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Original Investigation

Fine-scale movements of rural free-ranging dogs in conservation areas in the temperate rainforest of the coastal range of southern Chile

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ABSTRACT

Domestic dogs can play a variety of important roles for farmers. However, when in proximity to conservation areas, the presence of rural free-ranging dogs can be problematic due to the potential for predation of, competition with, or transmission of infectious disease to local threatened fauna. We used a frequent location radio tracking technology to study rural free-ranging dog movements and habitat use into sensitive conservation habitats. To achieve a better understanding of foray behaviors in dogs we monitored dogs ($n = 14$) in rural households located in an isolated area between the Valdivian Coastal Reserve and the Alerce Costero National Park in southern Chile. Dogs were mostly located near households (<200 m) but exhibited a diurnal pattern of directed excursions (forays) away from their home locations. Dogs spent, on average, 5.3% of their time in forays with average per dog foray distances from the house ranging 0.5–1.9 km (maximum distance detected 4.3 km). Foraying behavior was positively associated with pasture habitat compared to forest habitat including protected lands. Foraying dogs rarely used forest habitat and, when entered, trails and/or roads were selected for movement. Our study provides important information about how dogs interact in a fine-scale with wildlife habitat, and, in particular, protected lands, providing insight into how dog behavior might drive wildlife interactions, and, in turn, how an understanding of dog behavior can be used to manage these interactions.

Introduction

Despite the global trend of urbanization, in most developing countries protected lands are in remote areas, far from urban settlements (Joppa and Pfaff, 2009). The landscapes surrounding these protected lands are typically inhabited by rural human communities that are highly dependent on the use of natural resources (Baland and Platteau, 1996; Shackleton et al., 2002). In these communities, proximity to protected lands can lead to conflict with conservation efforts (e.g., hunting bushmeat) but can also provide opportunities for the community (e.g., ecotourism) (Andam et al., 2010; Naughton-Treves et al., 2005; Wittemyer et al., 2008). In addition to forest resources, small-scale agriculture is typically the primary economic driver of these communities and farm animals, such as cattle and sheep, provide a key source of animal protein (Dovie et al., 2006; Waters-Bayer and Bayer, 1992). In these rural communities, domestic dogs (*Canis familiaris*) are common and play a variety of roles on the farm, including the guarding of livestock and the protection of households (Gehring et al., 2010; González et al., 2012; Rigg, 2001; Sepúlveda et al., 2014a).

However, dogs in rural areas can be problematic. Dogs represent an increasing problem for biodiversity conservation (Gompper, 2013; Hughes and Macdonald, 2013; Young et al., 2011). Free-ranging dogs are common in developing countries (Dalla Villa et al., 2010) and are frequently found around or inside protected areas in Africa (Atickem et al., 2009; Butler and du Toit, 2002; Butler et al., 2004), Central and South America (Fiorello et al., 2006; Koster, 2008; Lacerda et al., 2009) and Asia (Vanak and Gompper, 2009a). The occurrence of domestic carnivores in natural ecosystems can affect the local fauna through a variety of mechanisms (Hughes and Macdonald, 2013; Vanak and Gompper, 2009b). Dogs, particularly free-ranging dogs, have been responsible for declines in threatened populations due to predation in a variety of species including marine iguanas (*Amblyrhynchus cristatus*) (Kruuk and Snell, 1981),

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Galapagos giant tortoises (*Chelonoidis nigra*) (MacFarland et al., 1974), and kiwis (*Apteryx mantelli*) (Taborsky, 1988). Moreover, the transmission of infectious diseases from populations of dogs around parks also poses a significant threat to endangered wildlife (Cleaveland et al., 2000; Funk et al., 2001). For example, viruses such as canine distemper and rabies have caused population declines in African wild dogs (*Lycaon pictus*) (Alexander and Appel, 1994), lions (*Panthera leo*) (Roelke Parker et al., 1996), black footed-ferret (*Mustela nigripes*) (Williams et al., 1988) and Ethiopian wolves (*Canis simiensis*) (Sillero Zubiri et al., 1996).

