Impacts of Domestic Dogs on the Native Mammalian Fauna of the Ecuadorian Andes

A dissertation presented to the Graduate School of the University of Florida in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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December, 2014
IMPACTS OF DOMESTIC DOGS ON THE NATIVE MAMMALIAN FAUNA OF THE ECUADORIAN ANDES

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2014
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To María Claudia, María Emilia and Juan Diego
*Sine quibus non!*
ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor, Dr. Lyn C. Branch, and committee members, Dr. Karen A. Kainer, Dr. Katie E. Sieving, Robert J. Fletcher, and Dr. Melvin E. Sunquist. I have benefitted tremendously from participating in their courses, and they have always been available, ready to help, and have provided insightful reviews and ideas for my dissertation project. I would also like to thank all my professors and fellow students at the University of Florida who contributed greatly to my academic growth.

I am thankful for funding for fieldwork from the Compton Foundation through the Program for Tropical Studies and Conservation, University of Florida; Proyecto Páramo Andino, CONDESAN; and Tropical Conservation and Development Program, University of Florida. My studies at University of Florida were funded by the Amazon – Andes Conservation Program, Wildlife Conservation Society; the Amazon Conservation Leadership Initiative, University of Florida; and SENESCYT – Ecuador. A warm thank you to Hannah Covert, Patricia Sampaio, Wanda Carter, and Caprice McRae for their help with administrative issues and bridging many bureaucratic hurdles during my years as a graduate student.

I would like to thank the Ministry of the Environment of Ecuador for permission to undertake this study (No.20-2009-IC-FAU-DPAP/MA), for providing me with much needed logistical support, and for kindly allowing some of their best wildlife trackers to work with me in the field. Thank you to Jaime Chimbo, Alfredo Gualavisí, Wilson Lastra, Luis Lucero, Carlos Oña, Segundo Rodríguez, Wilson Salazar, Edwin Taimal, and Oscar Tixi for their hard work helping me collect data in the field, their good spirits under what were at times adverse field conditions, and for sharing their traditional knowledge.
about Andean wildlife. The research protocol was approved by the Non-Regulatory Animal Research System of the Institute of Food and Agricultural Sciences, University of Florida (IFAS ARC#015-08WEC).

Special thanks to my mother and brothers: Cecilia, Xavier, Oscar and Andrés, who have always encouraged me to succeed at whatever I desired. None of this would have been possible without the patience and love from María Claudia, María Emilia and Juan Diego, my wife and children. Without their support and understanding I would never have made it this far.
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IMPACTS OF DOMESTIC DOGS ON THE NATIVE MAMMALIAN FAUNA OF THE ECUADORIAN ANDES

By

Galo Zapata-Ríos

December 2014

Domestic dogs are the most ubiquitous introduced carnivore species on the planet. Although the vast majority of dogs are owned as pets, a large percentage of them range freely and many have become feral, individuals that are completely wild and independent of human sources of food. The Ecuadorian Andes have long been occupied by people, and threats to biodiversity such as habitat loss and fragmentation are widely recognized and well documented. On the other hand, the threats posed by exotic species like free-ranging and feral dogs have been overlooked. I evaluated the effects of dogs on the native mammal community of the northern Ecuadorian Andes. Results suggest that the presence of dogs has detrimental effects on native mammals. Occupancy rates of dogs were the most important predictors of occupancy of four Andean carnivores (puma, Andean fox, Andean bear, and striped hog-nosed skunk) across a study area that spanned 2000 km². In Cayambe-Coca National Park where human impacts are very low, four native mammal species (mountain coati, mountain paca, long-tailed weasel, and northern pudu) have been extirpated in areas where feral dogs are abundant, and six other showed significantly reduced relative abundance compared to areas without dogs (puma, Andean fox, Andean bear, striped hog-nosed...
skunk, mountain tapir, and little red brocket deer). Furthermore, the presence of dogs altered significantly the activity patterns of three species (Andean bear, mountain tapir, and little red brocket deer). The increasing number of dogs in wilderness areas have varied and complex ecological effects, influencing community dynamics in innumerable ways, including direct and indirect effects that could cascade down several trophic levels. Dogs have become a conservation, animal welfare, and public health problem in vast areas of the Ecuadorian highlands, as a result of human population growth, poor waste management practices, absence of responsible dog ownership, and low awareness of zoonotic disease issues. Dogs have negative ecological impacts, but policies so far do not focus on this species, but rather on species documented to cause economic losses, diminished food security, and public health issues. The findings of this study have implications for the protection of natural areas worldwide where domestic dogs are present; particularly those that contain endangered and endemic species.
CHAPTER 1
INTRODUCTION

