and of multiple species. On the other side, landscapes with greater coverage and less fragmentation of the native forest class (higher values of CA, PLAND, LPI, PROX and AREA metrics) we observed, which are characterized by belonging to the mountain ranges and Chiloé, not possessing dogs or farm animals, or owning livestock for subsistence, and engaging in marine species extraction activities, services and/or agroforestry. Our results reveal that several local SE factors are associated with class level metrics of the current landscape structure, and suggest the important role that rural communities have in defining the landscape structure through practices that depend directly on the use of natural resources.

Keywords: Land cover; landscape structure; class level metrics; local socio-economic factors; rural community; geographic area; temperate forests.

1. Introduction

The land surface is continuously subject to changes in soil cover (biophysical attributes of the land surface) and land use (human use or intent applied to these attributes) (Lambin et al., 1999; Turner et al., 2001; August et al., 2002; Bürgi et al., 2004). These changes are the result of a combination of natural disturbances, such as glaciations, floods, alluviums, droughts and anthropogenic disturbances related to land habilitation for agriculture, deforestation and urbanization (Leitão et al., 2006; Armesto et al., 2010; Curtis et al., 2018). The landscape, understood as a process emerging from the interaction of humans with their physical-biotic environment and modulated by technology and the laws of time and place, can be seen from a historical point of view as the expression of the past and present interrelationship between society and nature and the dialogue that has been generated around the exploitation of natural resources (Varga and Vila, 2005). The way in which anthropogenic pressures change the spatial patterns of the landscape (i.e. the spatial configuration of landscape patches in various sizes and shapes and the spatial relations between them, Forman and Godron, 1986) is strongly linked to the historical development of society (Torres-Gómez et al., 2009; Miranda et al., 2015) and to socio-cultural and economic aspects of the population (Naveh 1987; DeFries et al., 2004, 2006; Giannecchini et al., 2007; Fu et al., 2013). This change, understood as a complex socio-economic and environmental problem, requires a comprehensive understanding of the relationship between human-induced activities and the constituent attributes of the landscape (Gastó et al., 2012; Brown et al., 2013). The fragmentation, loss and/or transformation of forest ecosystems into land suitable for agricultural, livestock, forestry and urban development has played the most important role in the formation of the spatial configuration and composition of landscape elements (i.e. landscape structure) (Medley et al., 1995; Sala et al., 2000; Turner, 2005; August et al., 2012; Echeverría et al., 2012; Curtis et al., 2018), particularly in rural communities in developing countries with subsistence economies (Kaeslin et al., 2013).

Rural communities in the Temperate Rainforest Ecoregion of southern Chile are experiencing a socio-cultural and economic transition that directly and indirectly influences the way society interacts with nature. Many of these households, mainly traditional rural families, still rely heavily on nature for their subsistence (see chapter 1 of this thesis). This historical interaction has made temperate forests the biome with the second highest loss of natural forests (3.5%) in recent years (2000 to 2005) (Hansen et al., 2010), and the preferred biome for land conversion to agriculture and grazing (Ellis, 2011). The Temperate Rainforest Ecoregion is considered a hotspot for biodiversity conservation (Myers et al., 2000). Due to the prolonged isolation of the habitats, the biodiversity in these forests shows high levels of endemism, which makes it an important target for conservation (Armesto et al., 1992, 1998; Myers et al., 2000; Smith-Ramirez 2004). The temperate forests of South America have experienced a long history of intense landscape modification. They originally occupied most of continental and insular Chile (latitude 36º S), and the eastern slopes of the Andes Range in Argentina (Armesto et al., 1998). However, throughout history the southern temperate forests have been highly susceptible to land cover change and species invasions (Armesto et al., 1998). Only half of the forest that existed in the second half of the 16th century remains (Lara et al., 2012), and it is confined to inaccessible areas of the Andes and areas further south in its distribution. A large fraction of the native temperate forest has recently been cut for timber extraction, to open up agricultural land or to be replaced by forest plantations of exotic trees (Wilson and Armesto, 1996; Echeverría et al., 2006, Aguayo et al., 2009; Altamirano and Lara, 2010; Altamirano et al., 2013a; Altamirano et al., 2013b). As a result, the landscape is now made up of remnants of native forest that differ in extent and degree of intervention, surrounded by an anthropized matrix dominated by grasslands, farmland, forest plantations and scrub (Aravena et al., 2002; Echeverría et al., 2007). One of the historical strategies to conserve and separate biodiversity from these processes that threaten its existence in nature has been the creation of protected areas (PA) (Margules and Pressey, 2000). However, due to the intense landscape modification in these ecosystems, PAs may become immersed in a matrix of landscapes altered by human intervention and exposed to external factors such as rural communities and domestic species (DeFries et al., 2007; Jones et al., 2009; Lacerda et al., 2009; Bailey et al., 2015), so understanding how rural communities relate to landscape change in these areas is crucial for biodiversity conservation.

Because human perception significantly changes the interpretation of landscapes, methods such as landscape metrics have been developed for the objective quantification of spatial heterogeneity (Gustafson, 1998; Uuemaa et al., 2013). Quantification of landscape structure is essential to investigate relationships between spatial patterns and ecological processes (Turner, 1990; Turner, 2005; McGarigal et al, 2012; Uuemaa et al., 2013). While a number of studies have investigated the relationship between human activities and landscape change, only a small number have focused on linking landscape structure to socioeconomic drivers and a comparatively smaller number have associated landscape structure metrics with socioeconomic (SE) forces. Most studies linking landscape change to socio-economic drivers have focused on a single land cover type or on deforestation and forest use, and assessed variables that differ among them. The socio-economic variables analyzed have included socio-demographic data such as age, gender, education and household size, time spent living near the forest, productive activities and the ownership and number of livestock, among others (see Hietel et al., 2005; Echeverría et al, 2006; Giannecchini et al., 2007; Hietel et al., 2007; Mitinje et al., 2007; De Aranzabal et al., 2008; Gasparri and Grau, 2009; Carmona et al., 2010; Díaz et al, 2011; Echeverría et al., 2011; Giliba et al., 2011; Gong et al., 2013; Ghafouri et al., 2016; Lavelle et al., 2016; Xystrakis et al., 2017; Handavu et al., 2019). Studies that have directly and indirectly associated landscape structure metrics with SE drivers have used landscape metrics as predictor variables for SE factors. For example, Herzog et al. (2001) identified a set of metrics to monitor disturbed landscapes caused by agricultural intensification and mining in Germany and confirmed, indirectly, that the landscape had undergone considerable transformation caused by the economic need for natural resources and facilitated by technological advances in mining and agricultural production. Leitão and Ahern (2002) demonstrated that human activities such as agriculture and urban development are obvious causes of habitat fragmentation, and this phenomenon can be measured by landscape metrics. Ghafouri et al. (2016) found significant relationships between SE factors and landscape metrics in Iran, and concluded that land use/land cover data are applicable for modelling SE factors. While these studies have incorporated various SE variables, most of them were obtained from public regional and communal statistics, generalizing the local SE characteristics.

Because human population interaction with the landscape is complex and varies between regions, local and detailed studies of the relationship between landscape structure and human SE factors are necessary to avoid generalizations that could lead to the confusion of drivers of land cover change (Lambin et al. 2001; Geist and Lambin 2002; Giannecchini et al., 2007). Knowing the relationship between the current landscape structure and its local SE drivers is essential for the planning and implementation of management and conservation programs locally and regionally, since it will allow the SE reality of each community to be contextualized and social and ecological interests to be reconciled within a human development framework (DeFries et al. 2004; Matteucci et al. 2004; De Angelo 2009).

Our study focused on 14 rural communities of the Temperate Rainforest Ecoregion of southern Chile, located in four geographic zones with different histories of land use and human disturbance (Armesto et al., 1994), in order to cover the greatest possible heterogeneity of local SE contexts. We were interested in investigating what local SE factors of the rural population predict and relate to the current landscape structure, and how the class level metrics of the current landscape vary with different SE contexts. We selected 4 classes of land cover (Native Forest, Grassland, Scrub and Exotic Plantation) given their importance in the anthropic transformation of the rural landscape and the conservation of the temperate forests of southern Chile. To do this, we quantified the 14 landscapes in terms of their landscape structure based on a recognition of current land cover, characterized the SE factors of the rural communities that inhabit each of the 14 landscapes through the application of interviews, and modeled the relationship between class level metrics of the current landscape structure as a whole and the local SE variables of the 14 rural communities.

2. Material and methods

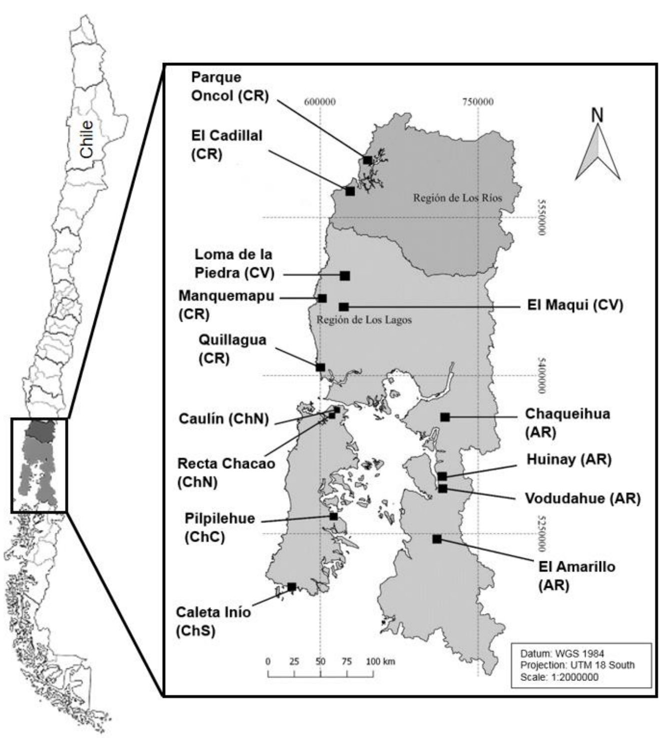
2.1 Study Area

The study was carried out in 14 rural communities in southern Chile located in the Los Ríos and Los Lagos Regions (39° 40' S to 43° 23' S) (Figure 1). The area's climate is temperate and rainy, with an average temperature of 10.6 °C and precipitation distributed throughout the year, decreasing from the mountains to the central valley (2,500 to 1,200 mm/year) (Rioseco and Tesser, n.d.). The dominant vegetation cover is temperate rainforest and Valdivian lauriphyllous forest (Luerbert and Pliscoff, 2004), located mainly within the PA and in areas with high elevation. The study area is ecologically unique because it is inserted in the Temperate Rainforest Ecoregion declared a hot spot for terrestrial biodiversity conservation (Myers et. al, 2000). The human settlement process has resulted in the introduction of several exotic species such as domestic dogs, which now coexist and interact with the local fauna and influence the forest remnants (Armesto et al., 1992).

2.2 Sample design and SE data collection

The 14 study sites were selected according to a set of criteria that would allow the representation of the four large geographical areas within the Temperate Rainforest Ecoregion of southern Chile and their SE heterogeneity (see chapter 1 of this thesis). The selected communities are located adjacent (<2 km) to PA and large extensions of native forest, and are located in four geographic areas with different histories of land use and human disturbance (Armesto et al., 1994): Coast Range, Andes Range, Central Valley and Chiloé Island (Figure 1). All communities have a low human population density and are uniquely rural. Economic activities vary between and within communities, and are mainly associated with livestock (raising cattle, sheep and poultry), agriculture, marine species extraction, forest resource use (timber) and services (OLR, 2018a; OLR, 2018b).

Figure 1. Rural communities visited during the study and number of interviews conducted by community and geographic area.



Geographic Zone		Community	Number of interviews
Coast Range (CR) (1)		Parque Oncol	23
		El Cadillal	11
		Manquemapu	16
		Quillagua	14
Andes Range (AR) (2)		Chaqueihua	12
		Huinay	6
		Vodudahue	7
		El Amarillo	18
Central Valley (CV) (3)		Loma de la Piedra	21
		El Maqui	21
Chiloé Island (4)	North (ChN)	Caulín	20
		Recta Chacao	16
	Center (ChC)	Pilpilehue	19
	South (ChS)	Caleta Inío	14
Number of total interviews			218

In order to collect socio-economic data from households in each community, semi-structured interviews with open responses (Newing, 2011) were conducted between December, 2016 and August, 2017 with one adult per household (n = 218 households) (Figure 1). More details of the methodology are provided in Chapter 1 of this thesis. The information collected from each interview included SE variables of the participants that have shown association with landscape changes in studies inside and outside the country (Carmona et al., 2010; De Aranzabal et al., 2008; Díaz et al., 2011; Ghafouri et al., 2016; Giliba et al., 2011; Handavu et al., 2019). The SE data collected were gender, age and years of schooling of the interviewee and/or head of household, number of people living in the household, years of residence in the sector, the economic activity to which they were dedicated, and if they owned farm animals, which ones and for what purposes (Table 1). The variables dog possession and number of dogs per household were also included, as these variables are closely linked to the social characteristics and type of economic activity and number of farm animals in these rural communities, and would therefore represent a socio-economic configuration not covered by the other variables (see Chapter 1 of this thesis). We included the variable geographic area since it involves a set of factors that are not within the model and that help to explain the other variables. This variable represents a grouping of physiographic environmental factors of the study area, which are known to have different histories of landscape change but were not measured (Table 1).

Table 1. SE variables used for modeling, obtained from 218 interviews in 14 rural communities of the temperate forests of southern Chile.

Variable	Type	Coding	Description
CPP	Dummy	0,1	Possession or not of dogs in the household
NPC	Numeric	-	Number of dogs in the household
GEF	Dummy	1,2	Female interviewee (1), male interviewee (2)
EE	Numeric	-	Age of the interviewee
AEE	Numeric	-	Years of schooling of the interviewee
GJF	Dummy	1,2	Head of household female (1), male (2)
EJ	Numeric	-	Age of head of household
AEJ	Numeric	-	Years of schooling of the head of household
NPH	Numeric	-	Number of people living in the household
ARS	Numeric	-	Years of residence in the sector
AGRA and AGRP	Dummy	0,1	Household dedicated or not to agroforestry activities at present and in the past
GNDA and GNDP	Dummy	0,1	Household dedicated or not to livestock activities at present and in the past
RRMA and RRMP	Dummy	0,1	Household dedicated or not to marine species extraction activities at present and in the past
SRVA and SRVP	Dummy	0,1	Household dedicated or not to service activities at present and in the past
POSG	Polytomic	0	No possession of farm animals
		1	Possession of farm animals for subsistence
		2	Possession of farm animals for sale
CA	Numeric	-	Number of farm animals
SPS	Polytomic	0	No possession of farm animals
		1	Possession of one species of farm animal
		2	Possession of several species of farm animals
AVC	Dummy	0,1	Possession or not of poultry
OVE	Dummy	0,1	Possession or not of sheep
VAC	Dummy	0,1	Possession or not of cows
CER	Dummy	0,1	Possession or not of pigs
ZNG	Polytomic	1	Household located in Coast Range
		2	Household located in Andes Range
		3	Household located in Central Valley
		4	Household located in Chiloé Island

2.3 Classification of land cover

To identify the land cover associated with each community, Landsat 8 satellite images of the summer season of 2018 with clear sky conditions were used to allow adequate comparability between them. To create the polygon and classify the land cover based on the characteristics of each landscape and the households interviewed, a buffer of 5 km (3400 to 4700 ha) was established, from the centroid of each community adjacent to the PA or large areas of forest. The images were processed to minimize errors in the classification process, applying geometric, atmospheric and topographic corrections (Horning et al., 2010). A supervised classification method based on a vector support machine was applied (Horning et al., 2010) considering the following land cover classes: (1) Water; (2) Forest; (3) Grassland; (4) Scrubland; (5) Bare soil; (6) Anthropogenic construction; (7) Shadows; (8) Plantation and (9) Wetland. The collection of control points for the validation of the classification was done using as sources: (1) high-resolution images available on Google Earth™ (Google Inc., 2016) and (2) field sampling conducted during the years 2016 and 2017. The accuracy of the classification was evaluated using a confounding matrix, obtaining an overall accuracy between 84.9% and 99.6% for the 14 locations and a Kappa Cohen coefficient between 0.80 and 0.99. The "Plantation" class, present in the communities of El Cadillal, Loma de la Piedra, El Maqui and Parque Oncol, was identified through photointerpretation and subsequently imported to the classification. The pre-processing and classification of images was done using the PCI Geomatics and ArcMap10 (ESRI, Redlands, CA) programs.

2.4 Analysis of the landscape structure

Landscape metrics were calculated from the recognized land cover for the classes Forest, Grassland, Scrubland and Plantation, given their importance in the anthropic transformation of the rural landscape and the conservation of the temperate forests of southern Chile. The following commonly used class level metrics were selected according to landscape composition and configuration attributes: (1) Total area (CA); (2) Percentage of landscape (PLAND); (3) Patch density (PD); (4) Edge density (ED); (5) Largest patch index (LPI); (6) Average area of all patches (AREA_MN) and

(7) Proximity index within 2000 m (PROX) (see Table 2). Metrics were quantified using FRAGSTATS 4 (McGarigal et al., 2012).

Table 2. Final selection of class level metrics to quantify landscape structure.

Measured attribute	**Index**	**Metric**	**Unit**	**Description**
Composition	CA	Total area	ha	Sum of the areas of all patches of the corresponding patch type.
Composition	AREA	Average area	ha	Average size of patches of the corresponding patch type
Composition	LPI	Largest patch index	%	Percentage of the landscape of the largest patch of the corresponding patch type
Composition	PLAND	Percentage of landscape	%	Percentage the landscape of the corresponding patch type.
Configuration	ED	Edge density	m/ha	Sum of the lengths of all edge segments involving the patch type, divided by the total landscape area
Configuration	PD	Patch density	Number/ 100 ha	Number of patches of the patch type divided by total landscape area
Configuration	PROX	Proximity index	None	Distance to the nearest patch of the patch type in a given search radius.

2.5 Data analysis

A model based on Partial Least Squares Regression (PLSR) was used to understand and predict the relationship between local SE factors of the rural population and the metrics of the current landscape structure of the four land cover classes as a whole.