A critical gap in minimizing the risk to wildlife associated with interactions with dogs is an understanding of the movement patterns and habitat use of these free-ranging dogs, particularly in relation to conservation areas and threatened species' habitat. Recent telemetry studies in dogs show a clear selection for anthropogenic-dominated landscapes in rural areas (Ruiz-Izaguirre et al., 2014; Vanak and Gompper, 2010; Woodroffe and Donnelly, 2011). In particular, it is clear that dogs mostly stay close to their house of origin. Despite the apparent generality of this pattern (e.g., Vanak and Gompper 2010; Woodroffe and Donnelly, 2011; Silva-Rodríguez and Sieving 2012; Ordeñana et al., 2010), it is also clear that dogs move inside conservation-sensitive areas (Parsons et al., 2014). These events, while infrequent at the individual dog scale, are key to understanding the impacts of dogs inside protected areas. The existing studies provide little information on how dogs move on the landscape during forays. To achieve a better understanding of foray behaviors in dogs, we used a novel, radio tracking technology to study dog forays into sensitive conservation habitats in the Valdivian Temperate Forest in southern Chile. Specifically, this study focused on understanding habitat use during forays in a context of agricultural and natural environments. Our specific goals were to determine: (1) dog movements in relation to their house of origin, (2) what habitats dogs utilize during foray behavior, (3) the daily pattern of dog forays and (4) the pattern of dog movements in and around protected areas and threatened species' habitats.

Material and methods

Study area

The study area is located in the Coastal Range of Southern Chile in the Valdivian Temperate Forest (39° 58′ Lat., 73° 31′ Long.), an ecosystem denominated as a global conservation hotspot (Brooks et al., 2006). Rural communities living in the lowlands of the forest ecosystem utilize cleared lands for livestock production (cattle and sheep). Dogs are present in the study area in most households and are used primarily for farm animal protection as well as house guarding (Sepúlveda et al., 2014a). These dogs can be classified following Vanak and Gompper (2009b) as 'rural free-ranging dogs', these are 'dogs that are owned or peripherally associated with human habitations but are not confined to a proscribed outdoor area. These include (but are not limited to) 'stray' dogs and owned farm and pastoral companion dogs whose daily activity pattern may involve ranging that can bring them into contact with wildlife, especially when human habitations border wildlife reserves or other natural areas'. In this area, dogs represent an important threat for the conservation of endangered species such as the southern pudu (*Pudu puda*) (Endangered, IUCN, 2014) by predation (Silva-Rodríguez and Sieving, 2012), Southern river otters (*Lontra provocax*) (Endangered, IUCN, 2014) by disease transmission (Sepúlveda et al., 2014b) and interspecific killing (Espinosa, 2012), and the Darwin fox (*Lycalopex fulvipes*) (Critically Endangered, IUCN, 2014) by interspecific killing and disease transmission (Farías et al., 2014). We conducted our study in Cadillal Alto, a small human settlement that includes 11 families/households located on the north bank of the Chaihuín River between two protected areas, the Valdivian Coastal Reserve (VCR) and the Alerce Costero National Park (ACNP) (Fig. 1), with 50,250 and 24,694 ha respectively. The location of small villages at the edge of protected areas is a common situation in southern Chile (Sepúlveda and Silva-Rodríguez, 2012), and therefore we assumed that the study site would be representative of other protected areas. The small number of households, and therefore of rural dogs, allowed us to monitor a representative number of all dogs. This village is accessible seasonally by road or by boat, has no electricity and is geographically isolated from other rural communities. Grazing pastures for livestock are distributed predominantly in the northern lowlands of the Chaihuín River (Fig. 1).

Dog sampling and data collection

Prior to the start of the study in December 2009, the goals and approaches for this research were presented to the community of Cadillal Alto and written permission was obtained from all participating households. All families had dogs for a total of 21 dogs in the community. We collected movement data from 14 dogs in 8 households (66.6% of total dogs). Two households did