Although the Andes have long been occupied by people, habitat loss and fragmentation through deforestation and human development has been severe during the past century. Recent research estimates that 80 to 95% of the native habitats in the Andean highlands, below 3000 m, have been converted to other uses. The fauna of this region is poorly studied, and knowledge of persistence of species in habitats disturbed by human activities is needed as a basis for conservation in these human dominated landscapes. In Chapter 2, I evaluated which variables (e.g., habitat loss, fragmentation, occupancy of domestic dogs) are associated with the occurrence of Andean carnivores in landscapes of the northern Ecuadorian Andes, and whether thresholds occurred in these variables beyond which carnivore occurrence declined markedly. Five study areas (each 20x20 km) were surveyed with a total effort of 2,800 camera trap nights. Four of the eight known species from the area were recorded frequently enough to build capture histories: Andean fox (*Lycalopex culpaeus*), puma (*Puma concolor*), striped hog-nosed skunk (*Conepatus semistriatus*), and Andean bear (*Tremarctos ornatus*). Occupancy of these native Andean carnivores was best predicted by the occupancy of domestic dogs, and not measures of habitat loss and fragmentation. The two largest carnivores, puma and Andean bear, demonstrated significant threshold responses to the presence of domestic dogs at two sites. The current extent and intensity of domestic dog impacts on native species at the regional scale is unknown. In tropical areas like the Ecuadorian Andes, dogs commonly are abandoned or poorly cared for. Under these circumstances, domestic dogs often become free-ranging or even feral, and represent a significant threat to native wildlife.
The negative impacts of introduced carnivores like feral cats are widespread, significant, and have been well documented. Comparatively, the impacts of feral dogs (individuals that are not associated with people or human settlements) on native wildlife have been overlooked. In Chapter 3, I evaluated the effects of feral dogs on the native mammal community of the northern Ecuadorian Andes. In Cayambe-Coca National Park, I compared relative abundance, activity and habitat use patterns of 10 species of mammals, in areas with and without feral dogs. I used three methods: line transect surveys, camera traps, and track and sign surveys. In areas where feral dogs were present, four native mammal species were absent: mountain coati (*Nasuella olivacea*), mountain paca (*Cuniculus taczanowski*), long-tailed weasel (*Mustela frenata*) and northern pudu (*Pudu mephistophiles*). Relative abundance of six species was reduced compared to areas without feral dogs: puma, Andean fox, Andean bear, striped hognosed skunk, mountain tapir (*Tapirus pinchaque*), and little red brocket deer (*Mazama rufina*). Three of these species also significantly altered their activity patterns where feral dogs were present (Andean bear, mountain tapir, and little red brocket deer). In contrast, none of the native mammal species exhibited shifts in habitat use patterns in areas with feral dogs, which used all habitat types according to availability. My results not only indicate that feral dogs are a significant problem for the native mammal community of this region, but also these findings have implications for the protection of natural areas worldwide where anthropogenic effects appear to be low but feral dogs are present, particularly those that contain endangered and endemic species.

To successfully address the problem of domestic dogs acting as invasive species requires political will and policy measures implemented at the local and national levels.
In Chapter 4, I seek to provide an overview of existing national strategies in South America designed specifically to mitigate and manage the impacts of domestic dogs, and propose potential strategies for the control and management of invasive domestic dogs in Ecuador. Domestic dogs are the most abundant carnivore in South America. As predators, dog populations have significant impacts on native species, and as a consequence have the potential to alter ecosystem structure and function in priority conservation areas. They also can compete with native predators for prey, cause losses to livestock, and transmit disease. A series of policy measures are required to successfully address the problem of domestic dogs as an invasive species. We conducted a review of national strategies for invasive species in South America to determine whether these countries have policies and strategies designed to mitigate and manage the impacts of domestic dogs. Although the domestic dog is officially listed as an invasive species in eight countries in South America, government agencies are not directly addressing problems associated with their impacts. In the short term, national policies for controlling and managing domestic dogs as an invasive species are unlikely to be developed. Reasons include political, economic and cultural issues such as lack of national prioritization schemes for invasive species, the relatively small economic impacts dogs have on human property, lack of information about dog impacts in most areas, and the very close relationship humans and dogs have had for several millennia. For the domestic dog, the most effective ways to prevent introductions into wilderness areas and reduce their impacts on all native ecosystems, include reduction of population size through sterilization programs in urban and rural areas, elimination of
individuals without owners, prevention of free-ranging activity, vaccination programs to reduce the potential for disease transmission, and improved feeding and care.