This covariance-based multivariate technique is an extension of multiple regression analysis in which the effects of linear combinations of several predictors on one or multiple response variables are analyzed. In PLSR, the general objective is to use factors to predict population responses. This is achieved indirectly by extracting the latent variables T and U from the sampled factors (predictor variables) and responses, respectively. The extracted factors T (also called X-scores) are used to predict the Y-scores U, and then the predicted Y-scores are used to construct predictions for the responses (Tobias, 2003). These latent factors are defined as linear combinations built between the predictor and response variables, so that the original multidimensionality is reduced to a smaller number of orthogonal factors to detect the structure in the relationships between the predictor variables and between these latent factors and the response variables. The extracted factors account for successively lower proportions of the original variance (Hubert and Branden, 2003, Carrascal et al., 2009). PLSR is particularly suitable when the predictors are highly correlated (i.e. there is strong collinearity), the number of predictor variables is similar to or greater than the number of observations (i.e. overfitting) and/or there is a non-normal distribution of data (Abdi, 2007; Carrascal et al., 2009). Although this type of data is quite common in ecological studies, the use of PLSR remains rare (Carrascal et al., 2009).

Therefore, the PLSR model used has the following structure:

$$X = TP^T + E$$
$$Y = UQ^T + F,$$

where X is a matrix of $n \times m$ predictors, Y is a matrix of $n \times p$ responses; T and U are $n \times l$ matrices which are projections of X (X-scores) and projections of Y (Y-scores), respectively; P and Q are $n \times l$ and $p \times l$ matrices of orthogonal charges, respectively; and the E and F matrices are the error terms. The decompositions of X and Y are done to maximize the covariance of T and U.

The data set used for the PLSR analysis included all observations of the households interviewed (n = 218). The PLSR model was run at an aggregate scale, i.e. all metrics of the four land cover classes (i.e. Native Forest, Grassland, Scrubland and Exotic Plantation) were incorporated into the modeling to understand their overall behavior within the landscape. Performing the analysis at an aggregated scale allows a better understanding of the structural reality of the landscape, because the patches of each land cover class and their metrics are related within and between them. For example, several authors have reported interactions between agricultural, shrublands and grasslands covers with native forest cover (Schulz et al., 2010; Díaz et al., 2011; Schulz et al., 2011; Echeverría et al., 2012), increases in forest cover as a result of reduced agricultural cover (Díaz et al., 2011; Hernández et al, 2016), and loss or replacement of forest and shrub cover by exotic plantations (Altamirano and Lara, 2010; Miranda et al., 2015; Zamorano-Elgueta et al., 2015). This would explain the structural relationship of the different patches and classes, where an increase in one land cover would lead to a decrease or transformation of another.

The statistical analysis was performed using the "ade4" package (see Bougeard and Dray, 2018) in the R software (R Development Core Team 2018). The optimal model and predictive ability were evaluated by double cross-validation (Stone, 1974). The optimal number of dimensions (or multivariate axes) sufficient to describe the main gradients of covariation between the variables was determined through the trade-off between good fit (minimizing the root mean square error of calibration, RMSECC) and good predictive ability (minimizing the root mean square error of validation, RMSECV) (Bougeard and Dray, 2018). To identify significant relationships between predictive and dependent variables in the optimal model, 1000 bootstrap simulations were performed to provide confidence intervals, calculated by the non-Studentized pivotal method (Carpenter and Bithell, 2000). The regression coefficients of the optimal model measure the links between each explanatory and dependent variable. A coefficient is considered significant if the 95% bootstrap confidence interval did not contain the threshold value 0.

3. Results

3.1 SE characteristics of rural households

Table 3 presents the socioeconomic characteristics of the 218 households interviewed, on average and by geographical area. It can be seen that households in zone 3 (Central Valley) have a larger number of houses with dogs, a larger number of dogs/house, a larger number of households dedicated to livestock activities and a larger number of farm animals for sale of several species. The households in zone 2 (Andes Range) have the lowest number of dogs, more years of schooling and more households dedicated to service activities.

Table 3. Social and economic characteristics by geographical area and overall average of 218 households in 14 rural communities of the temperate forests of southern Chile.

Measured aspect	**Response**				
Social characteristics	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Total or average**
Total number of households interviewed	64	43	42	69	218
Households with dog ownership (%)	57 (89.1)	28 (65.1)	40 (95.2)	62 (89.9)	187 (85.8)
Total number of dogs; No. of dogs per dog owning household (SD)	122; 2.2 (1.1)	48; 1.7 (0.7)	120; 3.0 (1.8)	145; 2.3 (1.4)	435; 2.3 (1.4)
Gender of respondents: Male (%); Female (%)	33 (51.6); 31 48.4)	16 (37.2); 27 (62.8)	18 (42.9); 24 (57.1)	32 (46.4); 37 (53.6)	99 (45.4); 119 (54.6)
Average age of interviewees (SD)	52.2 (16.7)	53.0 (16.2)	51.2 (17.3)	49.2 (14.3)	51.3 (15.9)
Average years of schooling of interviewees (SD)	7.5 (4.1)	9.8 (5.0)	8.9 (4.4)	8.7 (3.6)	8.6 (4.3)
Gender of head of household: Male (%); Female (%)	52 (81.3); 12 (18.7)	27 (62.8); 16 (37.2)	28 (66.7); 14 (33.3)	42 (60.9); 27 (39.1)	149 (68.3); 69 (31.7)
Average age of head of household (SD)	55.7 (14.5)	53.4 (17.1)	55.1 (12.9)	50.4 (14.3)	53.6 (14.7)
Average years of schooling of the head of household (SD)	7.0 (3.6)	9.9 (5.3)	8.3 (3.8)	8.3 (3.6)	8.3 (4.1)

Average number of people per household (SD)	3.4 (1.8)	2.7 (1.5)	2.8 (1.6)	3.4 (1.4)	3.1 (1.6)
Average years of residence in the sector (SD)	40.6 (22.2)	25.7 (24.9)	28.4 (23.3)	36.1 (18.8)	34.0 (22.6)
Economic characteristics	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Total or average**
Households dedicated to agroforestry activity (%)	45 (70.3)	16 (37.2)	22 (52.4)	34 (49.3)	117 (53.7)
Households dedicated to livestock activity (%)	31 (48.3)	14 (32.6)	24 (57.1)	22 (31.9)	91 (41.7)
Households dedicated to marine species extraction activity (%)	11 (17.2)	2 (4.7)	0 (0.0)	23 (33.3)	36 (16.5)
Households dedicated to service activity (%)	27 (42.2)	34 (79.1)	20 (47.6)	36 (52.2)	117 (53.7)
Total number of households with possession of farm animals (%)	55 (85.9)	26 (60.5)	34 (81.0)	58 (84.1)	173 (79.4)
For subsistence (%)	24 (37.5)	12 (27.9)	11 (26.2)	36 (52.2)	83 (38.1)
For sale (%)	31 (48.4)	14 (32.6)	23 (54.8)	22 (31.9)	90 (41.3)
With one species (%)	22 (34.4)	12 (27.9)	10 (23.8)	20 (29.0)	64 (29.4)
With 2 or more species (%)	33 (51.7)	14 (32.6)	24 (57.1)	39 (56.5)	109 (50.0)
Average number of farm animals per household (SD)	22.3 (19.6)	21.6 (43.5)	34.2 (42.1)	27.5 (29.7)	33.1 (34.3)
No. of households with poultry (%)	38 (59.4)	19 (44.2)	24 (57.1)	45 (65.2)	126 (57.8)
No. of households with sheep (%)	28 (43.8)	11 (25.6)	22 (52.4)	38 (55.1)	99 (45.4)
No. of households with cows (%)	34 (53.1)	15 (34.9)	20 (47.6)	22 (31.9)	91 (41.7)
No. of households with pigs (%)	16 (25)	5 (11.6)	15 (35.7)	19 (27.5)	55 (25.2)

3.2. Characteristics of the landscape structure

Table 4 presents class level metrics of landscape structure in the study area by zone, community and land cover class. The communities in zone 1 (Coast Range) and 2 (Andes Range) had higher average values of CA, PLAND, LPI and AREA metrics in the Native Forest class, while localities in zone 3 (Central Valley) and 4 (Chiloé Island) had higher average values of CA, PLAND, LPI and AREA metrics in the Scrubland and Grassland classes. The exotic plantation class was only present in communities of zone 1 and zone 3.

Table 4. Class level metrics of the landscape structure of the classes Native Forest, Grassland, Scrubland and Exotic Plantation of 14 rural communities of the temperate forests of southern Chile. CA = Total area, PLAND = Percentage of landscape, PD = Patch density, ED = Edge density, LPI = Largest patch index, AREA = Average area of all patches, PROX = Proximity index within 2000 m.

Native forest class								
Zone	**Community**	**CA**	**PLAND**	**PD**	**LPI**	**ED**	**AREA**	**PROX**
1 (CR)	Parque Oncol	2914.56	80.85	2.11	78.97	43.38	38.35	5792.12
	El Cadillal	2843.28	82.78	3.87	71.97	33.05	21.38	2862.84
	Manquemapu	2289.55	75.72	2.81	39.92	57.78	26.94	2532.54
	Quillagua	2568.65	67.76	1.90	63.75	34.77	35.68	5204.23
	Zone average 1	**2670.39**	**77.04**	**2.54**	**64.67**	**43.32**	**31.99**	**4345.16**
2 (AR)	Chaqueihua	4038.28	85.85	1.76	83.36	28.57	48.65	7560.74
	Huinay	1280.48	80.89	1.39	80.61	44.81	58.20	3765.23
	Vodudahue	1728.40	64.86	4.54	17.00	65.29	14.28	821.08
	El Amarillo	3273.32	80.80	3.26	78.43	52.60	24.80	6842.44
	Zone average 2	**2957.23**	**79.63**	**2.79**	**70.11**	**46.87**	**34.41**	**5633.30**
3 (CV)	Loma de la Piedra	2118.69	61.96	3.60	50.14	59.04	17.23	1810.64
	El Maqui	1847.61	53.32	7.53	40.86	51.36	7.08	507.73
	Zone average 3	**1983.15**	**57.64**	**5.56**	**45.50**	**55.20**	**12.15**	**1159.19**
4 (Ch)	Caulín	1039.47	59.80	5.12	48.96	50.65	11.68	1079.18
	Recta Chacao	1189.84	47.39	10.75	19.71	93.45	4.41	479.35
	Pilpilehue	1802.16	68.57	1.67	26.07	46.19	40.96	1417.20
	Caleta Inío	1721.23	45.29	6.66	34.22	64.71	6.80	2069.25
	Zone average 4	**1422.68**	**56.39**	**5.79**	**32.88**	**62.20**	**17.07**	**1234.05**
Grassland Class								
Zone	**Community**	**CA**	**PLAND**	**PD**	**LPI**	**ED**	**AREA**	**PROX**
1 (CR)	Parque Oncol	200.79	5.57	7.05	0.77	25.76	0.79	7.82
	El Cadillal	145.80	4.24	2.33	1.61	14.07	1.82	39.62
	Manquemapu	202.34	6.69	7.28	1.12	29.35	0.92	0.00
	Quillagua	311.30	8.21	9.10	1.20	34.88	0.90	20.45
	Zone average 1	**215.90**	**6.20**	**6.74**	**1.10**	**26.64**	**1.02**	**14.09**
2 (AR)	Chaqueihua	286.15	6.08	4.08	1.00	18.68	1.49	29.91
	Huinay	33.50	2.12	3.98	0.51	12.19	0.53	4.95
	Vodudahue	341.90	12.83	12.35	5.09	44.92	1.04	48.02
	El Amarillo	344.47	8.50	11.65	0.77	39.99	0.73	13.07
	Zone average 2	**284.38**	**7.64**	**8.58**	**1.50**	**30.97**	**0.96**	**22.33**
3 (CV)	Loma de la Piedra	356.04	10.41	7.05	1.19	35.43	1.48	34.94
	El Maqui	1303.20	37.61	6.20	33.74	73.68	6.06	2393.48
	Zone average 3	**829.62**	**24.01**	**6.63**	**17.47**	**54.56**	**3.77**	**1214.21**
4 (Ch)	Caulín	337.52	19.42	13.75	4.33	72.33	1.41	63.70
	Recta Chacao	654.62	26.07	10.63	11.05	70.67	2.45	249.52
	Pilpilehue	427.96	16.28	10.88	2.83	54.26	1.50	38.19
	Caleta Inío	172.07	4.53	5.63	0.62	21.72	0.80	8.66
	Zone average 4	**402.38**	**17.08**	**10.59**	**4.72**	**56.70**	**1.55**	**88.60**
Scrubland Class								
Zone	**Community**	**CA**	**PLAND**	**PD**	**LPI**	**ED**	**AREA**	**PROX**
1 (CR)	Parque Oncol	164.88	4.57	15.34	0.20	35.22	0.30	5.15
	El Cadillal	239.94	6.99	9.93	1.07	32.86	0.70	21.52
	Manquemapu	265.82	8.79	17.69	0.90	51.92	0.50	0.00
	Quillagua	236.72	6.24	9.52	0.95	33.00	0.66	16.32
	Zone average 1	**218.73**	**6.41**	**13.73**	**0.69**	**38.50**	**0.50**	**9.12**
2 (AR)	Chaqueihua	39.75	0.85	1.53	0.21	4.31	0.55	4.34
	Huinay	68.71	4.34	13.27	0.51	29.91	0.33	3.93
	Vodudahue	73.41	2.75	6.75	0.41	17.09	0.41	5.46
	El Amarillo	146.71	3.62	4.32	1.06	13.86	0.84	28.93
	Zone average 2	**94.04**	**2.81**	**5.19**	**0.64**	**13.96**	**0.62**	**14.76**
3 (CV)	Loma de la Piedra	582.03	17.02	16.61	3.20	82.71	1.02	60.57
	El Maqui	124.56	3.59	16.91	0.14	31.92	0.21	2.64

	Zone average 3	**353.30**	**10.31**	**16.76**	**1.67**	**57.32**	**0.62**	**31.60**
4 (Ch)	Caulín	136.23	7.84	24.39	0.35	59.04	0.32	5.94
	Recta Chacao	425.74	16.96	21.03	2.57	73.75	0.81	24.20
	Pilpilehue	13.31	0.51	3.04	0.08	4.86	0.17	0.58
	Caleta Inío	836.13	22.00	14.97	2.11	76.35	1.47	45.76
	Zone average 4	**311.53**	**10.81**	**15.82**	**1.15**	**51.05**	**0.62**	**16.78**
Exotic Plantation Class								
Zone	**Community**	**CA**	**PLAND**	**PD**	**LPI**	**ED**	**AREA**	**PROX**
1 (CR)	Parque Oncol	55.53	1.54	0.06	1.30	1.61	27.77	0.00
	El Cadillal	130.32	3.79	0.09	2.92	5.29	43.44	215.71
	Manquemapu	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Quillagua	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Zone average 1	**42.35**	**1.21**	**0.03**	**0.97**	**1.49**	**17.44**	**37.08**
2 (AR)	Chaqueihua	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Huinay	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vodudahue	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	El Amarillo	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Zone average 2	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
3 (CV)	Loma de la Piedra	156.51	4.58	0.26	2.15	7.51	17.39	128.01
	El Maqui	72.27	2.09	0.32	0.97	4.80	6.57	1.95
	Zone average 3	**114.39**	**3.33**	**0.29**	**1.56**	**6.15**	**11.98**	**64.98**
4 (Ch)	Caulín	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Recta Chacao	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pilpilehue	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Caleta Inío	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Zone average 4	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

3.3 Landscape structure and its relationship to SE factors

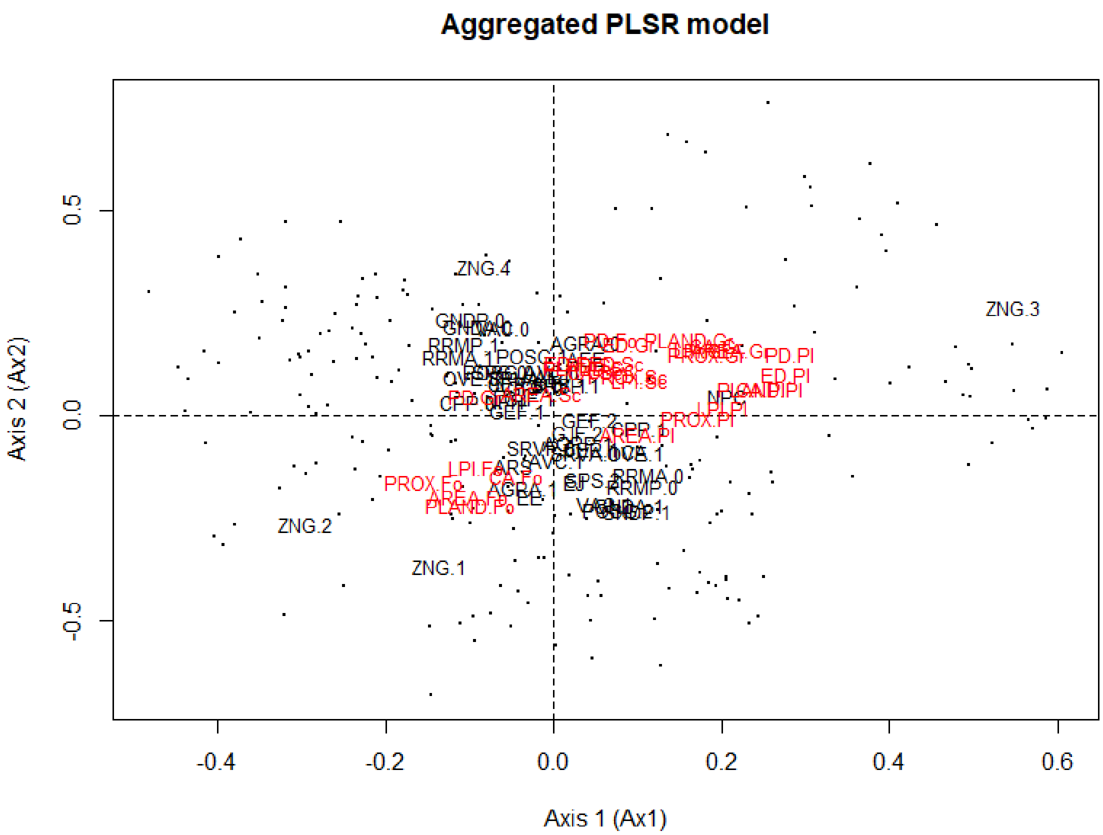
The PLSR model showed the lowest RMSECC and RMSECV for the first dimension (Ax1; Var. Y = 25.4%) (Table 5). Therefore, it is considered that one latent variable would be sufficient to describe the main patterns of covariance among the variables of the model analyzed.