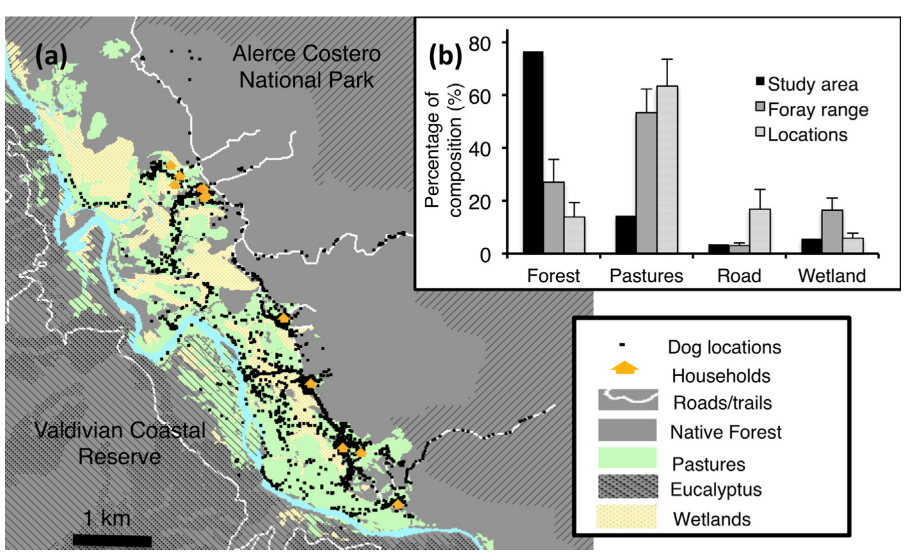

Fig. 1. Study area, GPS of 14 radiomonitored dogs and proportion of habitat composition for total study area, foray ranges and radiolocations by dogs.

not agree to participate (3 dogs were present in each of these houses) and a third house had one aggressive dog excluded from the study. Twelve of the monitored dogs were from six households (2 dogs/households) and the remaining two dogs from two households (1 dog/household). Considering the limited sample size we did not control by dog's ownership assuming all dogs were independent and the study analyzed all dogs pooled.

We collected information on dog movement using GPS radio collars developed for tracking hunting dogs (GPS/receiver Garmin Astro 220, Garmin, USA). Once placed and activated, the collars are capable of sending locations from up to 10 dogs and as frequently as every 30 s for 12–24 h depending on the number of dogs tracked and collar battery life. Locations were sent to a base station receiver with a maximum reception range of 11 km. After the collars were fitted on a maximum of ten dogs in the village, the receiver was placed in a centralized location with a maximum distance of 1.5 km from all monitored households. Accuracy of GPS locations was measured for all radio collars at the beginning and the end of the study with an error of <20 m from a stationary location. These cohorts of collared dogs were monitored continuously for 12–24 h, which was considered a monitoring period. The number of dogs monitored per period varied depending on how many owners and dogs were at home when the collars were fit. Each dog was tracked between one and seven periods (mean: 3.1) per month between January–June and November–December 2010. We planned to obtain 5–7 monitoring periods per dog per month but two main factors affected the number of periods per dog: (1) the absence of people and/or the absence of dogs at the moment of the visit to the household and (2) weather conditions (heavy rains) that limited our capacity to visit households, which affected the amount of data collected per month and by dog. No data were collected between July–September 2010 due to the seasonal heavy rains that limited our access to the study site. After the fourth month of the study, the frequency of GPS data collection in the radio collars changed from readings every 30 s to readings every 10 min. The reason for this change is unknown. Because all dogs' data were affected similarly, and because the dog cohort monitoring periods and forays were scaled in hours rather than minutes, the 10 min interval was not considered problematic. After the change in recording time interval, the collar locations were verified using hand held GPS units to assure continued accuracy.

Habitat classification and analysis of dog habitat use and foray behavior

To determine habitat types, a land cover map was created by photo-interpreting in ArcGIS 10.0 (ESRI Inc., Redlands, CA, USA) a satellite image from Google Earth of May 2010 (QuickBird, Special Agency Digital Globe, USA), including 60-cm/pixel resolution and 4 multispectral bands. Habitats were categorized as native forest, eucalyptus, pastures, wetlands, rivers and trail/roads at a minimum resolution of 3 m × 3 m.

To determine the overall pattern of dog movement, we calculated for each dog the percentage of locations within each sequential 200 m interval from the household of origin. For purposes of analysis, we defined forays as a directional movement where the dog moved at least 200 m from the household for a minimum duration of 1 h (Fig. 2). For all foray analyses, we only utilized locations collected during a foray. All other locations were not used in the analysis. Although data locations within monitoring periods were not independent due to the high frequency of the movement data (30 s to 10 min), we used all the information available, as it was key to address the problem of forays.