Chapters 2 through 4 are written in a format suitable for submission to scientific journals. Because they will include one or more coauthors, they are written in the first person plural.
MAMMALIAN CARNIVORE OCCUPANCY IS INVERSELY RELATED TO DOMESTIC DOG PRESENCE IN THE HIGH ANDES OF ECUADOR

Overview

Mammalian carnivores are thought to be particularly vulnerable to local extinction in disturbed landscapes because of their relatively large home ranges, low population sizes, and direct persecution by humans (Sunquist & Sunquist 2001; Crooks 2002; Virgós et al. 2002). Although carnivores are considered members of the same ecological guild, their response to the impacts of human activities and other changes in the landscape vary considerably (Weber & Rabinowitz 1996; Crooks 2002; Virgós et al. 2002; Cardillo 2003; Carbone et al. 2007). At the same time, carnivores are difficult to study because they occur in low densities and are elusive and wary of humans. As a consequence, the ecology of the vast majority of carnivore species and their responses to human-caused disturbances are poorly understood.

Both habitat loss and fragmentation threaten the persistence of many carnivore species increasing their extinction risk. This increased risk has been attributed to decreased population size, increased isolation, and edge effects (Saunders et al., 1991; Smith & Hellmann, 2002; Fahrig, 2003; Melbourne et al., 2004; Asquith & Mejía-Chang, 2005; Tabarelli & Gascon, 2005). The magnitude of the ecological impacts of habitat loss and fragmentation often are exacerbated because other forms of human disturbance co-occur (e.g., hunting, domestic dogs – *Canis lupus familiaris* – as invasive species) and are likely to increase and have synergistic effects as habitat loss and fragmentation increase (Peres 2001; Tabarelli et al. 2004; Cardillo et al. 2005; Ewers & Didham 2006). Hunting is probably the most extensive threat, and has long been recognized as a primary cause of carnivore depletion, leading to cascading
declines of other plants and animals (Estes 1996; Weber & Rabinowitz 1996; Terborgh et al. 1999, 2001; Johnson et al. 2001; Treves & Karanth 2003; Cardillo et al. 2004; Gittleman & Gompper 2005). The threat of domestic dogs as an invasive species, on the other hand, has been recognized more recently. Invasive domestic dogs can be classified as free-ranging or feral. Free-ranging dogs are unconfined dogs that are owned or associated to human settlements, and feral dogs are individuals that are completely wild and independent of human sources of food and avoid contact with people (Butler et al. 2004; Vanak & Gompper 2009). Domestic dogs are the most abundant carnivore on Earth with a great impact on native species. Dogs can spread disease, prey on wildlife, and compete with native carnivores for limited resources (Vanak & Gompper 2009; Young et al. 2011; Hughes & Macdonald 2013; Gompper 2014; Knobel et al. 2014; Vanak et al. 2014).

In the heart of the Tropical Andes region, the Ecuadorian Andes are one of the most biologically diverse regions on Earth (e.g., Gentry 1982; Fjeldså 1994; Duellman 1999; Knapp 2002). Also the Ecuadorian Andes have long been occupied by people, and therefore are considered cultural landscapes. Habitat loss through deforestation and human development has been severe throughout the past century, but land conversion and human population growth have increased in recent decades (Young 1997; Sarmiento & Frolich 2002; Josse et al. 2011). Because of growth of existing human populations, advance of the agricultural frontier, construction of new roads, and the resulting influx of new settlers into previously isolated areas, 80% of the native habitats below 3,000 m has been converted to other uses, and the agricultural frontier is growing steadily higher in elevation (Hofstede et al. 2002; Sarmiento 2002). In addition
to the impacts of habitat loss and fragmentation, other disturbance such as hunting and the presence of invasive domestic dogs occur in the Ecuadorian Andes. Intentional killing of carnivores (e.g., puma, Andean bear) because of conflict and cultural intolerance has increased recently in the Ecuadorian Andes, and threaten the long-term persistence of these species (Goldstein et al. 2006; Castellanos et al. 2010). Also, growing evidence suggests both free-ranging and feral dogs occur in the Ecuadorian Andes, including isolated regions where there are few or no people, and inside protected areas that are considered pristine (Olmedo & Montoya 2011). This variety of anthropogenic impacts have created a hotspot of endangerment and extinction for the highly endemic, but poorly known, biota in the region (Mittermeier et al. 1998; Myers et al. 2000). Greater understanding of factors that influence the current persistence of carnivores in habitats disturbed by human activities in the Andes is needed for biodiversity conservation in these cultural landscapes.