Table 5. Aggregate-scale PLSR analysis of human SE factors (x) and landscape class level metrics, with cross-validation and 1000 replicates. Only the first 5 of 29 axes are shown (Ax29).

No. of PLS latent variables	**Percentage** Var. Acum. Y				**RMSECV**	**RMSECC**
	Variance X	**Var. Acum. X**	**Variance Y**	**Var. Acum. Y**	**Average**	**Average**
Aggregated clases						
Ax1	**11.945**	**11.9**	**25.406**	**25.4**	**0.986**	**0.961**
Ax2	11.353	23.3	21.578	47.0	1.005	0.996
Ax3	10.006	33.3	14.154	61.1	1.021	1.004
Ax4	5.088	38.4	13.833	75.0	1.049	1.024
Ax5	4.248	42.6	5.643	80.6	1.106	1.058

The result of the aggregated PLSR model is summarized in the biplot in Fig. 2, and the main gradient found (Ax1) is synthesized in the scheme in Fig. 3. Table 6 shows the results of the multiple bootstrapping procedure with 1 optimal dimension and the respective associated regression coefficients (b) for the aggregate scale PLSR model. Only the variables that were significant are shown.

Figure 2. Biplot summarizing the result of the aggregated PLSR model in the ordered space of the first (Ax1) and second dimensions (Ax2). In black, the sign and relative contribution of each explanatory variable (i.e. SE aspects of the rural population) are shown on each axis, and in red the projection of the response variables (landscape metrics of classes) on the multivariate plane. See variables description in table 1 and 2.



The biplot of aggregated PLSR model to the Ax1 axis (Fig. 2) suggests a gradient between two geographic areas. The positive axis shows landscapes belonging to the Central Valley (3), and the negative axis shows landscapes belonging to the Coast Range (1), the Andes (2) and Chiloé Island (4). The landscapes in zone 3 are characterized by a greater number of dogs, past and/or present livestock activities and a greater number of farm animals of several species for sale. These landscapes are associated with a greater coverage and representation of grasslands, scrubland and exotic plantation classes (higher values of CA, PLAND, LPI, AREA, PD, ED and PROX metrics) and with a greater fragmentation of native forest cover (higher values of PD and ED metrics). The landscapes of the Coast Range, Andes Range and Chiloé are characterized by having economic activities linked to the extraction of marine species in the past and/or present, not possessing cattle or owning them for subsistence, not owning dogs, having a greater number of people per household, more years of residence and older interviewees. These landscapes are associated with a greater coverage and less fragmentation of the native forest class (higher values of CA, PLAND, LPI, AREA and PROX metrics).

Figure 3. Schematic of the relationships between explanatory (class-level landscape metrics) and predictive (rural household SE factors) variables, elaborated from the biplot of the aggregated PLSR analysis. Own elaboration.

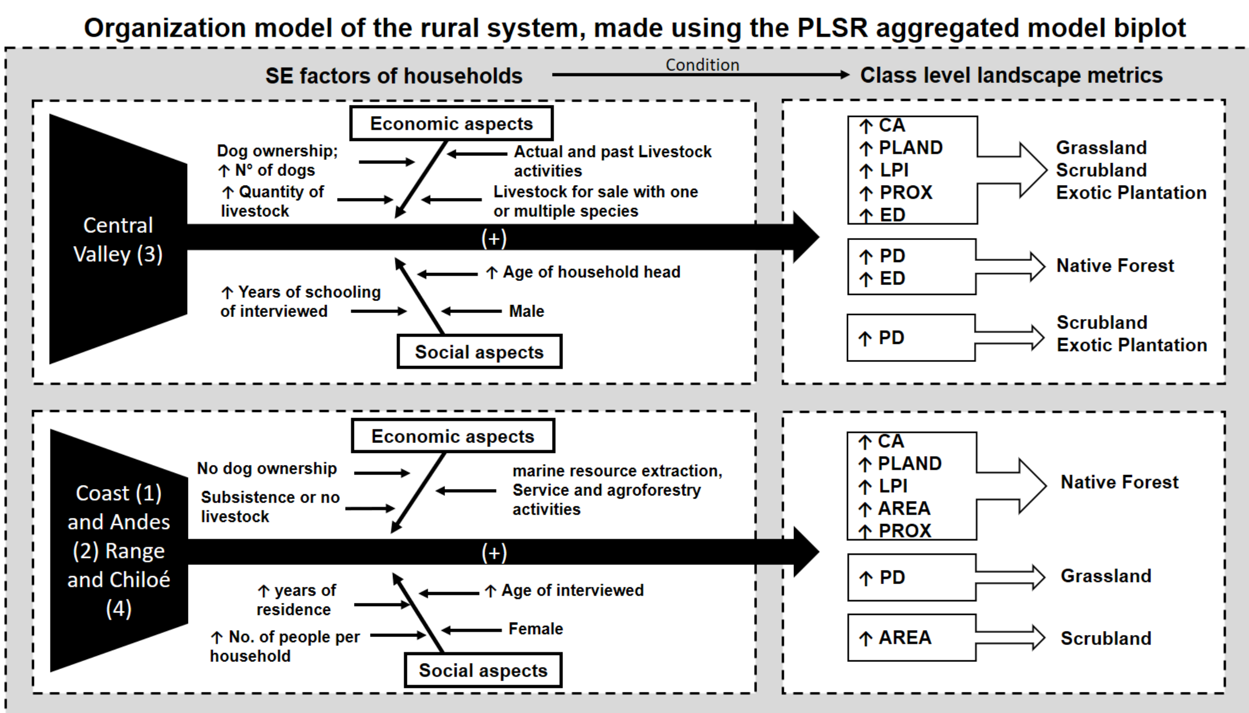


Table 6. Results of the multiple bootstrapping procedure of the aggregated PLSR model with 1 optimal dimension. Only the explanatory variables that were significant for each metric in each class are shown. The + (positive) and - (negative) signs are associated with the regression coefficients (b) and indicate the type of relationship between each SE variable and each variable of the landscape metrics for the year 2018.No. of repetitions = 1000. No. of optimal dimensions = 1. n = 218.

Landscape Metrics (y)	Human SE factors (x)																															
	CPP	NPC	GEF	EE	AEE	GJF	EJ	AEJ	NPH	ARS	AGRA	GNDA	RRMA	SRVA	AGRP	GNDP	RRMP	SRVP	SPG	PGS	PGV	GUE	GME	CA	AVC	OVE	VAC	CER	ZCC	ZCA	ZVC	ZCH
Explained variance of y = 25.4%	Regression coefficients (b)																															
Native Forest Class																																
CA																																+ 0.01
PLAND																– 0.02																+ 0.02
PD																+ 0.02																– 0.01
ED																																– 0.01
LPI													+ 0.02			– 0.02	+ 0.02															+ 0.02
AREA												– 0.02				– 0.02																+ 0.02
PROX												– 0.03	+ 0.04			– 0.04	+ 0.04				– 0.03						– 0.02				– 0.20	+ 0.03
Grassland Class																																
CA		+ 0.09							– 0.03			+ 0.04	– 0.05			+ 0.04	– 0.05		– 0.03		+ 0.04					+ 0.04	+ 0.03				+ 0.25	
PLAND									– 0.02			+ 0.03	– 0.04			+ 0.04	– 0.04				+ 0.03					+ 0.04	+ 0.02				+ 0.21	
PD	– 0.02	– 0.04																						– 0.02					+ 0.03	+ 0.06	– 0.12	
ED												+ 0.02																				– 0.02
LPI		+ 0.08							– 0.02			+ 0.04	– 0.05			+ 0.04	– 0.04		– 0.03		+ 0.03					+ 0.04	+ 0.03			– 0.12	+ 0.22	
AREA	+ 0.05	+ 0.10							– 0.03			+ 0.04	– 0.06			+ 0.05	– 0.05		– 0.03		+ 0.04			+ 0.05		+ 0.05	+ 0.03			– 0.14	+ 0.27	
PROX	+ 0.04	+ 0.09							– 0.02			+ 0.04	– 0.05			+ 0.04	– 0.05		– 0.03		+ 0.03			+ 0.04		+ 0.04	+ 0.03			– 0.13	+ 0.23	
Scrubland Class																																
CA																																
PLAND																																
PD																																– 0.01
ED													– 0.02				– 0.02															– 0.01
LPI												+ 0.02	– 0.03			+ 0.02	– 0.03				+ 0.02			+ 0.02		+ 0.02					+ 0.13	
AREA																																
PROX												+ 0.02	– 0.02				– 0.02				+ 0.02					+ 0.02					+ 0.11	
Exotic Plantation Class																																
CA	+ 0.06	+ 0.12										+ 0.05	– 0.06			+ 0.06	– 0.06		– 0.04		+ 0.05		+ 0.03	+ 0.06		+ 0.06			– 0.08	– 0.17	+ 0.31	
PLAND	+ 0.06	+ 0.12										+ 0.05	– 0.07			+ 0.06	– 0.06		– 0.04		+ 0.05		+ 0.03	+ 0.06		+ 0.06			– 0.08	– 0.17	+ 0.31	
PD	+ 0.07	+ 0.14										+ 0.06	– 0.07			+ 0.06	– 0.07		– 0.04		+ 0.05		+ 0.03	+ 0.06		+ 0.06	+ 0.04			– 0.19	+ 0.36	
ED	+ 0.07	+ 0.13										+ 0.06	– 0.07			+ 0.06	– 0.07		– 0.04		+ 0.05		+ 0.03	+ 0.06		+ 0.06	+ 0.04		– 0.09	– 0.19	+ 0.35	
LPI	+ 0.05	+ 0.10										+ 0.04	– 0.05				– 0.05		– 0.03		+ 0.04		+ 0.02	+ 0.05		+ 0.05			– 0.06	– 0.14	+ 0.26	
AREA	+ 0.02	+ 0.05																						+ 0.02		+ 0.02			– 0.03	– 0.09	+ 0.13	
PROX	+ 0.04	+ 0.08										+ 0.04	– 0.05				– 0.04		– 0.03		+ 0.03			+ 0.04		+ 0.04		+ 0.02	– 0.05	– 0.12	+ 0.22	

CA = Total class area, PLAND = Percentage of the landscape the class occupies, PD = Patch density, LPI = Largest patch index, PROX = Proximity index, CPP= With possession of dogs, NPC= Number of dogs per house, GEF= Female gender interviewed, EE= Age interviewed, AEE= Years of schooling interviewed, GJF= Female head of household gender, EJ= Head of household age, AEJ= Years of schooling head of household, NPH= No. of people per household, ARS= Years of residence in the sector, AGRA= Current agroforestry activity, GNDA= Current livestock activity, RRMA= Current marine species extraction activity, SRVA= Current service activity, AGRP= Past agroforestry activity GNDP= Past livestock activity, RRMP= Past marine species extraction activity, SRVP= Past service activity, SPG= No livestock possession, PGS= Possession of livestock for subsistence, PGV= Possession of livestock for sale, GUE= Livestock with a species, GME= Livestock with multiple species, CA= No. of farm animals, AVC= Poultry possession, OVE= Sheep possession, VAC= Cow possession, CER= Pig possession, ZCC= Coastal mountain zone, ZCA= Andes mountain zone, ZVC= Central Valley zone, ZCH= Chiloé Island zone

4. Discussion

Various researches have emphasized the need to see the landscape simultaneously as a biophysical and social reality (Tress et al., 2001; Wu and Hobbs, 2002; Domon and Bouchard, 2007). In this study we have attempted to address this challenge by integrating local SE factors of rural households and the metrics of current landscape structure, given the fundamental role of SE factors in driving land cover change. Modeling this relationship is challenging because it is not possible to include all SE factors that influence landscape structure metrics, due to unavailable data, unknown influencing factors and factors that are impossible to quantify (Marcucci, 2000; Hietel et al., 2005; 2007). SE and land cover data are found at different spatial resolutions. Most of the SE data available in public statistics are measured at national, regional and/or municipal levels, while land cover data are available at smaller scales. For this reason, we conducted semi-structured interviews with one family member per household in each of the communities analyzed, in order to obtain detailed SE data at the household and community level. This data collection tool is especially useful in this type of study because each community develops homogeneous SE characteristics that depend largely on local cultural traditions (Hietel et al., 2005).

While some landscape change studies have linked landscape metrics to human processes, most of these models consider landscape metrics as indicators of human SE aspects or have focused on a particular type of land cover. Our study is the first to relate current landscape class level metrics in conjunction with different local SE factors of the population, using SE variables as predictors of current landscape structure. The selection of the 14 study sites from different geographical areas allowed us to cover most of the SE heterogeneity present in the Temperate Forest Ecoregion of rural southern Chile. In addition, using PLSR allowed us to model landscape metrics of all classes together despite the high correlation between them.

The variance explained by the model (Var. Acum. Y = 25.4%; Table 5) was expected given the complexity of modeling this relationship and the large number of variables included in the PLSR model. Despite this, a large part of the local SE variables that were included in the models would be predicting and explaining the current class level metrics of the landscape structure (Table 6). Our results confirm the association between various local SE factors and class level metrics of current landscape structure, and suggest the important role that rural communities have in defining the structure of the landscape through practices that depend directly on the use of natural resources. Our PLSR model (Table 6) revealed the importance of subsistence economic activities and the ownership and number of livestock species of the rural communities in the metrics of the current landscape structure. Our results are supported by the work of Aguayo et al. (2009), Carmona et al. (2010), Díaz et al. (2010), Echeverría et al. (2012), Marín et al. (2011), Miranda et al. (2015) and Zamorano-Elgueta et al. (2015), who conclude that exotic forest development, the logging of forests for firewood, woodchips and agricultural expansion, the maintenance of subsistence farming practices, the intensification of agricultural production and the abandonment of agricultural land were the main forces transforming the landscape of southern Chile.

Our sampling design allowed us to cover most of the socioeconomic heterogeneity of the 4 representative geographic areas of the Temperate Forest Ecoregion of southern Chile and to obtain reliable estimates of the influence of these variables on current landscape metrics. From the biplot (Fig. 2 and Fig. 3) and the multiple bootstrapping procedure of the aggregated PLSR model (Table 6) we obtained a socioeconomic gradient between two well-differentiated geographical areas, which was expressed in the metrics of the current landscape structure. On the one side, we observed landscapes belonging to the Central Valley and on the other side we observed landscapes belonging to the mountainous areas and Chiloé.

The Central Valley landscapes were characterized by a predominance of grassland, scrubland and exotic plantation land cover, with larger and less fragmented patches (higher values of the AREA, CA, PLAND, LPI, ED and PROX metrics) and more fragmented native forest land cover (higher values of the PD and ED metrics). This landscape structure would be influenced by economic activities linked to cattle raising both in the past and/or the present and a greater number of farm animals of multiple species destined for sale, and socially by having a greater number of dogs. This association would be supported by the results of Chapter 1 of this thesis, where households with subsistence economies mainly linked to livestock owned a greater number of dogs, mainly for herding and care of animals, which could be representing a particular socio-economic context of rural communities. Our results coincide with other studies carried out in Chile, where cattle grazing, exotic tree plantations and forest clearing for the creation of grasslands are mentioned as the main causes of native forest degradation, mainly in areas of the Central Valley (Aguayo et al, 2009; Carmona et al., 2010; Díaz et al., 2010; Schulz et al., 2010; Marín et al., 2011; Schulz et al., 2011; Echeverría et al., 2012; Miranda et al., 2015; Zamorano-Elgueta et al., 2015).

The landscapes of the Andes Range, Coast Range and Chiloé were characterized by a predominance of native forest class land cover, with larger, less fragmented and closer patches (higher values of AREA, CA, PLAND, LPI and PROX metrics). This landscape structure would be generated by economic activities linked to the service and collection of marine species in the past and/or present and the absence of livestock, or to owning it only for subsistence purposes. These findings coincide with those reported by Aguayo et al. (2009) who indicated that, at present, the areas of native forest remaining in southern Chile are located in sectors that are difficult to access, steep slopes, altitudes above 800 m, or within protected areas, all of them characteristics that are representative of these geographical zones.

These substantial differences in the land cover and metrics of the current landscape between geographical areas could be related to the history of human occupation and transformation of the landscape of southern Chile and its main socio-economic drivers. The central valley areas were occupied earlier because of their better environmental conditions and accessibility during the Spanish conquest in the 18th and 19th centuries. This historical event resulted in the massive logging of native forests, for the construction of villages, boats and fence posts (Armesto et al., 2010). Deforestation by logging and fire to open up agricultural land, the expansion of wheat fields in the mid-19th century driven by the "gold rush" in California and Australia, and the massive introduction of domestic cattle led to the devastation of native forest in much of central and southern Chile (Castro-Lobos, 2002; Camus, 2006; Armesto et al., 2010). In the late 19th and early 20th centuries, the "golden age" of timber exploitation led to timber being extracted from forests without any concern for the renewal of the resource (Donoso and Lara, 1996). On the other side, the intense soil erosion caused by the collapse and abandonment of agriculture in the late 19th and early 20th centuries (Castro-Lobos, 2002; Camus, 2006), marked the beginning of Chilean environmental policies that promoted exotic plantations to protect severely eroded soils (Aguayo et al., 2009; Armesto et al., 2010). In the second half of the 20th century, the promulgation of Decree Law 701 gave a decisive boost to forestry development (Millán and Carrasco, 1993; Donoso and Lara, 1996). This resulted in many farmlands and native forests being replaced by exotic plantations and becoming one of the main land cover areas, mainly in the central valley and later in the coast range (Lara and Veblen, 1993; Donoso and Lara, 1996; Echeverría et al., 2006; Aguayo et al. 2009; Armesto et al., 2010; Nahuelhual et al., 2012; Zamorano-Elgueta et al., 2015). The immediate consequence of forest loss and the abandonment of land used for agriculture that was not converted to exotic plantations was the presence of scrub (Marín et al., 2011). Shrublands are an intermediate stage of forest succession and can be considered the main source of long-term land for agriculture and forest recovery (Marín et al., 2011). Currently, some recovery of shrub covers and abandoned agricultural land has been reported in southern Chile (Carmona et al., 2010; Díaz et al., 2011). All these historical antecedents coincide with our results, where we obtained a smaller occupied area and greater fragmentation of native forest cover in landscapes located in the central valley zone, and a greater representation of grassland, scrubland and exotic plantation cover in this zone that has been highly degraded throughout history. Since the second half of the 20th century, the opening of new routes (e.g. southern highway, coastal highway) allowed for the extraction of native wood from previously inaccessible remote sites (Armesto et al., 2010). This meant that interventions in the Andes and Coast mountain ranges were more recent than those in the central valley (Aguayo et al., 2009). This lag in the history of occupation of the landscape would explain our results and the differences found in the presence of native forest cover between geographical zones, where most of the remaining temperate forest is currently limited to areas of the Andes Range, southern section of the Coast Range and Chiloé (Smith-Ramírez, 2004). Our results coincide with those reported by Miranda et al. (2015) who found substantial differences in the patterns of forest loss between the central valley, Coast Range and Andes Range and concluded that the areas with better environmental conditions and accessibility were occupied first for productive activities.