For each dog we determined the 'foray range'. Foray range was defined as the estimate of the home range by using only foray locations. The foray range was estimated using a 95% fixed kernel. Kernel estimators are based on probability kernels, which are regions around each point location containing some likelihood of animal presence (Worton, 1989). To estimate 'foray ranges' we used the Home Range Tools in ArcGIS 10.0. Foray range was calculated for all dogs having >35 foray locations. This decision considered that thirty locations as the minimum threshold to estimate fixed kernel home ranges (Seaman and Powell, 1996). Habitat use of the forays was estimated at second and third order of selection as defined by Johnson (1980) and adapted to only foray movements. Specifically, second order selection assessed dog foray range habitat composition compared to the total study area habitat distributions in order to determine how foray habitat selection differs from overall habitat availability. The study area was defined by the minimum convex polygon of all dog radiolocations pooled. Third order selection compared the composition of habitat used (the proportion of individual foray locations in each particular habitat category) to the available habitats within the foray range. Habitat use for both levels was analyzed using compositional analyses (Aebischer et al., 1993) using the package adehabitatHS and function compana (Calenge, 2006) in software R (R Development Core Team, 2011). The proportions of habitats used to those available were compared between the study area and the foray range and then between the foray range and the total of dog foray locations using a Wilk's lambda (λ) distribution. If habitat use in this analysis was found not to be random, we performed pairwise comparisons. Zero values of proportions can be found in the available habitats when the third-order habitat selection is under focus. In this case, it may occur that some habitat types are available to some animals and not to others. Because third order analysis involves analysis of actual locations and, therefore, can have individual dogs that do not use a particular habitat (zero denominator), a weighted mean lambda was used in this analysis as described by Aebischer et al. (1993: Appendix 2) and estimation of *P*-values was performed using a randomization test. River habitat category was eliminated from this analysis since dog's use of rivers was clearly transitory.

The daylight activity pattern was analyzed dividing the diel cycle in 4 periods: dawn (±1 h from sunrise), day, dusk (±1 h from sunset) and night. Sunset and sunrise times were adjusted depending on the month of the year the data was obtained. We compared the total radio-tracking hours per dog for each of the 4 time periods to the hours of foray activity per dogs tracked during those periods. The daylight activity pattern of forays was analyzed by methods similar to the habitat use analysis described previously, by comparing the proportion of hours during dawn, day, dusk and night used during forays vs. the proportion of hours during monitoring. All statistical analyses used an α level = 0.1 considering the limited sample size of dogs (n = 14).

Finally, foray locations were characterized as being within a protected area or as using a known threatened species' habitat. Threatened or endangered species of concern known to be in the study area were described previously. The habitats of these species are native temperate forest (guigna, Darwin's fox, pudu) and riparian habitats (river otter). Species presence in these habitats in this particular study area had been confirmed by previous and continuing studies using camera traps and interviews (Farías et al., 2014; Sepúlveda et al., 2014a,b; Silva-Rodríguez and Sieving, 2012).

Forays in sensitive conservation areas were classified according to the following criteria: (1) Riparian Foray: defined as a foray with dog locations within riparian forest along the Chaihuín River (<20 m from river shore). This habitat was used as a proxy to represent the river otter primary habitat (Sepúlveda et al., 2007); (2) Forest Foray: defined as a foray with dog locations >50 m inside of a continuous native forest patch. This is the primary habitat for pudu (Silva-Rodríguez and Sieving, 2012), guigna (Dunstone et al., 2002) and Darwin's fox (Jiménez, 2007); (3) Reserve Foray: defined as forays with dog locations within the limits of the VCR; (4) Park