Our objective was to examine factors that influence occurrence of carnivores in the fragmented landscapes of the northern Ecuadorian Andes. Many carnivore species are sensitive to the negative effects of human activities, while others are highly tolerant, and some are even enhanced in disturbed areas (Crooks, 2002; Virgós et al., 2002). For example, at least eight species of native carnivores occur in the Ecuadorian highlands, and this group represents a wide range of biological strategies and includes species at all levels of extinction risk (Tirira 2007, 2011). Differences in habitat specialization among carnivores have been proposed as an important factor that determines extinction risk (Woodroffe, 2001; Cardillo et al., 2004; Carbone et al., 2007). Species that are habitat specialists are more prone to extinction due to changes in their
habitats than are habitat generalists (Arita et al., 1990; Purvis et al., 2001; Ceballos & Erlich, 2002). We hypothesized that habitat loss and fragmentation would be more important in explaining occupancy of habitat specialists than habitat generalists, and that other factors not directly related to landscape amount and configuration, such as hunting and presence of domestic dogs might be particularly important for habitat generalists. In addition, we examined whether thresholds occur in the evaluated factors beyond which carnivore occurrence declines markedly. A critical threshold in a species response to disturbance occurs when this response exhibits a sudden, disproportionate change at some value of the disturbance variable. Thresholds are important for management because slight changes in conditions near critical thresholds could produce large changes in presence-absence and distribution of wildlife species (With & Crist 1995; Keymer et al. 2000; Homan et al. 2004).

Methods

Study Area and Species

The study region, located in the northern Andes of Ecuador (Figure 2-1), is a mosaic of protected areas (e.g., Cayambe-Coca National Park, El Ángel Ecological Reserve, Antisana E.R.), agricultural areas, and indigenous territories (Andean Kichwas) that encompass snow-capped volcanoes, páramos (high altitude grasslands and shrublands), and Andean forests, dominated by tree line species (e.g., Polylepis spp. and Gynoxis spp.; Parsons 1982; Luteyn 1999). Land-cover classes such as agriculture, exotic tree plantations (Pinus radiata and Eucalyptus globulus), native forest patches, native shrubland and grassland patches are interspersed with human settlements, roads, wetlands, and streams (Hess 1990; Peters et al. 2010). Climate is
highly aseasonal, with a mean of 2000 mm annual precipitation, and an average monthly temperature of 14 °C (Winckell et al. 1997).

Five study areas (each 20 x 20 km) were sampled in this study (Figure 2-1). El Morán (00°47’58”N, 78°00’06”W) and Fuya-Fuya (00°08’06”N, 78°18’31”W) are located along the western Andean mountain range, and Filo Curiquingue (00°11’32”N, 77°59’55”W), San Marcos (00°06’19”N, 77°57’43”W) and Guaytaloma (00°19’31”S, 78°08’53”W) are located along the eastern mountain range. The percentage of native vegetation remaining in the five study areas varies from 56% in Fuya-Fuya to 73% in Filo Curiquingue (Baquero et al. 2004). The five study areas have the same vegetation types (Andean forests, páramo grasslands, páramo shrublands) and other ecological characteristics of the highlands (2800-3800 m). Andean Kichwa communities are located along the borders of protected areas, and base their livelihood on agriculture and livestock (Sarmiento 2000; Sarmiento & Frolich 2002; Stoorvogel et al. 2004), which results in a fragmented landscape with native vegetation (forest, shrubs, and grasslands) embedded in a matrix of livestock grazing areas (mainly cows and sheep) and agricultural land (mainly corn and potatoes).