5. Conclusion

This study achieved its objective of explaining how various local SE factors in 14 rural communities of the temperate forests of southern Chile predict and relate to the current landscape structure.

The results of our PLS models indicated that local SE factors in rural households are an important driving force in landscape configuration and composition and showed that the current rural landscape structure of the Southern Chilean Temperate Forest Ecoregion would be predicted by a combination of local SE variables. Our results would lay the foundation for future studies that directly relate various human factors to landscape structure.

Because native forest remnants are under increasing pressure from exotic plantations, livestock grazing, anthropogenic fires and the danger of conversion to other land uses (Echeverría et al, 2008; Wilson et al., 2005), considering the socio-economic reality of rural communities and households, and understanding the relationship between various human factors and the current landscape structure, should be of special interest for the planning and implementation of biodiversity management and conservation programs, particularly in developing countries such as Chile, since it is expected that in these countries the agricultural and/or productive frontier will continue to expand (Sala et al., 2000).

6. Ethics statement

Prior to each interview, we obtained the informed consent of each adult participant by reading a printed statement explaining the objectives of the project, the length of the interview and that it would not be recorded, the possibility of omitting questions, and that the interview was anonymous, confidential and voluntary. Participants who agreed to participate signed a copy of the informed consent and another copy was given to them. The paper interviews and their digital transcript were stored anonymously. The Scientific Ethical Committee of Social Sciences, Arts and Humanities of the Pontificia Universidad Católica de Chile certified the ethical approval of the instrument.

7. Conflict of interest statement

The authors of the study declare that there is no conflict of interest.

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Chapter 3

¿The owner or the landscape? Influence of the social and ecological context of rural communities on the occupation of domestic dogs and wild mammals in the temperate forests of southern Chile

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The owner or the landscape? Influence of the social and ecological context of rural communities on the occupation of domestic dogs and wild mammals in the temperate forests of southern Chile

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Abstract

Understanding how domestic dogs and wild mammals are spatially distributed and how dogs affect the presence of these species in rural landscapes is crucial to minimizing dog-wildlife contact and designing management strategies that promote wildlife conservation in anthropogenic areas. Through the development of single-season single-species occupation models, the influence of various social (domestic dog ownership and management) and ecological (landscape metrics) factors on the spatial distribution of dogs and three native medium-sized mammals: the Pudu, Darwin's fox and Kodkod, in 14 rural communities adjacent to protected areas or large forest remnants was analyzed. Our results revealed that for each of the native mammals a negative effect of the dogs was observed, either in their space occupation or in their detection. The more parsimonious model for the dogs indicated that their occupation was positively influenced by more disturbed and open coverages such as scrublands, grasslands, agricultural lands, and exotic plantations. Pudu occupation decreased with increased frequency of dog occurrence and with road and native forest cover and increased with grassland+agricultural land and exotic plantation covers, while detection decreased with increased number of dogs. The occupation of Darwin's fox decreased with grassland+agricultural land cover, while its detection decreased with a greater number of dogs. Kodkod occupation decreased with a greater frequency of dog occurrence. Our results highlight the importance of human land use practices and domestic dog ownership in the spatial distribution of dogs and three native mammal species in rural landscapes of the temperate forests of southern Chile.

Keywords: Camera traps, single-season single-species occupation model, landscape structure, domestic dog ownership and management, wild mammals, temperate forest.

1. Introduction

Habitat loss and fragmentation induced by land cover changes (Fahrig, 2003) and the introduction of species such as domestic dogs are the main drivers of biodiversity loss worldwide (Bellard et al., 2016). After more than 15,000 years of interacting with humans (Vila et al., 1997; Driscoll et al., 2009; Galibert et al., 2011; Larson et al., 2012; Thalmann et al., 2013; Frantz et al., 2016; Perri, 2016), the domestic dog (*Canis lupus familiaris*) has become one of the world's most successful invasive mammals, therefore reducing its impacts ecological impacts on wildlife is a central global conservation objective (Young et al., 2011; Glen et al., 2013; Ritchie et al., 2014; Doherty et al., 2016; 2017). Domestic dogs are a common species in rural areas and can reach population densities much higher than those of similarly-sized wild species (Franti et al., 1974; Knobel et al., 2008; Acosta-Jamett et al., 2010; Murray et al., 2010; Gompper, 2014a). When allowed to roam freely they can interact negatively with wildlife through predation, harassment, disease transmission, competition and hybridization, contributing to the decline of biodiversity (Hughes and Macdonald, 2013; Doherty et al., 2017). Sub-lethal interactions, such as avoidance of risky areas as a result of harassment, can affect the patterns of space occupation of native species as a consequence of a behavioral response mediated by fear of dogs (Doherty et al., 2015; Doherty et al., 2017; Banks and Bryant, 2007; Zapata-Ríos and Branch, 2016).

One of the historical strategies for wildlife conservation has been the creation of protected areas (PA) (Margules and Pressey, 2000). Due to land cover change in rural areas, PAs can become immersed in a matrix of anthropized landscapes and exposed to external factors such as habitat degradation and invasion of their boundaries (DeFries et al., 2007; Jones et al., 2009; Bailey et al., 2015). PAs may also be too small to protect wild species in the long term, so their conservation may depend on their survival outside PAs, where they come into contact with rural communities and domestic dogs (Lacerda et al., 2009; Ramesh and Downs, 2015).

To optimize future dog management and wildlife conservation programs in rural areas, it is necessary to identify the main factors shaping the spatial distribution of domestic dogs and wildlife species, particularly at the edges and within PA and forest remnants where dog-wildlife interactions are most likely to occur (Butler et al, 2004;

Lacerda et al., 2009; Srbek-Araujo and Chiarello, 2008; Marks and Duncan, 2009; Torres and Prado, 2010; Vanak et al., 2014; Soto and Palomares, 2014).

Dog-wildlife interaction is a function of the spatial distribution of dog activity, which varies with density of dogs, subsidized food, proximity to homes, function of dogs in the home, movement restriction and landscape structure (Vanak and Gompper, 2009, 2010; Silva-Rodríguez and Sieving, 2011, 2012; Sepúlveda et al., 2014, 2015; Soto and Palomares, 2014; Moreira-Arce et al., 2015a; Alves et al., 2017; Morin et al., 2018; Paschoal et al., 2018, Ribeiro et al., 2019). The spatial distribution of free-ranging dogs in rural areas is highly variable and probably location-specific. Few landscapes are free from the influence and disturbance of dogs (Hughes and Macdonald, 2013). Rural areas with subsistence economies dedicated mainly to raising cattle (see Chapter 1) and perturbed landscapes such as agricultural and forest systems are more likely to have the presence of dogs (Frigeri et al., 2014). Free-ranging dogs can easily cross these perturbed areas and invade adjacent habitats, including PAs and forest remnants, by selecting trails and/or roads for their movement (Silva-Rodríguez et al., 2010; Sepúlveda et al., 2015; Waldstein et al., 2016; Paschoal et al., 2018). When dogs exhibit foraying behavior they are mostly detected within 2 km of their homes, however, they spend most of their time near their homes (<200 m) (Sepúlveda et al., 2015; Morin et al., 2018; Pérez et al., 2018).

The influence of landscape structure on the use of space by wild species and domestic dogs and the negative relationship between the presence of native species and dogs have been previously reported in many studies, both in natural and anthropized environments (Silva-Rodríguez et al., 2010; Vanak and Gompper, 2010;

Silva-Rodríguez and Sieving, 2012; Cassano et al., 2014; Kowalski et al., 2015; Moreira-Arce et al., 2015a, 2016; Zapata-Ríos and Branch, 2016, 2018; Dos Santos et al., 2018; Murphy et al., 2018; Paschoal et al., 2018; Ribeiro et al., 2019). Since humans influence the dog ownership and management and landscape structure (see Chapters 1 and 2), humans can influence dog-wildlife interaction, especially if dogs access PA or forest remnants. Studies conducted in the Coast Range of the temperate forests of southern Chile and Mexico mention that the food given to dogs and their function in the home influence dog-wildlife interaction (see Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Ruiz-Izaguirre et al., 2015), while the free movement and foraging behavior of dogs could contribute to dog-wildlife interaction (Sepúlveda et al., 2015). It is important to understand the scope of human influence on the spatial distribution of dogs and native species in the Temperate Forest Ecoregion of southern Chile, due to the intense landscape modification and high degree of endemism in these forests (Armesto et al., 1992; Armesto et al., 1994; Echeverría et al. 2006), so the effect of dogs in this area would be particularly important for the conservation of these species.

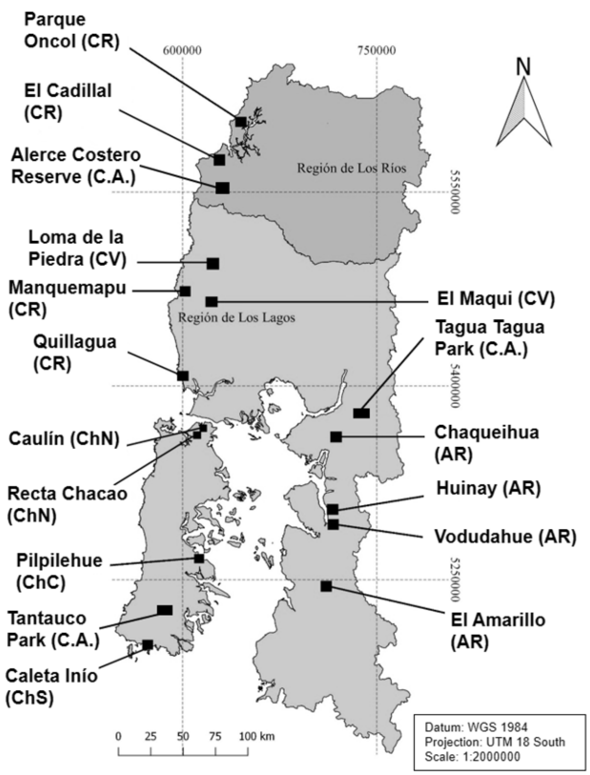
In this chapter we will analyze the relative importance of various ecological and social factors in the spatial distribution of domestic dogs and three medium-sized wild mammal species representative of the temperate forests of southern Chile. Although the movement of free-ranging dogs has been widely studied in suburban and rural areas, there is still limited knowledge about the factors that determine their occupation within and around PA and in forest remnants, and how their presence influences the occupation of native species, especially in Chile (e.g. Silva-Rodríguez and Sieving, 2012). Although various anthropogenic and landscape factors have been related to the presence of dogs and wildlife, few studies have evaluated these predictive factors to a landscape level resolution and to a regional level extension. To address this gap, this study was conducted in 17 rural communities located in different geographic areas of the Southern Chilean Temperate Forest Ecoregion, and explored the variables of landscape structure and dog ownership and management that may explain the variation in detection probabilities and space occupation of dogs and wild mammals. To achieve our objective, (1) landscape structure metrics were quantified at two different scales in order to characterize land cover associated with the replacement of native forest by human land uses considering the range of distances usually exhibited by free-ranging dogs during their foraging behaviors, (2) data on dog ownership and management obtained from household interviews were used, (3) data on the presence of species from camera traps were used, and (4) the relationship of these variables was modelled using single-season single-species occupancy models. It is important to understand what can affect the occupation of domestic dogs, how they move in conservation-sensitive areas, and how they affect the presence of native species, in order to minimize contact and loss of native species with conservation problems.

2. Material and methods

2.1 Study area

The study area extends for over 400 km in southern Chile (latitude 39°40’ S to 43° 23’ S), from the Los Ríos region to the southern end of Chiloé Island, and its continental counterpart in the province of Palena (Figure 1). The climate of the area is temperate rainy, with an average temperature of 10.6 °C, with precipitation occurring throughout the year, decreasing from the mountains to the central valley (2,500 to 1,200 mm/year) (Rioseco and Tesser, n.d.). The dominant vegetation cover is temperate rainforest and Valdivian temperate rainforest (Luerbert and Pliscoff, 2004), found mainly within protected areas and high-elevation areas.

Figure 1. Sample sites visited during the conduct of the study and number of dogs recorded in interviews by community and geographic area.



Geographic Zone	Community	N° dogs recorded in interviews
Coast Range (CR)	Alerce Costero Reserve	**Control area (C.A.)**
	Parque Oncol	40
	El Cadillal	25
	Manquemapu	27
	Quillagua	30
Andes Range (AR)	Tagua Tagua Park	**Control area (C.A.)**
	Chaqueihua	13
	Huinay	2
	Vodudahue	7
	El Amarillo	26
Central Valley (CV)	Loma de la Piedra	58
	El Maqui	62
Chiloé Island (Ch)	Tantauco Park	**Control area (C.A.)**
	Caulín (North)	30
	Recta Chacao (North)	47
	Pilpilehue (Center)	50
	Caleta Inío (South)	18
Total n° of dogs recorded in interviews		435

The study area is ecologically unique because it is located in the Temperate Rainforest Ecoregion, which is considered a hotspot for biodiversity conservation (Myers et al., 2000). Due to the prolonged isolation of its habitats, the fauna in these forests shows high levels of endemism that make them major conservation objects worldwide (Armesto et al., 1992, 1998; Myers et al., 2000; Smith-Ramírez 2004). The temperate forests of South America have experienced a long history of intense landscape modification. They originally occupied most of continental and insular Chile (from latitude 36º S), and the eastern sides of the Andes Range in Argentina (Armesto et al., 1998). However, throughout history southern temperate forests have been highly susceptible to land cover change and species invasions (Armesto et al., 1998). A large fraction of the native temperate forest has been cut down for timber extraction, opening up agricultural land or replacing it with exotic tree plantations (Wilson and Armesto, 1996; Aravena et al., 2002; Grez et al., 2006). As a result, the landscape is now composed of remnants of native forest that differ in extent and degree of intervention, surrounded by an anthropized matrix dominated by grassland, agricultural land, forest plantations and scrubland (Aravena et al., 2002; Echeverría et al. 2007). The process of human settlement has also resulted in the introduction of several exotic species such as the domestic dog, which now coexist and interact with local fauna and influence the remaining forest (Armesto et al., 1992).

Domestic dogs are common in the study area, and interact with most medium-sized wild mammals present in the temperate forests of southern Chile, including the pudu (*Pudu puda*), Darwin's fox (*Lycalopex fulvipes*) and the Kodkod (*Leopardus guigna guigna*) (Silva-Rodríguez and Sieving, 2012; Farías et al, 2014; Sepúlveda et al., 2014; Silva-Rodríguez et al., 2018)

The pudu is one of the smallest deer in the world. Its range is restricted; in the last 15 years its population has been declining in response to a combination of anthropogenic threats such as forest loss, predation by domestic dogs, poaching and competition with domestic herbivores (Silva-Rodríguez et al., 2010, 2016a).

Because of these threats the pudu is currently classified as Near Threatened by the International Union for Conservation of Nature (IUCN, 2020) (Silva-Rodríguez et al.2016a).

Darwin's fox is the smallest of the three canid species that inhabit Chile and one of the smallest in the world (52 to 67 cm long and 1.8 to 4 kg weight) (Iriarte, 2008; Iriarte and Jaksic, 2012). Its range is limited to Chiloé Island and discontinuous areas of the Coast Range in continental Chile (Jiménez and McMahon, 2004; Vila et al., 2004, D'Elia et al., 2013, Farías et al., 2014; Silva-Rodríguez et al., 2018). Due to its small population size (<700 mature individuals), restricted range and exposure to anthropogenic threats such as predation and disease transmission by domestic dogs, poaching, and forest loss (Silva-Rodríguez et al., 2016b), it is listed as one of the canid species with the highest conservation priority worldwide, being considered Endangered by IUCN (Silva-Rodríguez et al., 2016b).

The Kodkod is the smallest cat in the Americas and one of the smallest in the world (Nowell and Jackson, 1996). It has the smallest range of distribution among New World cats, being limited to central and southern Chile (30° to 48° S) and marginally to the adjacent areas of southwestern Argentina (Nowell and Jackson, 1996; Quintana et al., 2000). Two subspecies are recognized (Cabrera, 1957; Napolitano et al., 2012): *L. guigna tigrillo*, which inhabits sclerophyllous forests and Mediterranean scrub in north-central and central Chile (30° to 38° S), and *L. guigna guigna*, which inhabits temperate rainforest and northern Patagonian forests (38° to 48° S). Due to its habitat specificity, forest loss, human persecution, predation by dogs and disease transmission by domestic cats, the species is considered Vulnerable by the IUCN (Napolitano et al., 2015).

2.2 Selection of sampling sites

Since the ecotone between anthropic environments and forest remnants is where dog-wildlife interactions are most likely to occur (Vanak and Gompper, 2010; Lacerda et al., 2009; Soto and Palomares, 2014), we selected communities adjacent to protected areas or forest remnants, within a buffer distance of 2 km, representing the distance usually travelled by free-ranging dogs (Sepúlveda et al., 2015).