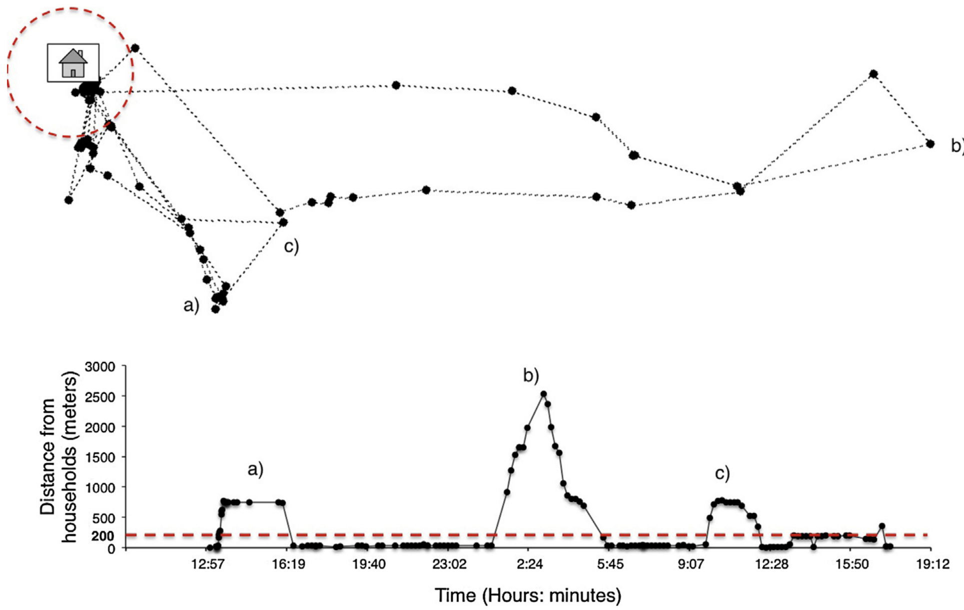

Fig. 2. Track of a rural domestic dog and foray dog definition.

Foray: defined as a foray with dog locations within the limits of the ACNP. All remaining forays were classified as confined to human dominated landscapes.

Results

We collected 19,224 locations from the 14 monitored dogs. The total number of monitoring days for all dogs pooled was 70.1 days (mean days per dog: 5.01 ± 0.08 SE). For all dogs, the mean duration of a monitoring period was 13.4 ± 0.7 SE hours. The mean time distance between periods of radiomonitoring was 10.2 days (range 4–29 days). The average maximum distances of forays from the house of origin per dog are described in Table 1, with a maximum distance observed of 4.3 km (Information about dog's sex, age, number of monitoring periods by collared dog is provided in Supplementary Material, Table 1S).

Supplementary table related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.mambio.2015.03.001

Dogs exhibited foraying behavior only 5.3% of the total monitored time; the rest of the observations were at locations <200 m from the household or represented longer distance movements of less than an hour in duration (Fig. 3).

Foray habitat use was not random at a second order of selection (foray range vs. study area) ($\lambda = 0.13$, $df = 3$; P-value < 0.005) with dogs selecting pastures during forays more than forest or roads compared to what would be expected based on the study area habitat distribution (Fig. 1 and Table 2). In the analysis of third order foray habitat use (all foray locations vs. foray range), a different pattern was observed. Overall, third order selection was significant ($P = 0.086$), with roads being the most selected habitat for actual use by dogs and both road and pasture showing more dog locations than would be expected based on foray range alone compared to forest and wetland (Fig. 1 and Table 2).

Dog forays were mostly during the day period, with 80.1% ± 29.8% of dog forays occurring on this interval (=0.127, $df = 3$; P-value = 0.008). Dog forays during dawn, dusk and night did not occur with greater frequency than expected.

Not all the dogs contributed evenly to the number of forays. For a total of 51 forays, five dogs represent 76.5% of the total number of forays. Nine dogs composed the remaining 23.5%, including

Table 1
Summary of foray activity by dog of 14 radio-collared rural dogs around the Valdivian Coastal Reserve, Alerce Costero National Park and Chaihuín River. Forays are characterized as Sensitive Conservation Forays if they contained locations in riparian habitat (Riparian), forest habitat (forest), National Park (Park) or Coastal Reserve (reserve). Otherwise as human dominated land forays.

Dog ID	Time spent in forays (% of total time)	Sensitive Conservation Forays				Human dominated land forays	Mean maximum distance (m) of forays from house of origin (SE)
		Riparian	Forest	Park	Reserve		
D1	7.0	1	0	0	0	2	529 (150)
D2	5.7	0	0	0	0	1	1108
D3	4.23	0	0	0	0	5	1025 (96)
D4	0	0	0	0	0	0	–
D5	5.1	0	1	0	0	0	1008
D6	11.1	1	0	0	0	9	798 (175)
D7	3.0	0	0	0	0	2	534 (23)
D8	0	0	0	0	0	0	–
D9	6.2	0	0	0	0	7	1085 (558)
D10	4.5	0	0	0	0	2	956 (31)
D11	10.5	3	0	0	3	5	1181 (755)
D12	6.5	1	0	0	2	3	1283 (836)
D13	0	0	0	0	0	0	–
D14	6.0	0	0	1	0	2	1985 (2048)
	Mean = 5.3	Sum = 6	Sum = 1	Sum = 1	Sum = 5	Sum = 38	