Eight species of carnivores occur in the highlands of the northern Ecuadorian Andes: Pampas cat (*Leopardus pajeros*), puma (*Puma concolor*), Andean fox (*Lycalopex culpaeus*), Andean bear (*Tremarctos ornatus*), Colombian weasel (*Mustela felipei*), long-tailed weasel (*Mustela frenata*), striped hog-nosed skunk (*Conepatus semistriatus*), and mountain coati (*Nasuella olivacea*). Two of these species (long-tailed weasel, striped hog-nosed skunk) are small (<10 kg), habitat generalists; three species (pampas cat, Colombian weasel, mountain coati) are small, habitat specialists; two
other species (puma, Andean fox) are large (>10 kg), habitat generalists; and the
Andean bear is a large species considered a habitat specialist (Sunquist et al. 1989;
Novaro 1997; Sheffield & Thomas 1997; Katan et al. 2004; Peralvo et al. 2005;
Goldstein et al. 2006; Tirira & González-Maya 2009; Garcia-Rangel 2012). Throughout
the Tropical Andes, these species occupy a variety of highland habitats and three are
endemic to this region (~2000-5000 m). Their ranges coincide with areas of high human
population density (Tirira 2007). According to the IUCN Red List of Threatened Species
(2013), the Andean bear and the Colombian weasel are considered Vulnerable, and the
mountain coati has been categorized as Data Deficient. At the national level, the
Ecuadorean Red List of Endangered Mammals (Tirira 2011) categorizes the Andean
bear as Endangered; the pampas cat, puma, Andean fox, and mountain coati as
Vulnerable; and the Colombian weasel as Data Deficient.

Carnivore Surveys

Between April 2009 and July 2010, we carried out presence-absence surveys of
native Andean carnivores and domestic dogs using camera traps (Bushnell Trail Sentry
STD). We subdivided each study area (400 km²) into 16 cells of 25 km²; and in each
cell, we placed randomly seven camera traps at least 1000 m apart (for a total of 112
camera traps in each study area). When a randomly selected site was inappropriate
(e.g., located on a rocky cliff), we selected the closest appropriate site to place the
camera. We used commercially available carnivore urine as an attractant (red fox and
bobcat urine; http://www.predatorpee.com). To create capture histories for each
species, we employed the camera traps for five consecutive days, for a total of 560 trap-
nights in each study area.
Assessment of Habitat Variables

We examined 10 variables related to habitat loss and fragmentation, and other human disturbance, as well as the presence of dogs, at three spatial scales (Table 2-1): 1) at the site scale, using a radial distance of 20 m from the camera trap; 2) at the home range scale, using a 1000-m radial distance from the camera trap for small species (<10 kg), and 5000 m for large species (>10 kg); and 3) at the landscape scale, the 400-km² study area. We measured the variables using ground assessments, camera traps, digital topographic maps scale 1:50,000 (Instituto Geográfico Militar 2011), digital vegetation maps scale 1:50,000 (Baquero et al. 2004), and the FRAGSTATS 3.0 software (McGarigal et al. 2002). Several of the 10 variables for habitat loss and fragmentation were highly correlated and were omitted from the occupancy analysis (Table 2-2). Proportion of habitat that was native (PRONH), number of patches of native vegetation (NUMPAT), land cover/land use native and nonnative (LANCOU), distance to nearest road (DISROA), and distance to nearest house (DISHOU) were uncorrelated and were retained for analyses.

Variables in Occupancy Models for Andean Carnivores and Domestic Dogs

For measures of habitat loss, we used proportion of habitat that was native (PRONH) at the home range scale (Table 2-1), and land use/land cover native or nonnative (LANCOU) at the site scale. Native vegetation included grass páramo, shrub páramo and Andean forest, and nonnative vegetation included grasslands, crops and forest plantations. For fragmentation we used number of patches of native vegetation (NUMPAT). We also included a model with interactive terms for habitat loss and fragmentation to acknowledge the complexity of these interacting processes of
landscape change. Occupancy rates of domestic dogs (DOG) were included as a measure of the introduction of this species.

We did not have direct measures of other types of human disturbance (e.g., hunting, noise, traffic). Therefore, we used distance to nearest house (DISHOU) and distance to nearest road (DISROA) as surrogates for the effects of other human activities that might negatively impact carnivores (Peres 2001; Suárez et al. 2009). Roads have direct impacts on wildlife by reducing movement and increasing mortality and provide access to previously isolated areas which facilitates activities like hunting (Young 1994; Spellerberg 1998).