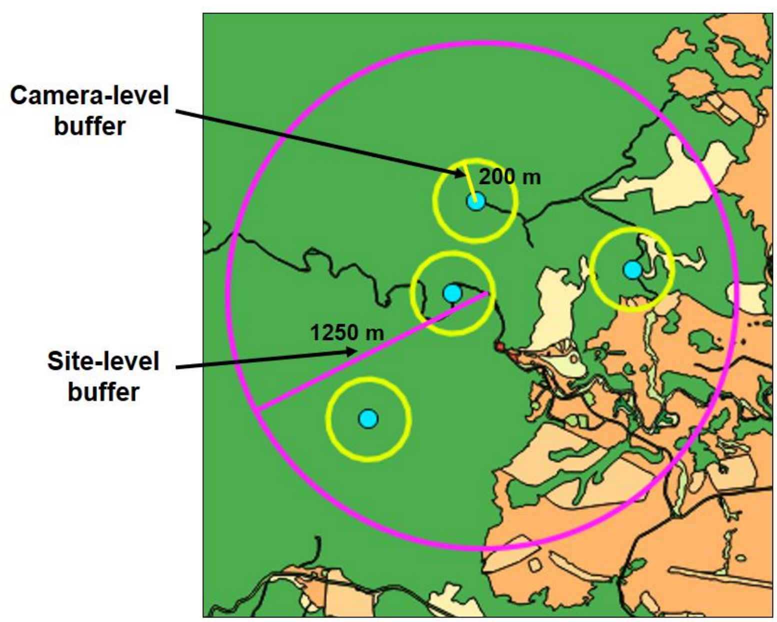
We recorded the presence of domestic dogs and wild mammals in 14 rural communities in four geographic areas with different land-use and human perturbation histories (Armesto et al., 1994): Coast Range, Andes Range, Central Valley and Chiloé Island (Figure 1). This made it possible to cover the greatest possible variability of social and ecological contexts in each community. The 14 communities have a low human population density and are completely rural. Economic activities vary between and within communities, and are mainly associated with livestock (raising cattle, sheep and poultry), agriculture, marine resource species extraction, forest resource use (timber) and services (OLR, 2018a; OLR, 2018b) (see Chapters 1 and 2 of this thesis). We also selected 3 sampling sites as control areas in which no domestic dogs or surrounding rural communities were recorded (Figure 1).

2.3 Landscape Analysis

To characterize the landscape structure of each of the 17 sampling sites, land use/land cover maps at a scale of 1:30,000 for observation and 1:10,000 for digitization were photo-interpreted from satellite images extracted from Google Earth™ (Google Inc., 2016). According to the importance of the land uses/coverages observed in the satellite images and the study objectives, 14 land uses were determined for the landscape: Area without vegetation, Native and exotic forest, Roads, Anthropic construction, Tree and scrub corridor, Water body, Wetland, Scrubland, Snow, Ocean, Plantation, Grassland, Agricultural land and Riparian vegetation. These categories correspond to a simplification and aggregation of the 'Cadastre and Evaluation of Native Vegetation Resources of Chile' (CONAF, 1999). To corroborate that there are no major differences between the cadastre and the current landscape structure, field validation of the information was carried out, verifying the type of use/coverage at different random points. The spatial geographic information and files were managed using QGIS 2.14.5 software (QGIS Development Team, 2016).

From the vectorial layer of the cartography of each locality, raster images were created on which the landscape metrics were quantified in the FRAGSTATS 4.2 program (MacGarigal et al., 2002). For this, circular buffers were created around the location point of each camera trap. Two different radius plots were established: 200 m around each camera (camera level) and 1250 m around each set of cameras (site level) (Figure 2), in order to calculate landscape metrics at two different spatial scales and characterize land cover associated with the replacement of native forest by human land uses. The buffers were selected according to the range of scales at which the dogs might be using the space, given their areas of action (200 m to 2 km from their homes; Sepúlveda et al., 2015). We selected the Percent of Landscape (PLAND) metric for the Forest, Grassland+Agriculture, Scrubland, Anthropogenic Construction, Roads and Exotic plantation classes because of their importance in dog movement and in the transformation of the landscape in this Ecoregion, and Patch Density (PD) at the landscape level because of its importance as an indicator of landscape fragmentation. These metrics were calculated at camera level (200 m buffer), at site level (1250 m buffer) and for the entire landscape in order to consider the context in which these buffers were inserted.

Figure 2. Illustration of the sampling buffers at camera level (yellow) and at site level (pink), on a fragment of the land cover map of the El Maqui location.



2.4 Photographic sampling

As part of a project to survey the diversity of carnivores in the temperate forest, during the spring-summer seasons of 2012 to 2016, 144 camera traps (Bushnell Trophy Cam, Bushnell Corporation, Overland Park, KS, USA) were installed in areas of old-growth forest or dense understory at the 17 sampling sites. All cameras were baited with raw chicken and lynx urine (Minnesota Brand Bobcat Urine, Minnesota Trapline Products Inc., Pennock, MN, USA), and some cameras used other commercial lures (Caven's Violator-7 and Terminator lures; Minnesota Trapline Products Inc., Pennock, MN, USA) to increase the probability of detecting carnivores.

The minimum distance between the cameras within the sites was about 500 m, although in most cases the minimum distance was close to 1 km. The cameras were strategically placed at different distances from the houses and from the edge of the PA and forest remnants to their interior. Some cameras were located directly on the trails, but most were close (i.e. < 200 m), on small trails or secondary roads. Dogs tend to be more active near human dwellings and move along roads and trails (Silva-Rodríguez et al., 2010; Silva-Rodríguez and Sieving, 2012; Sepúlveda et al., 2015), so it is likely that the increased activity of dogs is correlated with human activity (Silva-Rodríguez et al., 2018). The cameras were placed approximately 20-30 cm above the ground and movements that occurred approximately 10 cm above the ground were verified to activate the cameras.

The cameras were operational for 35 to 55 days, with the exception of four cameras whose sampling effort varied for 12 to 23 days due to failures during operation. The total accumulated sampling effort was 7,642 camera-days.

Records of the same species taken over a 24-hour period were considered as the same detection event to avoid false counts arising from time dependence. With these records we constructed the detection history for each photo station (i.e. values of 1 if the species was detected, 0 if not and NA if the cameras were not operational), dividing the total sampling period of each camera into sampling intervals (i.e. occasions) of 5 consecutive days, which resulted in a maximum of 11 recording occasions. We consider this sampling period to be sufficiently short to avoid violating the site closure assumption when using occupancy models for some described species (e.g. Darwin's fox; Jiménez, 2007; Rota et al., 2009)

2.5 Ecological and social covariates of the model

We quantified 13 landscape covariates to evaluate their influence on dog and wild mammal species occupation. We performed a Pearson correlation analysis to identify highly correlated variables (see Supplementary Material). We then performed a principal component analysis (PCA) with the aim of reducing the number of variables. For site landscape variables (landscape metrics within the 1250 m buffer) we included the scores of the first two axes obtained (explained cumulative variance = 67.5%). The first axis PCA (Land1) represents a gradient between anthropized landscapes on the positive axis (PPrAg, Pcam, Pcon, PD; see acronyms in Table 1) and more natural landscapes on the negative axis (PBo). The second PCA axis (Land2) represents a gradient between landscapes with exotic plantation coverage on the positive axis (PPl), and landscapes without exotic plantation coverage on the negative axis. We incorporated the camera-level landscape variables (landscape metrics within the 200 m buffer) Bo, Cam, Pl, Ma, Con and PrAg independently, as they were not related to each other (see supplementary material). Finally, eight covariates of landscape metrics were used to model the occupation of domestic dogs and wild mammals (see Table 1). We also included the covariate 'Control area' (CA; binomial) to model the occupation of domestic dogs, since there were 3 locations deliberately selected where no presence of dogs has been reported (PA), and the covariate 'Island' (binomial) to model the occupation of Darwin's fox, which indicates the location or not of each landscape on Chiloé Island, because its presence and occurrence in the continental area is much lower than on this island where the largest populations of this species have been reported (Jiménez et al., 1991; Silva-Rodríguez et al., 2018). Only data from the Coastal Range and Chiloé Island were used for Darwin's fox, since it is not known to inhabit the Andean Range (Silva-Rodríguez et al., 2018).

The social covariates of dog ownership and management were obtained from open semi-structured interviews conducted with one adult per household in each of the 14 rural communities (see detail in Chapter 1). We quantified a total of 15 covariates that could influence dog ownership and management. We conducted a PCA to decrease the dimensionality of the variables (see supplementary material). We included the first PCA axis (Dog1; explained variance PC1 = 32%) as a social variable to model the occupation of domestic dogs, since it represents a gradient between two-dog ownership and management profiles. The positive axis groups "best" managed dogs (fed two or more times a day with commercial food, with a companionship function and movement restriction) while the negative axis groups "worst" managed dogs (fed once a day with meal, with an animal herding and care function, without movement restriction and with a greater number of dogs per house). We also used 6 other covariates, Nd, DAc, Rceb, Oceb, Temp and CA, to model the detectability of dogs and wild mammals, since they could affect the activity of these species (see Table 1). We included interactions of the variables Nd and Dog1 with the ecological variables PrAg, Con and Cam, due to the association of dogs with these coverages (see Silva-Rodríguez et al., 2010; Silva-Rodríguez and Sieving, 2012; Sepúlveda et al., 2015).

Table 1. Ecological (landscape structure) and social (dog ownership and management) covariates used in single-season single-species occupation models (Ψ = probability of occupation; p = probability of detection).

Covariate	**Abbreviation in the model**	**Influential model parameter**
Landscape PC1 at site level	Land1	Ψ dog – Ψ mammals
Landscape PC2 at site level	Land2	Ψ dog – Ψ mammals
% forest coverage at camera level	Bo	Ψ dog – Ψ mammals
% coverage of roads at camera Level	Cam	Ψ dog – Ψ mammals
% Exotic plantation coverage at camera level	Pl	Ψ dog – Ψ mammals
% scrub coverage at camera level	Ma	Ψ dog – Ψ mammals
% Anthropic construction coverage at camera level	Con	Ψ dog – Ψ mammals
% coverage of Grassland + Agriculture at camera level	PrAg	Ψ dog – Ψ mammals
Occurrence frequency of dogs in the camera	FOd	Ψ mammals
Camera location on Chiloé Island	Isla	Ψ Darwin's fox
PC1 of domestic dog ownership and management	Dog1	Ψ dog
Number of dogs reported in interviews by location	Nd	Ψ dog – Ψ mammals p dog – p mammals
No. of active camera days per 5-day period	DAc	p dog – p mammals
Re-baited	Rceb	p dog – p mammals
Use of other bait	Oceb	p dog – p mammals
Installation Season	Temp	p dog – p mammals
Control area	CA	p Kodkod – Ψ dog

2.6 Data analysis

We adjusted single-season, single-species occupation models (MacKenzie et al., 2002) to investigate which ecological and social covariates influence the occupation and detection of domestic dogs and medium-sized wild mammals. Occupancy modeling requires data that be replicated temporally or spatially to account for imperfect detection, allowing us to estimate site occupancy rate (probability that a site is occupied; ψ) and detectability (probability of detecting at least one individual given that it is present at the site; p) (MacKenzie et al., 2006).

Given the large number of covariates in which we were interested, we divided the modeling into 2 steps (MacKenzie et al., 2006): 1) we determined the "best fit" model for the detection probability while only adjusting an intercept for occupation, and 2) we determined the "best fit" model for the occupation while modeling detection as obtained in the first step.

The occupancy models of each of the four species were analyzed using the "unmarked" package of the R environment (R Development Core Team, 2019; Fiske and Chandler, 2011). Our best fit model was selected using the Akaike Information Criterion (AIC). We then performed a goodness-of-fit test by MacKenzie and Bailey (2004) based on Pearson's chi-square statistics. We evaluated the model fit (p) and the over-dispersion parameter (c-hat) using 2000 bootstrap repetitions. We considered that p values of bootstrap < 0.05 indicated lack of fit and c-hat values >1.0 indicated overdispersion (Burnham and Anderson, 2002; MacKenzie and Bailey, 2004). When models were overdispersed, we corrected with the c-hat value obtained and used the QAIC or QAICc value (quasi-Akaike Information Criterion corrected for small sample sizes) for model selection. We considered that models with ΔQAICc, ΔAICc or ΔAIC <2 had "substantial empirical support" and were therefore considered equivalent (Burnham and Anderson, 2002). We determined the level of support for each predictor variable by summing the Akaike weights (AICw) of all models containing the variable of interest (w*) (Burnham et al., 2010). The classification and relative importance of the model parameters were calculated with the R package "AICmodavg" (Mazerolle, 2015).

3. Results

We obtained 451 detections in total of the four species during the 55 days (maximum) that the camera traps were active in the 17 locations. The Kodkod and Darwin's fox were the most and least detected species, on 162 and 44 different occasions, respectively (Ψnaïve = 0.49 and 0.15 for Kodkod and Darwin's fox, respectively, Table 2).

Table 2. Records of the four species studied in the 17 rural locations and three main indices: Number of detection occasions (number of records of each species in the detection history of all the camera traps (N = 144; N = 82 for Darwin's fox), Overall naive occupation (Ψ overall-naïve, number of positive sites for the presence of the species divided by the total number of sites sampled), and Proportion of occupied sites estimated from the model (PAO).

Specie	Detections (n)	Ψ overall-naïve	PAO
Domestic dog (*Canis lupus familiaris*)	150	0.3	0.33
Pudu (*Pudu puda*)	95	0.24	0.53
Darwin’s fox (*Lycalopex fulvipes*)	44	0.15	0.15
Kodkod (*Leopardus guigna guigna*)	162	0.49	0.60

3.1 Domestic dog

We analyzed a total of 72 models: 28 for model detectability while maintaining constant occupancy, and 44 for model occupancy. There was no evidence of lack of fit (p-value >0.05) nor of overdispersion (c-hat <1), which suggested that the selection of the best model with AICc was reasonable. The 20 most plausible models (with the lowest AICc values) are shown in Table 3. According to the AICc, the most parsimonious occupancy model for the domestic dog includes the effects of re-baiting and other bait for the detection probability, and the effects of the Landscape PC2 at the site level, control area, % scrub cover and % grassland and agricultural cover for the occupancy probability. Based on the AICcW, it is suggested that these covariates are important predictors of occupancy probability, as the 20 best models involve these terms and have substantially smaller AICc values. The coefficients of the best-supported occupancy models indicated that (i) the control area decreased the probability of dog occupation (w* = 0.91) while (ii) higher % scrub coverage within 200 m (w* = 0.64) and higher % grassland+agricultural coverage within 200 m (w* = 0.64) increased the probability of dog occupation. The coefficients showed low support for positive effects of landscapes with the presence of exotic plantation cover within 1250 m (Land2) (w* = 0.25). Detectability of dogs decreased with re-baiting camera traps and increased with the application of 'other bait'.

Table 3 Model selection based on AICc (c-hat estimate = 1; P-value = 0.31). Top 20 best-ranking single-season single-species detectability and occupancy models for domestic dogs (*Canis lupus familiaris*) in 17 rural communities of Chile, estimated using 144 camera trap records between December, 2012 and March, 2016. The detection model structure was p(Rceb+Oceb) for all models.

Detectability and occupancy models	**K**	**AICc**	**∆AICc**	**AICcW**	**Cum.W**
p(Rceb+Oceb)psi(Land2+CA+Ma+PrAg)	8	660.09	0	0.17	0.17
p(Rceb+Oceb)psi(Land1+Land2+CA+Ma+PrAg)	9	660.52	0.43	0.14	0.31
p(Rceb+Oceb)psi(CA+Ma+PrAg:Dog1)	7	660.59	0.5	0.13	0.44
p(Rceb+Oceb)psi(CA+Ma+PrAg)	7	661.19	1.1	0.1	0.54
p(Rceb+Oceb)psi(CA+PrAg)	6	661.9	1.81	0.07	0.61
p(Rceb+Oceb)psi(CA+PrAg+Dog1)	7	662.44	2.36	0.05	0.67
p(Rceb+Oceb)psi(CA+PrAg+Dog1+PrAg:Nd)	8	662.6	2.51	0.05	0.72
p(Rceb+Oceb)psi(CA+Con+Con:Dog1)	7	662.85	2.76	0.04	0.76
p(Rceb+Oceb)psi(Land1+CA+Ma+PrAg)	8	662.88	2.79	0.04	0.8
p(Rceb+Oceb)psi(CA+Ma+PrAg:Nd)	7	663.55	3.47	0.03	0.83
p(Rceb+Oceb)psi(CA+PrAg+Nd)	7	663.77	3.68	0.03	0.86
p(Rceb+Oceb)psi(CA)	5	664.2	4.11	0.02	0.88
p(Rceb+Oceb)psi(Land2+CA+Con+Con:Dog1)	8	664.45	4.36	0.02	0.9
p(Rceb+Oceb)psi(Land1+Land2+CA+Ma+Con+PrAg+Dog1)	11	664.64	4.55	0.02	0.92
p(Rceb+Oceb)psi(Land2+PrAg+PrAg:Nd)	7	665.14	5.05	0.01	0.93
p(Rceb+Oceb)psi(Land2+CA)	6	665.38	5.3	0.01	0.94
p(Rceb+Oceb)psi(Land2+Ma+PrAg+PrAg:Nd)	8	665.8	5.71	0.01	0.95
p(Rceb+Oceb)psi(Land1+CA)	6	665.95	5.87	0.01	0.96
p(Rceb+Oceb)psi(CA+Con)	6	666.35	6.26	0.01	0.97
p(Rceb+Oceb)psi(Land1+Land2+CA+Con+Con:Dog1)	9	666.72	6.63	0.01	0.98

Abbreviations: K = number of parameters; AICc = small sample Akaike Information Criterion; ∆AICc = change in AICc; AICcw = small sample Akaike weight; cumltvW = small sample Akaike cumulative weight.

3.2 Pudú

We analyzed a total of 52 models: 28 for model detectability while maintaining constant occupancy, and 24 for model occupancy. There was no evidence of lack of fit (p-value >0.05) or overdispersion (c-hat <1), so the selection of the best model was made with AICc. The 20 most plausible models (with the lowest AICc values) are shown in Table 4. According to the AICc, the most parsimonious occupation model for the pudú includes the effects of number of dogs, other bait and season for detection probability, and the effects of the Landscape PC2 at site level, % forest cover, % road cover, % grassland and agricultural land cover and dog occurrence frequency for occupation probability. The best-supported coefficients of the occupation models indicated that (i) the probability of pudú occupation increased in landscapes with exotic plantation cover within 1250 m (Land2) (w* = 0.94) and (ii) it increased with higher % grassland + agricultural cover within 200 m (w* = 0. 67), while (iii) the probability of occupation decreased with higher frequency of dog occurrence (w* = 0.96), (iv) decreased with higher % road cover within 200 m (w* = 0.87) and (v) decreased with higher % native forest cover within 200 m (w* = 0.77). The probability of detection decreased with a greater number of dogs (w* = 0.98), decreased with the application of other bait (w* = 0.98) and increased in the autumn season (w* = 0.98).