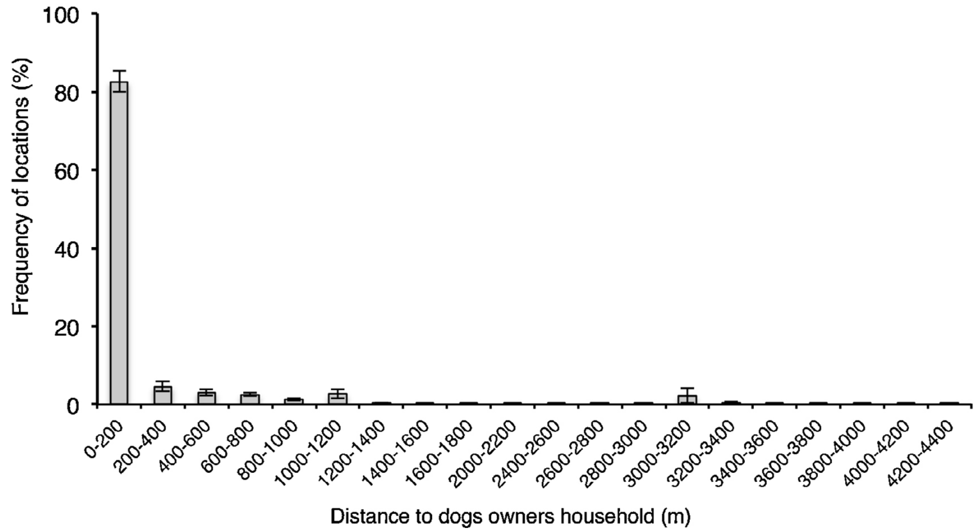

Fig. 3. Percentage of total locations by distances from dog owner's households per dog.

Table 2
Habitat use selection of dog forays at a second order of selection (foray range vs. study area) and third order of selection (dog locations vs. foray range). For second order analyses, a '+++' indicates that the habitat in the row is selected more often for forays compared to the habitat in the column than would be expected given the distribution of habitat in the study area. For third order analysis, a '+++' indicates that the habitat in the row was selected by dogs for forays more often compared to the habitat in the column than would be expected based on the distribution of habitat in the foray range alone.

	Forest	Pastures	Road	Wetland	Ranking
Second order[a]					
Forest	0	−−−	+	−	1
Pastures	+++	0	+++	+	3
Road	−	−−−	0	−	0
Wetland	+	−	+	0	2
Third order[b]					
Forest	0	−−−	−−−	−	0
Pastures	+++	0	−	+++	2
Road	+++	+	0	+++	3
Wetland	+	−−−	−−−	0	1

[a] =0.12; $df = 3$; $P < 0.005$.
[b] Randomization test: $\lambda = 0.15$; $P = 0.086$.

3 with zero forays during the monitoring periods (Table 1). One of these dogs was only collared for one monitoring period of 18 h. There were a total of 13 forays made by 6 dogs into sensitive conservation areas (42.8% of total radio-collared dogs and 25% of all forays) throughout the study-monitoring period. Riparian forays and Reserve forays occurred 6 and 5 times, respectively. Forest forays and Park forays only occurred once each, and the use of trails by dogs was particularly important during these forays (Fig. 1).

Discussion

The dog is one of the world's most widely distributed and abundant carnivores, with an estimated global population of 0.9 billion (Gompper, 2013). Although it is increasingly clear that dogs are impacting natural ecosystems (Gompper, 2013; Hughes and Macdonald, 2013; Young et al., 2011), dog movement and habitat use in natural areas has been poorly investigated (but see Parsons et al. (2014)). This study characterizes, for the first time, the fine-scale movement, behavior and habitat use of dogs during the time they are most likely to interact with wildlife: during forays away from their house of origin. These foray behaviors have distinct characteristics. First, they are infrequent. As expected and as previously reported (Ruiz-Izaguirre et al., 2014; Woodroffe and Donnelly, 2011), dogs spend most of their time close to their homestead. Second, when forays occur, movement is directional and follows primarily human-dominated landscapes with occasional excursions into protected habitats, particularly where roads facilitate movement into forested areas. Thus, based on this study, it is clear that, most of the time, dogs are not exhibiting behavior that is problematic to wildlife conservation and that certain habitat types (i.e., unbroken forest) present a barrier to dog-wildlife interactions and specific landscape attributes such as roads and trails can facilitate dog's displacement.