To model occupancy of domestic dogs, we used the same variables for Andean carnivores. We predicted a positive correlation between occupancy rates of domestic dogs and habitat loss (PRONH) and fragmentation (NUMPAT). In addition, we predicted a positive correlation between occupancy rates of domestic dogs and distance to nearest house (DISHOU) and distance to nearest road (DISROA).

**Detectability of Andean Carnivores and Domestic Dogs**

We modeled detection probability of both Andean carnivores and dogs as a function of the lunar cycle (MOON), and two types of attractants, red fox urine and bobcat urine (LURE). These variables influenced the probability of detection, but not the probability of occupancy. Moon phase likely affects carnivore behavior and activity because moon brightness alters the detectability of both predators and prey (Lucherini et al. 2009; Cozzi et al. 2012). The use of attractants in carnivore surveys significantly increases the detection probability of the species of interest, and generally does not affect movement patterns, abundance or temporal activity patterns (Barea-Azcón et al. 2007; Gerber et al. 2012).
Modeling Approach

We evaluated the influence of habitat loss and fragmentation, the presence of dogs and other human disturbance on carnivore occupancy ($\Psi$) and detectability ($p$) using single-species, single-season occupancy models (MacKenzie et al. 2002, 2006). For each species, we first modeled detection probability using the global model of occupancy, and then only the best detection models were used in the selection of occupancy models (MacKenzie 2006; Schuette et al. 2013). For both, detectability and occupancy, we included among the set of candidate models an intercept model with no covariate effects. Values of the Akaike Information Criterion corrected for small sample size (AICc) were used to rank candidate models (Burnham & Anderson 2002). Akaike model weights ($w_i$) for each occupancy covariable were summed across all models to compare their relative influence for each species ($w_+$; Burnham & Anderson 2004). We assessed the fit of our global models with a goodness-of-fit test based on Pearson $X^2$ statistic and bootstrapping (MacKenzie & Bailey 2004). Occupancy modeling was performed with the PRESENCE 3.1 software (Hines 2006).

We tested for lack of independence among sampling units due to spatial autocorrelation (Lichstein et al. 2002) with the weighted correlation coefficient of Moran (Moran’s $I$; Legendre & Legendre 1998) in ArcView 3.2a (Wong & Lee 2005). No evidence of spatial correlation was present for all species included in the occupancy analyses (Moran’s $I$ range = -0.18-0.34 for all species across sites). To evaluate the existence of significant thresholds in the responses of Andean carnivores to the most important variables (distance to roads, occupancy rates of domestic dogs), we applied generalized piecewise linear regression models to the occupancy rates of native carnivores with the segmented package of R (R Core Team 2013). This type of model
identifies existing discontinuities in the data in the form of break points (Stasinopoulos & Rigby 1992).

Results

Carnivore Surveys

Four species of native carnivores were recorded frequently enough to build capture histories: Andean fox, puma, striped hog-nosed skunk, and Andean bear. The Andean fox and striped hog-nosed skunk were the only species that were recorded in all five study areas and had sufficient data for modeling occupancy in all sites. The puma and Andean bear were recorded in four and three study areas respectively, but only had enough data to construct models for Filo Curiquingue and San Marcos. The pampas cat and Colombian weasel were not detected. The long-tailed weasel and mountain coati were detected only occasionally in two study areas (Filo Curiquingue and San Marcos) and were not included in analyses. Domestic dogs were recorded in the five study areas.

Occupancy and Detectability of Domestic Dogs

The most important predictors of occupancy of domestic dogs were distance to nearest house in San Marcos, El Morán, and Fuya-Fuya; and distance to nearest road in Filo Curiquingue and Guaytaloma (Tables 2-3–2-5). At two sites, Filo Curiquingue and Fuya-Fuya, occupancy was inversely related to distance to houses and distance to roads as expected, but at San Marcos, Guaytaloma and El Morán, occupancy of dogs increased with distance from roads and houses, the opposite of the expected response (Table 2-4). Detection probability of domestic dogs was related to the lunar cycle in Filo Curiquingue and Guaytaloma ($w^+ = 0.69$ and 0.87 respectively), and remained constant in San Marcos, El Morán, and Fuya-Fuya (Table 2-3). The type of carnivore urine used
as a lure had no effect on detection of domestic dogs. Mean estimated occupancy ($\Psi^*$) of domestic dogs varied from 0.53 to 0.79 in the five study areas (Table 2-4).