Table 4. Model selection based on AICc (c-hat estimate = 1; P-value = 0.35): Top 20 best-ranking single-season single-species detectability and occupancy models for pudú (*Pudu puda*) in 17 rural communities, Chile, estimated using 144 camera trap records between December, 2012 and March, 2016. The detection model structure was p(Nd+Oceb+Temp).

Detectability and occupancy models	K	AICc	∆AICc	AICcW	Cum.W
p(Nd+Oceb+Temp)psi(Land2+Bo+Cam+Con+FOd+PrAg)	11	510.19	0	0.3	0.3
p(Nd+Oceb+Temp)psi(Land2+Bo+Cam+FOd+PrAg)	10	510.57	0.37	0.25	0.55
p(Nd+Oceb+Temp)psi(Land2+Bo+Cam+Pl+FOd)	10	512.77	2.58	0.08	0.64
p(Nd+Oceb+Temp)psi(Land2+Bo+Cam+Pl+Con+FOd)	11	512.9	2.7	0.08	0.72
p(Nd+Oceb+Temp)psi(Land2+Cam+FOd+PrAg)	8	513.42	3.23	0.06	0.78
p(Nd+Oceb+Temp)psi(Land2+FOd)	7	513.73	3.54	0.05	0.83
p(Nd+Oceb+Temp)psi(Land1+Land2+Bo+Cam+Con+ PrAg+FOd+PrAg:Nd)	13	513.89	3.7	0.05	0.88
p(Nd+Oceb+Temp)psi(Land2+Cam+Pl+FOd)	9	514.67	4.48	0.03	0.91
p(Nd+Oceb+Temp)psi(Land1+Pl+FOd)	8	515.35	5.16	0.02	0.93
p(Nd+Oceb+Temp)psi(Land2)	6	515.61	5.42	0.02	0.95
p(Nd+Oceb+Temp)psi(Pl+FOd)	7	515.77	5.58	0.02	0.97
p(Nd+Oceb+Temp)psi(Land1+Land2+Bo+Cam+Pl+Ma+ Con+PrAg+FOd)	14	517.36	7.16	0.01	0.98
p(Nd+Oceb+Temp)psi(Land1+Land2+Cam+Pl+Con+FOd)	11	518.3	8.11	0.01	0.98
p(Nd+Oceb+Temp)psi(Land1+Land2+Bo+Cam+Pl+Ma+ Con+PrAg+FOd+PrAg:Nd)	15	518.65	8.46	0	0.99
p(Nd+Oceb+Temp)psi(FOd)	6	519.48	9.29	0	0.99
p(Nd+Oceb+Temp)psi(Nd)	6	520.17	9.98	0	0.99
p(Nd+Oceb+Temp)psi(Cam)	6	520.57	10.37	0	0.99
p(Nd+Oceb+Temp)psi(Land1)	6	520.83	10.63	0	1
p(Nd+Oceb+Temp)psi(PrAg)	6	520.98	10.78	0	1
p(Nd+Oceb+Temp)psi(Land1+FOd)	7	521.11	10.91	0	1

Abbreviations: K = number of parameters; AICc = small sample Akaike Information Criterion; ∆AICc = change in AICc; AICcw = small sample Akaike weight; cumltvW = small sample Akaike cumulative weight.

3.3 Darwin’s fox

We analyzed a total of 67 models: 24 for model detectability while maintaining constant occupancy and 43 for model occupancy. There was no evidence of lack of fit (p-value >0.05) but there was a slight overdispersion (c-hat >1), so the selection of the best model was made with QAICc. The 20 most plausible models (with the lowest QAICc value) are shown in Table 5. According to the QAICc, the most parsimonious occupation model for Darwin's fox includes the effect of the number of dogs for the detection probability, and the effect of the % grassland and agricultural cover for the occupation probability. Based on the QAICcW, it is suggested that these covariates are important predictors of occupancy and detection probability, as the 20 best models involve these terms. The coefficients of the best-supported models indicated that: (i) the higher the % of grassland+agricultural coverage within 200 m (w* = 0.55), the lower the probability of occupation by Darwin's foxes and (ii) the higher the number of dogs (w* = 0.88), the lower the probability of detection.

Table 5 Model selection based on QAICc (c-hat estimate = 1.55; P-value = 0.09): Top 20 best-ranking single-season single-species detectability and occupancy models for Darwin's fox (*Lycalopex fulvipes*) in 17 rural communities of Chile, estimated using 82 camera trap records between December, 2012 and March, 2016. The detection model structure was p(Np+Receb+Temp), p(DAc+Temp+Nd) and p(Nd).

Detectability and occupancy models	**K**	**QAICc**	**∆QAICc**	**QAICcW**	**Cum. W**
p(Nd)psi(PrAg)	5	139.22	0	0.15	0.15
p(Nd+Rceb+Temp)psi(Land2+Isla+Cam)	9	139.98	0.76	0.1	0.26
p(Nd+Rceb)psi(PrAg)	6	140.39	1.18	0.08	0.34
p(Nd+DAc+Temp)psi(Land1+Isla)	8	140.47	1.26	0.08	0.42
p(Nd)psi(PrAg+FOd)	6	141.07	1.85	0.06	0.49
p(Nd+Rceb+Temp)psi(PrAg)	7	141.21	1.99	0.06	0.54
p(Nd+Rceb)psi(Isla+PrAg)	7	141.57	2.35	0.05	0.59
p(Nd+DAc+Temp)psi(Land1+Land2+Isla)	9	141.9	2.68	0.04	0.63
p(Nd+Rceb+Temp)psi(Land2+Isla+Cam+FOd)	10	142.23	3.02	0.03	0.66
p(Nd+DAc+Temp)psi(Land1+Land2+Isla+Cam)	10	142.32	3.11	0.03	0.7
p(Nd+Rceb+Temp)psi(Land2+Isla+Cam+Pl+ Con+PrAg)	12	142.52	3.3	0.03	0.72
p(Nd)psi(Land1+Nd)	6	142.84	3.63	0.02	0.75
p(Nd)psi(Nd)	5	142.88	3.66	0.02	0.77
p(Nd+Rceb+Temp)psi(Isla+PrAg)	8	142.9	3.69	0.02	0.8
p(Nd+Rceb+Temp)psi(Land2+Isla+Con+PrAg)	10	142.96	3.74	0.02	0.82
p(Nd)psi(Pl+Con+PrAg+FOd)	8	143.21	3.99	0.02	0.84
p(Nd+Rceb+Temp)psi(Land2+PrAg)	8	143.43	4.21	0.02	0.86
p(Nd)psi(Isla+Con+PrAg+FOd)	8	143.44	4.23	0.02	0.88
p(Nd+Rceb)psi(Land2+Isla+PrAg)	8	143.56	4.34	0.02	0.9
p(Nd+Rceb+Temp)psi(Land2+Isla+FOd)	9	144.45	5.23	0.01	0.91

Abbreviations: K = number of parameters; QAICc = Quasi-likelihood small sample Akaike Information Criterion; ∆QAICc = change in QAICc; QAICw = Quasi-likelihood Akaike weight; cumltvW = Akaike cumulative weight.

3.4 Kodkod

We analyzed a total of 88 models: 28 for model detectability while maintaining constant occupancy, and 60 for model occupancy. There was evidence of lack of fit (p-value <0.05) and overdispersion (c-hat >1), so the selection of the best model was made with QAICc. The 20 most plausible models (with the lowest QAICc value) are shown in Table 6. According to the QAICc, the most parsimonious occupancy model for the Kodkod includes the effect of the control area, re-baiting, other bait and number of days the camera was active for the probability of detection, and the effect of dog occurrence frequency on probability of occupancy. The coefficients of the best-supported models indicated that the probability of Kodkod occupation decreases as the frequency of dog occurrence increases (w* = 0.7), while the probability of detection increases in the control areas (w* = 0.82) and decreases with re-baiting (w* = 0.87), installation of other bait (w* = 0.87) and the number of days the camera was active (w* = 0.85).

Tabla 6. Model selection based on QAICc (c-hat estimate = 3.2; P-value = 0.03): Top 20 best-ranking single-season single-species detectability and occupancy models for Kodkod (*Leopardus guigna guigna*) in 17 rural communities of Chile, estimated using 144 camera trap records between December, 2012 and March, 2016. The detection model structure was p(CA+Rceb+Oceb+DAc), p(CA+Rceb+Oceb+DAc+Temp), p(CA+Rceb+Oceb+Temp) and p(Np+CA+DAc+Rceb+Oceb+Temp).

Detectability and occupancy models	**K**	**QAICc**	**∆QAICc**	**QAICcW**	**Cum.W**
p(CA+Rceb+Oceb+DAc)psi(FOd)	8	287.53	0	0.17	0.17
p(CA+Rceb+Oceb+DAc)psi(Land1+FOd)	9	288.42	0.89	0.11	0.28
p(CA+Rceb+Oceb+DAc+Temp)psi(FOd)	9	288.84	1.31	0.09	0.37
p(CA+Rceb+Oceb+DAc)psi(Con+FOd)	9	289.65	2.12	0.06	0.42
p(CA+Rceb+Oceb+DAc)psi(Land1+FOd+Nd)	10	289.86	2.32	0.05	0.48
p(CA+Rceb+Oceb+DAc)psi(Land1+Con+FOd)	10	290.17	2.64	0.05	0.52
p(CA+Rceb+Oceb+DAc+Temp)psi(Land1+FOd)	10	290.29	2.76	0.04	0.56
p(CA+Rceb+Oceb+DAc)psi(Nd)	8	290.65	3.11	0.04	0.6
p(Nd+CA+DAc+Rceb+Oceb+Temp)psi(FOd)	10	290.89	3.36	0.03	0.63
p(CA+Rceb+Oceb+DAc)psi(Land1+Nd)	9	291.01	3.48	0.03	0.66
p(CA+Rceb+Oceb+DAc+Temp)psi(FOd+Nd)	10	291.13	3.6	0.03	0.69
p(CA+Rceb+Oceb+DAc)psi(Land1+Land2+FOd+ Nd)	11	291.54	4.01	0.02	0.71
p(CA+Rceb+Oceb+Temp)psi(Land1+Nd)	9	291.59	4.06	0.02	0.73
p(CA+Rceb+Oceb+DAc+Temp)psi(Land1)	9	291.67	4.14	0.02	0.76
p(Nd+CA+DAc+Rceb+Oceb+Temp)psi(Land1+FOd)	11	291.75	4.22	0.02	0.78
p(CA+Rceb+Oceb+DAc+Temp)psi(Land1+FOd+Nd)	11	291.93	4.39	0.02	0.79
p(CA+Rceb+Oceb+DAc+Temp)psi(Nd)	9	291.99	4.46	0.02	0.81
p(CA+Rceb+Oceb+DAc+Temp)psi(Land1+Con+ FOd)	11	292.03	4.49	0.02	0.83

p(CA+Rceb+Oceb+DAc)psi(Land1+Land2+Nd)	10	292.29	4.76	0.02	0.85
p(CA+Rceb+Oceb+DAc+Temp)psi(Land1+Land2+FOd)	11	292.58	5.05	0.01	0.86

Abbreviations: K = number of parameters; QAICc = Quasi-likelihood small sample Akaike Information Criterion; ∆QAICc = change in QAICc; QAICw = Quasi-likelihood Akaike weight; cumltvW = Akaike cumulative weight.

4. Discussion

While previous studies have addressed the patterns of occupation of domestic dogs and wild mammals in rural areas of southern Chile, most of these studies have been conducted in a single landscape and do not consider the diversity of socio-economic and environmental contexts present in rural southern Chile

The combination of social and ecological tools, including interviews, camera traps, occupation models and cartographic maps, and the heterogeneity of socioeconomic and environmental contexts of the 17 rural landscapes in four different geographical areas, allowed us to obtain reliable estimates of the spatial distribution of domestic dogs living in rural communities adjacent to PA or forest remnants, and of the spatial distribution of three medium-sized mammals with conservation problems: the pudú, Darwin's fox and Kodkod, whose occupation have been reported to be affected by the presence of dogs (Silva-Rodríguez and Sieving, 2012; Moreira-Arce et al., 2015a).

The abundance, management and spatial distribution of domestic dogs have been recognized as important factors determining their impact on wild communities (Vanak and Gompper, 2009; Gompper, 2014b; Silva-Rodríguez and Sieving, 2011; Sepúlveda et al., 2014; Ribeiro et al., 2019). Our results revealed that a negative effect of domestic dogs was observed for each of the native mammals, either in their occupation of space or in their probability of detection.

The results of this study indicate that free-ranging dogs are much more common than medium sized wild mammals, with the exception of the Kodkod, whose number of detections was slightly higher than that of dogs (Table 2). Our more parsimonious model for the domestic dog indicated that its occupation was strongly influenced by landscape structure (Table 3). Our results indicate that more disturbed and open areas such as scrublands, grasslands, agricultural lands and exotic plantations increased the probability of dog occupation. These results support what has been reported in other studies, which indicate that the occurrence of domestic dogs in rural areas is closely related to the type of land cover (Frigeri et al., 2014; Soto and Palomares, 2015; Morin et al., 2018; Paschoal et al., 2018). Although dogs were widespread throughout our study area, these findings suggest that the probability of dogs accessing forest and PA areas depends on how rural communities use the land around them, which could lead to a differential impact on native species depending on the landscape configuration in which they are inserted.

In contrast to other studies (Silva-Rodríguez et al., 2010; Silva-Rodríguez and Sieving, 2012; Moreira-Arce et al., 2015a; Paschoal et al., 2018) we found no influence of human construction or road coverage on dog occupation, which may be due to the sampling design of our study, where we selected communities with low population density, and the scale of photo-interpretation of our landscapes in which we could only differentiate large main roads, generating an underestimation of this coverage. However, the close relationship between roads and exotic plantations cover variables in the PCA (see Supplementary Material) alludes to a higher density of roads and trails in forest plantations, so their availability to dogs could be represented by the cover of this form of land use.

In our study the dogs showed no differences in habitat selection between landscapes or sites (i.e. there was no support for interactions), but rather showed an expected higher occupancy in more disturbed landscapes. This finding is consistent with that reported in Chapter 2 of this thesis, where we revealed that more disturbed landscapes, with higher proportions of grassland, agricultural land, scrubland and exotic plantation cover were associated with a larger number of dogs. Therefore, the effect of dog ownership and management would be seen mainly by the number of dogs moving freely in the landscape and not by a change in dog behavior. For example, we observed no evidence of more exploratory behavior in sites where dogs were poorly managed, i.e. dog management would not be as relevant as a consequence of the presence of a high number of dogs.

The extensive landscape modification that has occurred in the temperate forests of southern Chile indicates that these landscapes have become ideal areas for the presence of domestic dogs. Our landscape structure variables were important predictors of dog occupation in these landscapes and indicate the great adaptation of dogs to disturbed landscapes (Silva-Rodríguez and Sieving, 2012; Vanak and Gompper, 2010). Consequently, their potential interaction with wildlife would be strongly influenced by human landscape modification activities in areas adjacent to PA and remnants of forest (Butler et al., 2004; Srbeck-Araujo and Chiarello, 2008; Vanak and Gompper, 2010), and by the presence of a greater number of free-roaming dogs in more disturbed landscapes. Because dogs are strongly associated with humans, their invasion process is somewhat different. Unlike wild species, dogs do not respond numerically to prey decline; their populations are highly dependent on human subsidy (Vanak and Gompper, 2009; Silva-RodrÍguez et al., 2010). Predicting the potential effects of domestic dogs on wildlife is complicated by a nuanced interaction between landscape structure, human density and human culture and behavior, so simplistic perceptions of dog threats may be altered. These results highlight the importance of the human dimension in the anthropogenic impact of dogs on wildlife (Miller et al., 2014). The effect of human behavior on the landscape and the human-dog relationship could be considered from an optimistic perspective, since those human actions which favor the movement of dogs could also influence a decrease in their occupation (Morin et al., 2018). More studies are needed to understand the human dimension of this problem. Social studies may help explain human values, attitudes, behaviors and knowledge of this problem, therefore, they may provide a useful framework for understanding the human dimension of domestic dog use and dog-wildlife interaction (Miller et al., 2014).

Our most parsimonious model that explained the occupation of the pudú (Table 5) indicated a strong avoidance to domestic dogs. The probability of pudú occupation decreased with higher dog occurrence frequency, while its detection decreased with a higher number of dogs. Our findings are consistent with the results of Silva-RodrÍguez and Sieving (2012), who reported that the variable that best explained the occupation of pudú was the probability of dog presence. Covariates of landscape structure were also strongly supported as predictors of pudú occupation. Road coverage had a negative influence on the occupation of the pudú. Similar results were found by Silva-Rodríguez and Sieving (2012), who reported that the presence of trails in front of the cameras decreased the probability of detecting pudu. This could be due to a higher probability of finding predators such as pumas, dogs and humans on roads and trails (Sepúlveda et al., 2015; Zúñiga and Jiménez, 2018). Exotic plantation coverage had a positive effect on their occupation. This contrasts with that reported by Silva-Rodríguez and Sieving (2012) who found no difference in pudu occupation between native cover and plantations. Although exotic plantations are one of the possible causes of the decline of the pudú (Jiménez, 2010), our findings indicate that this type of cover would be providing adequate habitat for this species, possibly due to the presence, of a dense and complex understory in many cases, and exotic herbs that would act as shelter and food (Jiménez, 1995; Silva-Rodríguez and Sieving, 2012). The coverage of grassland and agricultural land also had a positive effect on the occupation of the pudú. Jiménez (1995) noted that pudús moved to edge habitats and more open areas to feed since there is greater availability and diversity of soft-growing plant tissue, which would indicate that this species does not depend exclusively on mature forest for all its needs. Although it is known that habitat fragmentation and loss due to deforestation, as well as pressure from domestic animals such as dogs, constantly threaten the pudú (Jiménez, 2010), the increased occupation of pudú in land cover suitable for dogs could be suggesting a temporary modification of their activity patterns, as a mechanism for avoiding dogs and other predators (Zúñiga and Jiménez, 2018). Zúñiga and Jiménez (2018) found that this deer was largely nocturnal with little activity during the day, contrary to the activity patterns of domestic dogs whose forays and peak hours are during the day (see Silva-Rodríguez and Sieving, 2012; Moreira-Arce et al., 2015a; Sepúlveda et al., 2015). We suggest further research be conducted regarding changes in the temporal occupation patterns of the pudú in response to the presence of the dogs. The fact that we obtained a lower probability of detecting pudú with the application of other bait was not surprising, since the strong odor of these commercial lures acted as an attractant for domestic dogs, increasing their probability of detection (see Table 3). The increased probability of detection during the autumn season also coincides with the reproductive biology of this deer, whose mating season occurs between the months of March and June (Reyes et al., 1988; MacNamara and Eldridge, 1987; Whitehead, 1993).