Dogs spent 5.3% of the total time in foray activity, which represents ~1 h during a 24 h period. This value may be considered low in a per capita-dog unit, but dogs can reach high densities due to their strong human subsidy (Gompper, 2013; Vanak and Gompper, 2009a) determining a substantial presence of dogs in natural habitats. The association of dog habitat use and human settlements has been widely reported in agricultural lands in India (Vanak and Gompper, 2010), Kenya (Woodroffe and Donnelly, 2011) and also in more urbanized areas in Spain (Pita et al., 2009) and North America (Maestas et al., 2003; Ordeñana et al., 2010). Furthermore, a previous study with camera traps in our study area observed that distance to households was a significant variable to predict the presence of dogs (Silva-Rodríguez and Sieving, 2012). Thus, our work confirms that proximity to human houses is probably the most important factor in rural dog distribution. Ferreira et al. (2011) studied the abundance and distribution of free-ranging domestic cats in natural areas in Europe observing similar patterns with human-related variables as the main predictors of presence, abundance and space use of cats. This should not be surprising since, as domestic animals, both dogs and cats are provided with food and shelter at or in proximity to human dwellings.

Clearly, in our results, specific attributes of the landscape are shaping dogs' movements. At a second order of selection (foray range vs. study area), dogs selected pastures over forest or roads. This could be due to the movement of dogs with people or their farm animals (cattle and sheep) and the fact that open pastures offer little if any resistance to movement. A different pattern emerged at the third order of selection (dog locations vs. foray range), where dogs selected roads and pastures over forests and wetlands. The selection of roads for movement by dogs is a particularly interesting finding in this study for two reasons. First, roads and trails were important not only to connect households within the community, but also because dogs were using trails and roads to access

Fig. 4. Photos of rural owned dogs ranging in the study area.

conservation areas and forest habitat (Fig. 1). Second, roads were preferentially selected over forests and wetlands even though roads are a small proportion of habitat in the study area (Fig. 1). In Kenyan arid lands, Woodroffe and Donnelly (2011) assumed an isotropic (uniform in all directions) movement of dogs from bomas (livestock corrals where most people and dogs reside). Isotropic movement may be a reasonable assumption in an open Savannah habitat or other open habitats, but our study shows that this is not applicable in all ecosystems, especially heterogeneous habitats that include forest. Forest was a clear barrier to movement, showing significant negative selection at both the second and third order of selection. Wetlands, on the other hand, restricted fine-scale dog movements (third order) while dogs appeared to select roads at this scale. In an agricultural landscape in India, Vanak and Gompper (2010) observed a similar positive association of dogs to bare ground/roads and human settlements, supporting the selective nature of dog movement in heterogeneous landscapes.

The frequency of forays into sensitive conservation areas appeared to depend primarily on accessibility to the park and reserve based on this selective use of habitats. Forest represented an important barrier to dog movement into these areas, probably due to the dense understory vegetation dominant in this type of temperate ecosystem (Alaback, 1991) (Alaback, 1991). The habitats surrounding the VCR are composed, primarily, of pastures and the Chaihuín River, the latter of which clearly limited dog visits to the Reserve (Fig. 1). However, given the high frequency of dog movements in surrounding pastures adjacent to the river, it is not surprising that dogs were crossing the river and moving into the VCR (Fig. 4). Forays that entered the habitats of threatened species had a similar selective use of habitats, with few forays in dense and continuous forest patches. In contrast, riparian forest habitats were more frequently visited, likely due to the pastures adjacent to these habitats and the relative ease of movement in these areas. Because of the low number of forays observed and the small amount of total monitoring time, additional studies should be conducted to further refine these movement preferences. We observed that 43% of collared dogs made at least one foray into a sensitive conservation area during an average monitoring period per dog of 5 days. Although only 13 forays had dogs entering conservation areas in our study, this is only representative of approximately 70 days of dog activity. Given the ubiquity of human settlements around protected areas in southern Chile and the high levels of dog ownership among these rural farmers (Sepúlveda and Silva-Rodríguez, 2012), the probability of dog movements into protected lands is high.