**Occupancy and Detectability of Andean Carnivores**

Our models indicate that occupancy rates of domestic dogs are important predictors of occupancy of the four Andean carnivores (Tables 2-6–2-7). Except for one species and site (puma in Filo Curiquingue), occupancy of domestic dogs (DOG) was the only variable in the top models, and these models were substantially better at predicting Andean carnivore occupancy than models that included variables for habitat loss and fragmentation, and distance to nearest house and distance to nearest road as measures of disturbance (Table 2-8). In Filo Curiquingue, the most important variable for explaining puma occupancy was distance to nearest road (Table 2-6). Detection probability of two Andean carnivores (Andean fox and striped hog-nosed skunk) was related to the lunar cycle (range $w_+ = 0.64$-0.83), and detection probabilities were constant for the puma and Andean bear. These patterns suggest that activity of Andean fox and striped hog-nosed skunk change during the lunar cycle, and that activity patterns of pumas and Andean bears may be independent of moon phase. The type of carnivore urine used as a lure had no effect on species detection. Goodness-of-fit tests did not indicate lack of fit in our models ($X^2 \geq 12.31; p \geq 0.59$ for all species and sites).

**Thresholds**

Evidence for threshold responses by native carnivores to the most important variables was limited. Thresholds as a response to domestic dogs were detected in San Marcos for pumas (occupancy of domestic dogs at breakpoint, $\Psi_b = 0.42 \pm 0.08$ 95% CI, $p = 0.03$) and in Filo Curiquingue for Andean bears ($\Psi_b = 0.31 \pm 0.05$, $p = 0.04$;
Figure 2-2). No other threshold responses were detected for these species or the Andean fox and striped hog-nosed skunk ($p > 0.05$).

**Discussion**

Current occupancy of four native Andean carnivores, including three habitat generalists (puma, Andean fox, and striped hog-nosed skunk) and one specialist (Andean bear), was best predicted by the presence of domestic dogs, and not habitat loss, fragmentation, and other types of disturbance caused by human activities. These models provide significant evidence that the existence of domestic dogs negatively influences occupancy of Andean carnivores. Human induced forest destruction and the associated fragmentation of habitats are major drivers of biodiversity loss (e.g., Saunders et al. 1991; Smith & Hellmann, 2002; Fahrig 2003; Melbourne *et al.*, 2004; Asquith & Mejía-Chang, 2005). However, habitat loss and fragmentation are just the first steps of an alteration process that may include cascading edge effects, increased hunting, and introduction of exotic species, among others (Murcia 1995; Tabarelli & Gascon 2005). Our research suggest that the existence of domestic dogs in our study region currently represents a more imminent threat to Andean carnivores than landscape modification. Unlike habitat loss and fragmentation, occurrence of domestic dogs, is not easily mapped at large spatial scales, and as a result, the current extent and intensity of domestic dog impacts on native species are unknown. Several studies from localities across the globe suggest that this is an increasing and widespread problem (Vanak & Gompper 2009; Young *et al.* 2011; Vanak *et al.* 2014). Our study is the first to document domestic dogs as a problem for wildlife in the Tropical Andes.

Free-ranging domestic dogs usually occur at close proximity to human dominated areas, and are subsidized predators that rely heavily on human sources of food for
subsistence, and do not respond numerically to potential declines of native prey (Manor & Saltz 2004; Silva-Rodríguez et al. 2010; Vanak et al. 2014). Thus, free-ranging domestic dogs represent a substantial threat to Andean carnivores and other native species, because they have the potential to maintain predation pressure and competition levels as native prey and native carnivores decline, and as result drive them to extinction. Two of our sites provided support for this pattern. At Filo Curiquingue and Fuya-Fuya, occupancy of domestic dogs declined as distance from roads and houses, respectively, increased. In contrast, in San Marcos, Guaytaloma and El Morán, increased occupancy for domestic dogs is associated with increasing distances from houses and roads. This latter pattern likely occurs because feral dogs are present in these study areas. These results are congruent with observations of feral dogs reported by local people.