For carnivores, the best-supported models showed that Darwin's fox and Kodkod responded differently to landscape structure and dogs, suggesting that the number and frequency of occurrence of dogs better explains the distribution of these carnivores than landscape structure, at least for the gradient of landscape structure and cover incorporated in this study.

We found that the detection of Darwin's foxes was negatively influenced by the number of dogs (Table 5). Our findings are consistent with the results of Silva-RodrÍguez et al. (2018) and Moreira-Arce et al., (2015) who also found a negative relationship between the detection of Darwin's foxes and the presence of dogs on Chiloé Island and in the Nahuebulta Range, respectively. Domestic dogs would represent a risk for foxes through different mechanisms such as predation (D'Elia et al., 2013) and disease transmission (Cabello et al., 2013). The lower probability of fox occupation in grassland and agricultural cover (Table 5) may be due to the absence of forest cover and dense vegetation in these areas, which has been reported to be closely related to the presence of this species (e.g. Moreira-Arce et al., 2015a, 2016; Silva-Rodríguez et al., 2018). Deforestation may also favor other larger fox species (*Lycalopex griseus* and *L. culpaeus*), which are better adapted to open areas (Silva-Rodríguez et al., 2010; Moreira-Arce et al., 2015a) and may displace Darwin's foxes (Jiménez et al., 1991). We cannot separate the effect of the covariates on the presence of Darwin's foxes because dog occupation was higher in grassland and agricultural cover (Table 3). And we cannot exclude human influence because of the association of dogs with people (e.g. Silva-Rodríguez et al., 2010; Silva-Rodríguez and Sieving, 2012; Sepúlveda et al., 2015, Chapter 1) and because people can kill carnivores, including Darwin's foxes (Silva-Rodríguez et al., 2007, 2009b; 2018; Stowhas, 2012).

The probability of Kodkod occupation was negatively influenced by dog occurrence frequency (Table 6). Our finding disagrees with the results of Moreira-Arce et al. (2015) and Gálvez et al. (2018), who found no influence of the occurrence of dogs on the occurrence of this feline. However, Moreira-Arce et al. (2016) mentioned that the higher occurrence of this feline in areas of higher elevation could be due to its sensitivity to human activity and to exotic carnivores such as the domestic dog that occur at lower elevations. Our finding is strongly related to the increased detection of this feline in control areas (Table 6) in which no domestic dogs have been recorded. A covariate not included in the most parsimonious model for the Kodkod, and which had medium support, was Land1 ($w^* = 0.43$) (Table 6). This covariate suggests a higher probability of Kodkod occurrence in more disturbed landscapes, which could be due to the Kodkod's high tolerance for habitat loss (Gálvez et al., 2018) and altered habitats such as exotic plantations, fragmented landscapes, forest edges and rural settlements (Sanderson et al., 2002, Zúñiga et al., 2009; Napolitano et al., 2015). However, despite this potential influence of 'Land1', our results reveal that Kodkod space use is more strongly influenced by domestic dogs (w* = 0.7) than by landscape structure (w* = 0.43). This can be further supported by the lower probability of detection of Kodkod with the application of other bait, which increases the probability of detection of the dogs (see Table 3). Further studies on the influence of domestic dogs on this small cat should be conducted to understand better their habitat use in rural landscapes surrounding the PA.

Our results and the differences obtained in the global naïve occupancy and the overall occupancy estimated from the models (PAO) for the pudú (0.24 and 0.53) and Kodkod (0.49 and 0.60) (see Table 2) would highlight the need to (1) take into account imperfect detection (probability of detection of animals <1); (2) model species occupation using fine-grained habitat covariates such as understory cover and complexity of habitat structure (Moreira-Arce et al, 2016), which may be better predictors of space use for these species; and (3) take into account additional information, such as the number of individuals and their movement behavior, to estimate their occupation reliably, since a low density of individuals moving rapidly over large home ranges may be overestimating PAO, as it could have occurred in our study (see Neilson et al., 2018).

5. Conclusion

To ensure the long-term future of wild mammal populations in human-dominated landscapes, both outside and inside PA, it is imperative that we identify potential ecological and social drivers of species decline and assess their relative importance (Redpath et al., 2013). Our results highlighted the importance of the human dimension in the spatial distribution of domestic dogs and three representative mammal species of the temperate forests of southern Chile. Through cultural practices of land use and dog ownership and management, humans can influence the use of space by domestic dogs and wildlife, so they must be considered key actors in the conservation of these species and they must be at the center of any intervention that aims to preserve cultural practices of land management and wildlife conservation. The results of this study can be used by any professional interested in wildlife conservation and territorial landscape planning, in order to facilitate human-wildlife coexistence.

Conflict of interest statement

The authors of the study declare that there is no conflict of interest.

Appendix. Supplementary Material

S1. R results of Pearson's correlation analysis of landscape variables at site level (a) and at camera level (b).

S2. R results from the Principal Component Analysis (PCA) for landscape structure variables at site level

S3. PCA biplot for landscape variables at site level (a) and camera level (b)

S4. R results from the Principal Component Analysis (PCA) for the variables of dog ownership and management.

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General Discussion

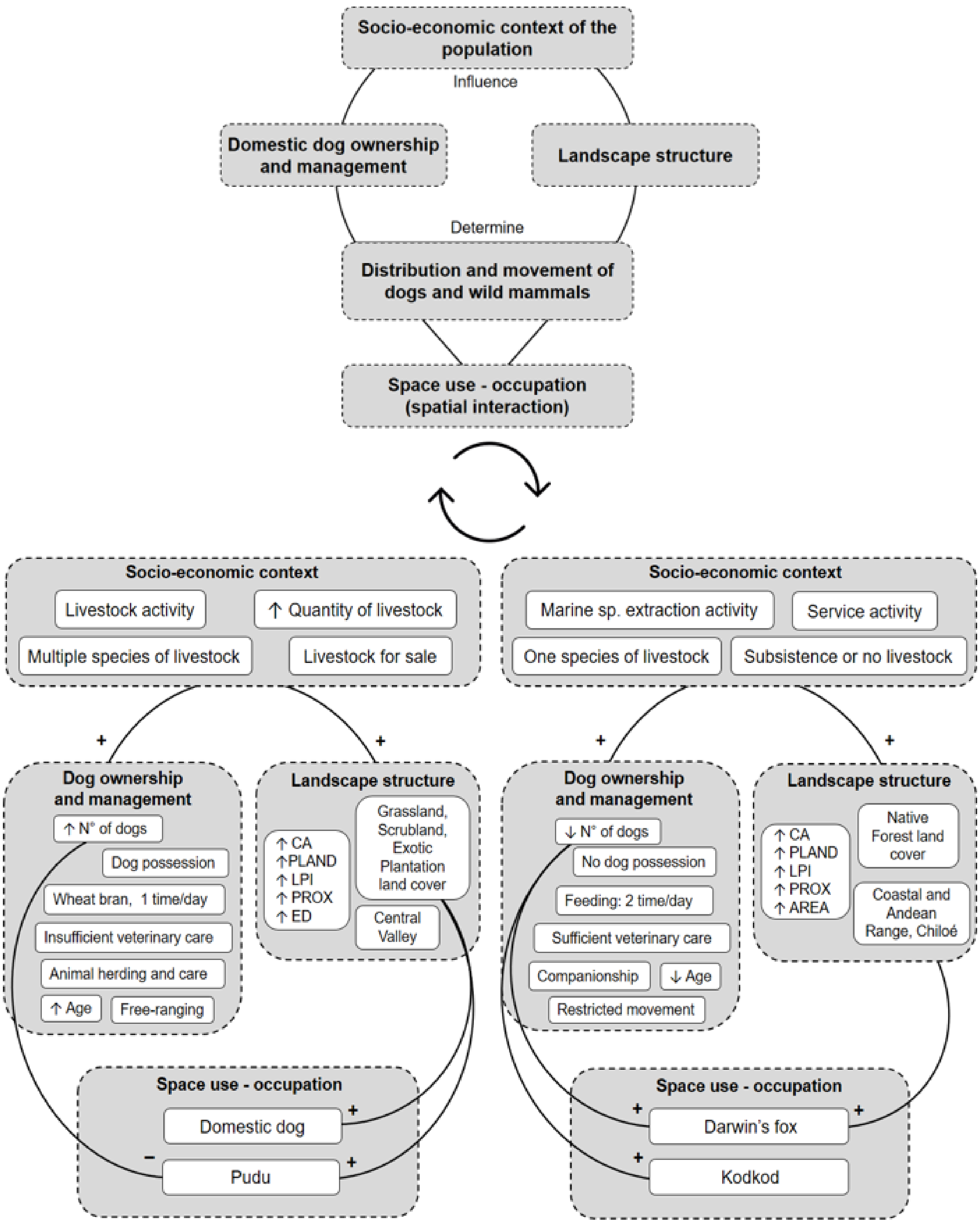
The current Anthropocene era (Crutzen, 2002) is characterized by profound human influences resulting in global environmental degradation, species introduction and biodiversity loss (Dirzo et al., 2014; Lewis and Maslin, 2015; Tucker et al., 2018). Forests, the dominant terrestrial ecosystem on Earth (Pan et al., 2013), are rapidly converting to non-forest land uses such as agriculture, livestock, industry and other infrastructure (Curtis et al., 2018). In these human-dominated landscapes, mammal populations are being threatened directly by human behavior (Ceballos et al., 2005; Woodroffe et al., 2005; Silva-Rodríguez et al., 2007, 2009b; Stowhas, 2012; Napolitano et al., 2016), and indirectly by habitat degradation and fragmentation (Fahrig, 2003; Crooks et al., 2017; Lino et al., 2018) and the introduction of invasive species, such as domestic animals, which can prey on wild species, transmit diseases or compete for resources (Hughes and Macdonald, 2013; Bellard et al., 2016a, 2016b; Doherty et al., 2016, 2017). Among the many species of plants and animals that have been domesticated, the dog has the distinction of being the first (Galibert et al., 2011). Its threat to biodiversity is of increasing concern as dog populations are associated with almost all human populations, and as the human population has increased in density and expanded in range, so have domestic dog populations (Gompper, 2014; Morin et al., 2018). To ensure the long-term future of mammal populations in human-dominated rural landscapes within and around protected areas, it is imperative to identify potential ecological and social drivers of species decline (Redpath et al., 2013).

This thesis proposed a socio-ecological approach, bringing together methods from the natural and social sciences, to examine how the socio-economic context of the rural human population influences the occupation and spatial distribution of domestic dogs and wild mammals through dog ownership and management practices and landscape structure modification. For this purpose, 14 rural communities adjacent to protected areas and large forest remnants located in different geographical areas, with different land use histories, were selected to cover most of the socioeconomic heterogeneity of the temperate forests of rural southern Chile. An important aspect of the socio-ecological approach is that social and ecological data are collected at the same spatial scale, allowing the different potential drivers of species decline to be contrasted and assessed (Gálvez et al., 2018). Specifically, in this thesis we used data derived from camera trap sampling, remote sensing images and semi-structured interviews with rural households to understand the role of humans in the interaction between dogs and wild mammals.

This thesis is the first to characterize, on a regional scale, the variability of social and economic factors of the rural human population with dog possession, and documents the incidence that this variability has on domestic dog ownership and management, on the metrics of current landscape structure, and on the spatial distribution of dogs and wild mammals in the Southern Chilean Temperate Forest Ecoregion. Our work achieved its general and specific objectives, and the results obtained support the hypothesis the dog-wildlife interaction in protected areas and forest remnants is influenced by a combination of effects of the socio-economic context of surrounding rural communities on landscape structure and domestic dog ownership and management, which in turn influence the spatial occupation patterns of domestic dogs and wild mammals in these areas (Figure 1).

The main results of this thesis are summarized in Figure 1. From this, we observe a gradient between two socioeconomic contexts that characterize the rural landscapes of the Temperate Forest Ecoregion of southern Chile. On the one side contexts linked to livestock activities and on the other side contexts linked to activities of marine species extraction and services. These socioeconomic contexts influenced different dog ownership and management and different landscape structures. On the one side, livestock contexts were associated with a greater possession and number of dogs and with a worse management given to them, while their landscape structure was characterized by a greater coverage of grasslands, scrublands and exotic plantations and by a greater fragmentation of the native forest. On the other side, contexts of marine species collection and services were associated with less possession and number of dogs and with better management given to them, while their landscape structure was characterized by greater native forest coverage less fragmented. Dog ownership and management and landscape structure in turn influenced the patterns of species occupation. More disturbed landscapes with a greater presence of dogs, characteristic of contexts linked to livestock activities, were associated with a greater occupation of domestic dogs and pudúes, although a greater number of dogs decreased the occupation of the pudú. Less disturbed landscapes with less presence of dogs, characteristic of contexts linked to the collection of marine species and services, were associated with a greater occupation of Darwin's Foxes and Kodkod.

Fig. 1. Final scheme of the systemic relationship where the dog-wildlife interaction resulting from the interaction of social and ecological components is contextualized. The ultimate cause of dog-wildlife interaction is the socio-economic context of the population, which influences the landscape structure and the domestic dog ownership and management. These in turn determine the distribution and movement of dogs and wild mammals, and thus their patterns of occupation (spatial interaction). Own elaboration.



The results of our study highlighted the importance of the human dimension in dog-wildlife interaction and provided a reliable evidence base to guide future studies and conservation programs in rural areas.

The results of the first chapter highlighted the significant influence of the socio-economic context of rural households on domestic dog ownership and management,

a. The probability of dog possession was negatively associated with years of schooling of the head of household and positively associated with number of people living in the household.
b. The results suggest two distinct rural socio-economic contexts, reflecting the current rural scenario in southern Chile. On the one side, we observed households associated to a socioeconomic context mainly livestock and/or agroforestry, which are characterized by the possession of a greater number and variety of farm animals as a preponderant activity, and where the head of household and/or interviewee have less years of schooling, more years of residence in the sector and more age. On the other side, we observed households associated to a socioeconomic context linked to service activities and extraction of marine species, which are characterized by not owning livestock or owning only one species for subsistence purposes, and where the head of household and interviewee have more years of schooling, less years of residence in the sector and less age.
c. The influence of the socio-economic context of rural households was reflected in a gradient between two contrasting profiles of domestic dogs, which differed in ownership (i.e. number and age of dogs) and in the management

exerted on the dogs (i.e. feeding, veterinary care, function and confinement). Livestock/agroforestry socio-economic contexts were associated with a higher number of dogs, poor quality of food (fed with wheat bran and once a day), insufficient veterinary care, with functions mainly linked to the herding and care of animals, and with dogs without movement restriction. On the other side, socio-economic contexts linked to service and marine species extraction activities were associated with a lower number of dogs, higher feeding frequency (twice a day), sufficient or optimal veterinary care, with mainly companionship functions and with some degree of movement restriction.

d. This observed pattern could be due, according to Teel et al. (2010), to the modernization of rural systems, including economic development, urbanization and increased levels of income and education, which would have predictable effects on social values, contributing to an intergenerational shift in value orientations towards wildlife and perception of the environment, from a vision of dominance to one of mutualism (Manfredo et al., 2009).

e. These findings reveal that there is no single "rural dog", but in fact various types of rural dogs, with ownership and management varied according to the SE characteristics of their owners.

The results of the second chapter highlighted the significant influence of the socioeconomic context of rural communities on the class level metrics of current landscape structure (CA = Total area, PLAND = Percentage of landscape, PD = Patch density, ED = Edge density, LPI = Largest patch index, AREA = Average area of all patches, PROX = Proximity index within 2000 m),

a. The most important socio-economic variable was geographical area, which suggests two distinct rural socio-economic contexts. On the one side, we observed households belonging to the Central Valley, which were characterized by having more houses with dogs, a greater number of dogs and farm animals, engaging in livestock activities and owning livestock for sale and of multiple species. On the other side, households belonging to the Coast Range, the Andes Range and Chiloé Island which were characterized by not possessing dogs or farm animals, or by owning livestock for subsistence, and engaging in marine species extraction and service activities.
b. The influence of the socioeconomic context of rural households was reflected in current landscape metrics, and substantial differences in landscape metrics were found between geographic areas. Landscapes with livestock contexts belonging to the Central Valley had a greater coverage and representation of the grassland, scrubland and exotic plantation classes (higher values of CA, PLAND, LPI, AREA, PD, ED and PROX metrics) and greater fragmentation of the native forest cover (higuer values of PD and ED metrics). Landscapes with marine species extraction contexts had a greater coverage and less fragmentation of the native forest class (higher values of CA, PLAND, LPI, PROX and AREA metrics).
c. The difference found in the current landscape metrics between geographical zones would be explained by the history of human occupation of the landscapes in southern Chile.
d. The results confirmed the strong association between local SE factors and class level metrics of current landscape structure, and suggest the important

role that rural communities have in defining the structure of the landscape through practices that depend directly on the use of natural resources.