After each period of dog radio-monitoring we did not ask the dog owners information whether they were accompanied by dogs in their daily movements and, if so, the types of activity they observed (e.g. interactions with wildlife, herding, etc.). This question of how human accompaniment changes timing and location of foray behavior is important in minimizing dog–wildlife interactions. For example, interactions between dogs and wildlife would vary if a dog moves alone versus with its owner and also dependent on the human motivations for the movement. For example, a human out hunting might encourage interactions with prey species whereas a person herding livestock might encourage interactions with carnivores (Koster, 2008; Sepúlveda et al., 2014a). This information should clarify the influence of human presence in dog forays and future studies should explore this important aspect. Previous studies in the area, including the same participants, have determined that locals do not hunt pudu (Silva-Rodríguez and Sieving, 2012), but their dogs are interacting with threatened wildlife such as foxes, guignas and pudus (Sepúlveda et al., 2014a). These dog–wildlife interactions are associated with prey such as pudu when dogs are fed inadequately (Silva-Rodriguez and Sieving, 2011), but dog–conflicting carnivores interactions such as guignas and foxes, which prey upon poultry, are associated with dog owners using dogs for protection against predators (Sepúlveda et al., 2014a). Considering that most dogs in this study were 'rural free ranging dogs', we suspect that humans accompanied dogs in some of these forays, however due to the nature of our data, we were unable to determine whether this was true.

In this study, the potential association of dog activity with humans is supported by the diurnal pattern observed. Camera trap data in the area also suggests that dogs' forays are mainly diurnal (Silva-Rodríguez and Sieving, 2012). Woodroffe and Donnelly (2011) in Kenya observed a similar activity pattern explained by dogs moving with their owners during routine farm or herding activities. In Mexico, Ruiz-Izaguirre et al. (2014) studied scavenging on sea turtles by rural free-ranging dogs observing a nocturnal and dawn dog activity on the beach explained by the authors by the high temperatures during the day (25–30 °C) and absence of shadow. These weather and environmental conditions were not present in our study and may explain the differences between the studies.

Our study did not address factors that can affect dogs' movement in natural areas such as: individual dog variables (i.e. dog's sex, reproductive status or age), influence of other dogs sharing same households, or human accompaniment during forays. All these aspects should be investigated in further studies.

Conclusion and conservation implications

Understanding the impact of dogs on wildlife is an urgent need for conservation (Young et al., 2011). However, the factors that influence these dog behaviors are rarely studied, and without this knowledge dog management strategies that are compatible with the needs of rural communities are likely to be misguided. Rural dogs play important roles within rural settlements (Butler and Bingham, 2000; Sepúlveda et al., 2014a) including the guarding of households and livestock and these functional roles need to be considered when planning dog management. In our study we focused on dog movements with the highest risk for interaction with wildlife: dog forays. We observed patterns attributed to the total population considering the type of habitat use analyses we performed. However, we also determined that not all dogs contributed evenly to this kind of movement, and only a small fraction explained most of the forays observed. This can have important management implications as future initiatives could focus on those 'problematic dogs' instead of implementing activities in all dogs. The identification of this type of dog could be particularly effective as dog owners can easily report this dog behavior as observed during informal conversations when the authors presented the study results to the local community. The promotion of management measures to restrict dog movement, particularly when owners are not present could help mitigate risk. Controlling dog movement through leash use or kennels around farm animal enclosures (e.g. henhouses) would allow dogs to effectively perform their primary guarding duty, while also minimizing roaming and hunting behaviors, but socio-cultural obstacles to implementing this management could be difficult to overcome. Based on our data, another strategy for controlling dog–wildlife interactions could be selective use of habitat or other movement barriers. Conservation programs could reduce dog access into forest ecosystems by reducing the presence of or access to trails or roads, and forest restoration efforts along roadways, particularly those close to rural communities. Such changes, of course, could lead to conflict with local communities who value access to these adjacent conservation areas and therefore a participatory community-based approach should be used. Ultimately, our data shows that the dog behavior exhibiting the highest risk for dog–wildlife interaction and conservation threat, foray behavior, is infrequent at an individual dog level and highly influenced by landscape. This presents an opportunity to minimize problematic dog movement without interfering with the important roles that dogs play in rural farming communities. As human settlements, and therefore, dog populations grow (Vanak and Gompper, 2009b) the understanding of how, when and why dogs move into wildlife habitat will help minimize dog–wildlife interactions and the conservation challenges they represent.

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