The results of the third chapter highlighted the importance of the human dimension in the spatial distribution of domestic dogs and three mammal species representative of the temperate forests of southern Chile: the pudú (*Pudu puda*), Darwin's Fox (*Lycalopex fulvipes*) and Kodkod (*Leopardus guigna*),

a. Landscape structure variables were important predictors of dog occupation and indicated the great adaptation of dogs to disturbed landscapes. Grassland, agricultural land and exotic plantations cover positively influenced dog occupation.
b. The potential interaction between dogs and wild mammals would be strongly influenced by human landscape modification activities and by the presence of a greater number of free ranging dogs in more disturbed landscapes.
c. The results revealed negative effects of dogs on the probability of occupation and/or detection for the three wild mammal species.
d. The occupation of the pudú decreased with a greater frequency of occurrence of dogs, with road cover and native forest cover. It increased with grassland and agricultural land cover and exotic plantation cover. Pudú detection decreased with a greater number of dogs. These results suggest that the pudú does not depend exclusively on the native forest for all its needs, and that it may be modifying its temporal patterns of activity to avoid dogs in more disturbed coverages.

e. The occupation of the Darwin's fox decreased with cover of grassland and agricultural land, where dogs are more likely to be present, and detection decreased with increased numbers of dogs.
f. The occupation of the Kodkod decreased with an increased frequency of occurrence of dogs.
g. Through cultural practices of land use and dog ownership, humans can influence the spatial distribution of domestic dogs and wild mammals and should therefore be considered key actors in species conservation.

Conclusions

“One of the anomalies of modern ecology is that it is the creation of two groups, each of which seems barely aware of the existence of the other. The one studies the human community almost as if it were a separate entity, and calls its findings sociology, economics, and history. The other studies the plant and animal community, [and] comfortably relegates the hodge-podge of politics to ‘the liberal arts.’ The inevitable fusion of these two lines of thought will, perhaps, constitute the outstanding advance of the present century” - (Wilderness, Aldo Leopold 2013 [1935], p. 375)

This refrain has become common in conservation science (e.g., Mascia et al., 2003; Bennett et al., 2017), yet researchers still struggle to overcome disciplinary boundaries. While there is growing recognition that approaches that integrate social and ecological knowledge should lead to more effective conservation solutions, difficulties in aligning data types, challenges in communicating across disciplines, and misperceptions about the quality and usefulness of social science information continue to affect these efforts (Fox et al., 2006; Pooley et al., 2014; Lischka et al., 2018). Knowledge sharing across all relevant disciplines and contexts will be a critical development for the conservation field in the coming years (Tallis and Lubchenco, 2014).

As we saw in this thesis, the need for socio-ecological integration is paramount to the understanding of human-dog-wildlife interactions, considering the strong association between humans and domestic dogs throughout history. While researchers recognize that ecological and social factors contribute to this interaction, there is still a dearth of interdisciplinary research that integrates both types of information to guide management and conservation decision-making.

Future studies should aim to link the two disciplines to better understand the social, cultural, economic and ecological factors that influence human-dog-wildlife interaction and should address the mechanistic aspects behind the patterns detected in this thesis. The results of this thesis mainly identified relevant associations and proposed hypotheses that deserve to be tested with more detailed studies. To achieve this, future research could aim to integrate traditional and local ecological knowledge, which has been broadly defined as “cumulative body of knowledge, practices, and beliefs about the relationship between humans and their environment, which changes over time through an adaptive process” (Berkes et al., 2013), to help improve management and conservation, especially in rural contexts where its success may be affected by local communities. At the same time, the use of local knowledge can provide a local and more detailed perspective on conflicts in the ecosystems under study (Berkes et al., 2004; 2013; Guerrero-Gatica et al., 2020). This type of ecological knowledge, rooted in social history, can offer alternatives to improve future research and achieve the coexistence of biodiversity conservation with land use productive practices (Gadgil et al., 2003; Guerrero-Gatica et al., 2020).

"Different parts of the Ocean contained different sorts of stories, and ... all the stories that had ever been told and many that were still in the process of being invented could be found here .... And because the stories were held here in fluid form, they retained the ability to change, to become new versions of themselves, to join up with other stories and so become yet other stories; so that ... the Ocean of the Streams of Story was much more than a storeroom of yarns. It was not dead but alive" – (Haroun and the Sea of Stories, Salman Rushdie 1990, p. 71)

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Appendix

Supplementary Material Chapter 1

Questionnaire S1. Interview conducted with rural populations

Dog ownership and management section

1. Do you have dogs?
2. How many dogs do you have?
3. What is the age and sex of each dog?
4. What do you feed your dogs? How many times each day?
5. How do you manage your dogs? (Permanently free-ranging, tethered, free-ranging and tethered)
6. Are your dogs sterilized? Do they have any vaccines? (Which?) Are the de-parasitized? (How long ago?) Have they been taken to see a veterinarian?

Socio-economic characteristics of the interviewee and head of household

1. General information of the interviewee: Sex, age, years of schooling.
2. General information of the head of household: Sex, age, years of schooling.
3. How long have you lived in this sector?
4. How many people live in your house?
5. What economic activities do you and your family pursue in this sector?
6. Do you have farm animals? What species of animals? How many of each?
7. Are the animals for household consumption or sale?

Supplementary Material Chapter 3

S1. R results of Pearson's correlation analysis of landscape variables at site level (a) and at camera level (b) (Pbo = % forest cover; PPrAg = % grassland + agricultural cover; PPl = % exotic plantation cover; Pcon = % anthropogenic building cover; PBo. ld = % Forest cover at total landscape scale; PPla.ld = % Exotic plantation cover at total landscape scale; PD.ld = Patch density at landscape level)

(a)

```
         Pbo PPrAg   PPl  Pcon PBo.ld PPla.ld PD.ld
Pbo      1.00 -0.61 -0.23 -0.56  0.63   -0.14 -0.10
PPrAg   -0.61  1.00  0.03  0.67 -0.51    0.22  0.34
PPl     -0.23  0.03  1.00  0.07 -0.12    0.71  0.04
Pcon    -0.56  0.67  0.07  1.00 -0.73    0.22  0.42
PBo.ld   0.63 -0.51 -0.12 -0.73  1.00   -0.23 -0.23
PPla.ld -0.14  0.22  0.71  0.22 -0.23    1.00  0.19
PD.ld   -0.10  0.34  0.04  0.42 -0.23    0.19  1.00
```

(b)

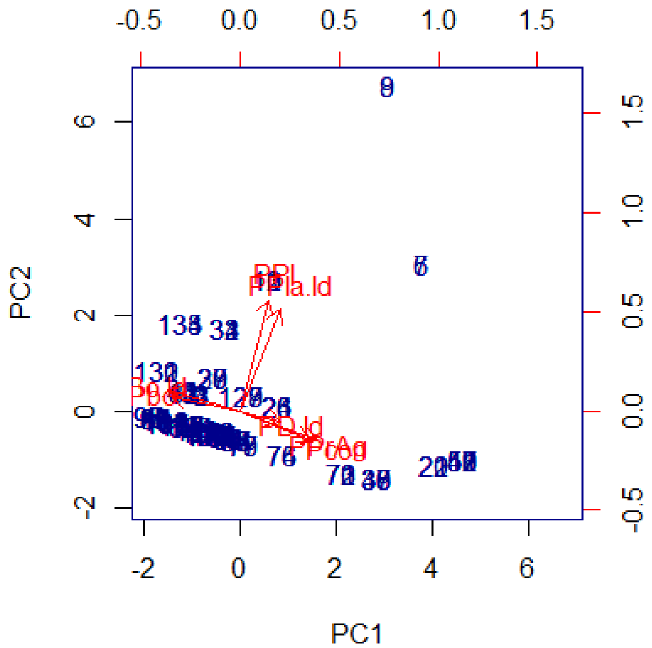
```
        Pbo  Pcam   PPl   Pma  Pcon PPrAg
Pbo     1.00 -0.13 -0.33 -0.54 -0.22 -0.60
Pcam   -0.13  1.00  0.23  0.06  0.05  0.01
PPl    -0.33  0.23  1.00 -0.10  0.04 -0.10
Pma    -0.54  0.06 -0.10  1.00  0.08  0.15
Pcon   -0.22  0.05  0.04  0.08  1.00  0.20
PPrAg -0.60  0.01 -0.10  0.15  0.20  1.00
```

S2. R results from the Principal Component Analysis (PCA) for landscape structure variables at site level (Pbo = % forest cover; PPrAg = % grassland + agricultural cover; PPl = % exotic plantation cover; Pcon = % anthropogenic construction cover; PBo. ld = % Forest cover at total landscape scale; PPla.ld = % Exotic plantation cover at total landscape scale; PD.ld = Patch density at landscape level)

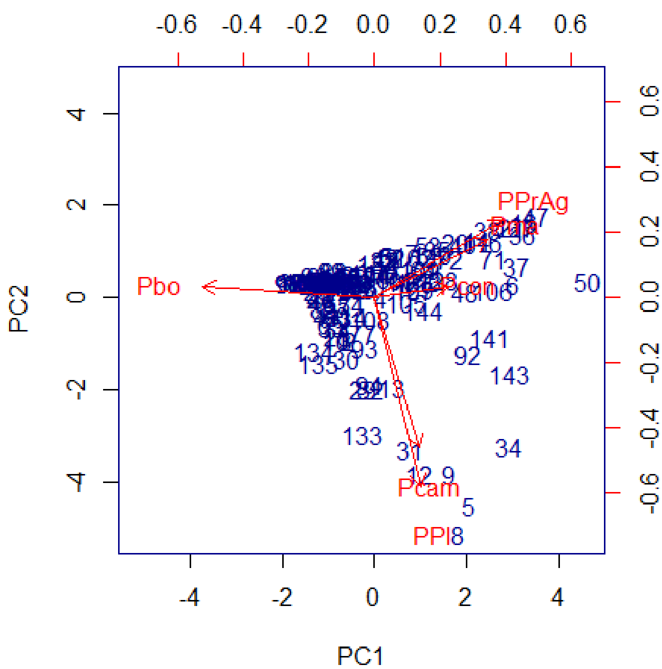
```
> summary(Metricas.pca)
Importance of components:
                          PC1    PC2    PC3     PC4     PC5     PC6     PC7
Standard deviation     1.7784 1.2508 0.9823 0.70925 0.64853 0.47815 0.39449
Proportion of Variance 0.4518 0.2235 0.1378 0.07186 0.06008 0.03266 0.02223
Cumulative Proportion  0.4518 0.6753 0.8132 0.88502 0.94511 0.97777 1.00000

> Metricas.pca$rotation
               PC1         PC2         PC3          PC4        PC5         PC6         PC7
Pbo     -0.4317622  0.09050823 -0.45060151  0.266006107 -0.5539824  0.16712440 -0.44357814
PPrAg    0.4478526 -0.18300794 -0.02294539 -0.673460787 -0.3675607 -0.05757689 -0.41646633
PPl      0.1794560  0.70253389  0.11020581 -0.025409625  0.3410290  0.39363672 -0.43611934
Pcon     0.4870995 -0.18568573 -0.08355346  0.263113562 -0.2485097  0.70453714  0.30645601
PBo.land -0.4594539  0.13126330 -0.19901231 -0.637013079  0.0356332  0.40426816  0.40196764
PPla.land 0.2536991  0.63956039 -0.13136948  0.004340909 -0.4380253 -0.36517929  0.42906921
PD.land  0.2609172 -0.06336997 -0.84878822 -0.003523955  0.4322139 -0.14367750 -0.00070511
```

S3. PCA biplot for landscape variables at site level (a) and camera level (b)

(a)



(b)

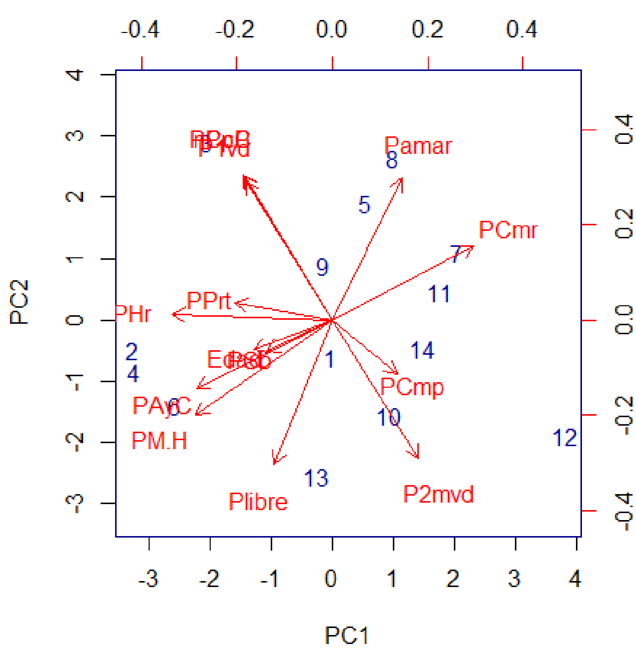


S4. R results from the Principal Component Analysis (PCA) for the variables of dog ownership and management. The first 6 axes (PC6) are shown. (PCmr = % of dogs fed commercial food, Pamar = % of dogs with movement restriction, PCmp = % of dogs with companion function, P2mvd = % of dogs fed 2 or more times a day, PHr= % of dogs fed meal, PAyC = % of dogs with herding and animal care function, PM. H = proportion of male/female dogs, Plibre = % of dogs handled without movement restriction, PPrt = % of dogs with house protection function, P1vd = % of dogs fed 1 time per day, nPpC = number of dogs per house; PCcP = % of houses with dogs, Age = age of dogs, PSb = % of dogs fed with leftovers).

```
Importance of components:
                          PC1    PC2    PC3    PC4     PC5    PC6
Standard deviation     2.1096 1.6955 1.5188 1.2574 0.93462 0.8341
Proportion of Variance 0.3179 0.2053 0.1648 0.1129 0.06239 0.0497
Cumulative Proportion  0.3179 0.5232 0.6880 0.8009 0.86333 0.9130
```

```
> Metricas.pca$rotation
              PC1         PC2         PC3          PC4         PC5         PC6
PCcP   -0.2338044  0.38099087  0.21473899  0.073710273  0.36420948 -0.25061449
nPpC   -0.2292240  0.37762622  0.16719113 -0.074004112 -0.08533986  0.34185565
PHr    -0.4186508  0.01447989 -0.20530455  0.050486781  0.11698376 -0.25256340
PCmr    0.3713614  0.19326710 -0.16283738 -0.040228764 -0.06817788  0.17508945
PSb    -0.1716485 -0.08202090  0.53472502 -0.069465922  0.20214574  0.30136409
P1vd   -0.2260667  0.36268174 -0.27782147 -0.347778159 -0.06305548  0.01737327
P2mvd   0.2260402 -0.36251506  0.27749177  0.348504956  0.06259192 -0.01707976
PCmp    0.1708282 -0.14259616  0.15973055 -0.544612836 -0.44929624 -0.31328651
PPrt   -0.2564002  0.04340305 -0.06438740  0.402924547 -0.57937162  0.37731815
PAyC   -0.3553269 -0.18019587 -0.06062554  0.239787322 -0.28047181 -0.17957380
Plibre -0.1518893 -0.37877040 -0.37031788 -0.200678837  0.02001500  0.12396487
Pamar   0.1820085  0.37109975  0.18378146  0.264082948 -0.34465802 -0.46946890
PM.H   -0.3589520 -0.25072810  0.09308483 -0.005318191  0.02311407 -0.33801980
Edad   -0.2042695 -0.07915335  0.45192945 -0.333470656 -0.23885447  0.10806823
```

S5. PCA Biplot for the variables of dog ownership and management



S6. R results of the most parsimonious occupation models for the 4 study species.

Modelo perros domésticos

```
> summaryOD(fm53, c.hat = 0.82)

Precision unadjusted for overdispersion:

                         Estimate Std. Error Lower 95% CL Upper 95% CL
psi(Int)                -0.765375   0.289914    -1.242242       -0.289
psi(covocup.Paisaje2)    0.300294   0.176942     0.009251        0.591
psi(covocup.Control)    -2.950095   1.178776    -4.889009       -1.011
psi(covocup.Pma)         0.037538   0.019887     0.004827        0.070
psi(covocup.PPrAg)       0.029102   0.018437    -0.001225        0.059
p(Int)                  -2.208457   0.385888    -2.843186       -1.574
p(Receb)                -0.460820   0.280148    -0.921623        0.000
p(Oceb)                  0.866684   0.419585     0.176528        1.557

(c-hat = 1)
```

Modelo Pudú

```
> summaryOD(fm52, c.hat = 0.87)

Precision unadjusted for overdispersion:

                         Estimate Std. Error Lower 95% CL Upper 95% CL
psi(Int)                3.065e+00  1.374e+00    8.056e-01        5.325
psi(covocup.Paisaje2)   3.557e+00  1.227e+00    1.539e+00        5.575
psi(covocup.Pbo)       -2.357e-02  1.600e-02   -4.988e-02        0.003
psi(covocup.Pcam)      -3.804e-01  1.763e-01   -6.703e-01       -0.090
psi(covocup.FOPerro)   -4.047e+01  1.872e+01   -7.126e+01       -9.682
psi(covocup.PPrAg)      6.547e-02  4.106e-02   -2.073e-03        0.133
p(Int)                 -1.721e+01  3.290e+03   -5.429e+03     5394.824
p(Np)                  -5.502e-02  8.818e-03   -6.953e-02       -0.041
p(Oceb)                -2.296e+00  4.229e-01   -2.991e+00       -1.600
p(Temp)                 1.831e+01  3.290e+03   -5.394e+03     5430.343

(c-hat = 1)
```

Modelo Zorro de Darwin

```
> summaryOD(fm40, c.hat = 1.67)

Precision adjusted for overdispersion:

                      Estimate Std. Error Lower 95% CL Upper 95% CL
psi(Int)              -0.96333    0.51340     -1.80779       -0.119
psi(covocup.PPrAg)   -11.62403   67.89692   -123.30452      100.056
p(Int)                -0.86452    0.32638     -1.40137       -0.328
p(Np)                 -0.03381    0.02062     -0.06773        0.000

(c-hat = 1.67)
```

Modelo KodKod

```
> summaryOD(fm49, c.hat = 3.2)

Precision adjusted for overdispersion:

                        Estimate Std. Error Lower 95% CL Upper 95% CL
psi(Int)                 1.15771    0.67282      0.05103        2.264
psi(covocup.FOPerro)   -24.31331   18.01261    -53.94142        5.315
p(Int)                   0.02599    1.07912     -1.74900        1.801
p(Control)               0.95539    0.42741      0.25236        1.658
p(Receb)                -0.57029    0.48421     -1.36675        0.226
p(Oceb)                 -0.74157    0.56811     -1.67602        0.193
p(DAc)                  -0.28008    0.21641     -0.63604        0.076

(c-hat = 3.2)
```