Other aspects of human disturbance that might be associated with distance to roads and houses (e.g., hunting), and presence or absence of native vegetation were not supported by our models as important for carnivores. Although local people throughout the northern Ecuadorian Andes do not hunt for subsistence purposes, relying instead on domestic animals as their main protein source, carnivore hunting as a result of retaliation or intolerance is considered a common practice (Goldstein et al. 2006; Castellanos et al. 2010; Tirira 2011). However, we found no evidence of any kind of hunting during fieldwork. The lack of support for the effects of habitat loss and fragmentation may be related to the characteristics of the species modeled. Three of the four species evaluated (puma, Andean fox, and striped hog-nosed skunk) are generalist species that traverse and forage in a wide variety of vegetation types both native and
nonnative (Novaro 1997; Broquet et al. 2006; Ausband & Moehrenschlager 2009; Elbroch et al. 2009), and the Andean bear is capable of long distance movements between resource-rich patches of native habitat (Cuesta et al. 2003; Ríos-Uzeda et al. 2010; García-Rangel 2012). In addition, these species have relatively large perceptual ranges, facilitating the detection of suitable habitat and allowing them to better respond to changes in land cover (Gehring & Swihart 2003; Hilty et al. 2006; Randa & Yunger 2006).

Half of the native carnivore species that should occur in the study region were not detected (pampas cat and Colombian weasel) or were recorded very rarely (long-tailed weasel and mountain coati). With the exception of the long-tailed weasel, all of these species are habitat specialists. Although the pampas cat is not an abundant species throughout its range, the species was not recorded using camera traps. This methodology has proven effective in detecting small cats in other parts of South America (Lucherini et al. 2009; Villalba et al. 2012). Based on information provided by field assistants, local people have the perception that pampas cat numbers have decreased dramatically in the last 10 to 15 years. Apparently, populations of these species have crashed in the northern part of its range, and an understanding of the factors affecting this species in the Tropical Andes is needed. The Colombian weasel is an extremely rare species that was first described in 1978 (Izor & de la Torre 1978), and the current conservation status and geographic distribution range of this species are unknown (Tirira & González-Mayá 2009; Tirira 2011). The long-tailed weasel, on the other hand, is a relatively common species in the study region, and can traverse and forage in matrix habitats (Gehring & Swihart 2004; Tirira 2009). The limited number of
pictures obtained for this species might be a result of the use of carnivore urine as an attractant. Scent-marking is the primary form of communication for weasels, and in experimental settings the species reacts conspicuously showing avoidance, fright and uneasiness when coming in contact with intense marked places (Erlinege et al. 1982; Hutchings & White 2000). The mountain coati also was recorded on very few occasions. The few published studies that have examined this species suggest that mountain coatis occur in very low population densities, present a patchy distribution, mostly limited to patches of Andean forest in well preserved areas, and that this species rarely occurs in disturbed and fragmented areas like the study region (Sánchez et al. 2008; Balaguera-Reina et al. 2009; Helgen et al. 2009).

Whether the pampas cat, Colombian weasel and mountain coati have always naturally occurred in very low population densities, or current status is the result of major declines related to habitat loss, fragmentation, and other human disturbance prior to our study is unknown. Although conversion of most native habitat below 3,000 m has occurred (Hofstede et al. 2002; Sarmiento 2002), no detailed accounts about the history of changes in the amount of habitat or configuration of the landscape exist (Sarmiento 2002; Beltrán et al. 2009). In addition, information about the mammalian fauna of the high Andes of Ecuador is limited and fragmentary. Most information on Andean mammal ecology is anecdotal from reports and descriptions by naturalists and local hunters, and some species are only known from few museum records (Young 1997; Tirira 2014). Given this lack of information, the importance of habitat loss and fragmentation as determinants for carnivore occupancy cannot be dismissed. The impacts of habitat loss and fragmentation may have resulted in decline and loss of
species in the past, and only the most resistant species remain today. On the other hand, habitat loss and fragmentation may not affect some Andean carnivore species because the landscape always has been patchy with a matrix dominated by grasslands (Parsons 1982; Sarmiento & Frolich 2002), and some crops and introduced grasslands resemble the structure of some of the native habitats.

The existence of thresholds has been recognized as potentially critical to inform conservation and management actions (Andrén 1994; Guénette & Villard 2005; Lindenmayer & Luck 2005; Andersen et al. 2009). However, we did not find support for the existence of thresholds as a prevalent response among Andean carnivores. The existence of thresholds in wildlife population responses to landscape change has not been consistently supported by empirical evidence (Parker & MacNally 2002; Radford & Bennett 2004; Betts et al. 2007; Denoël & Ficetola 2007; Lindemayer et al. 2005; Zuckerberg & Porter 2010). The inconsistencies in the existence of threshold responses of Andean carnivores to the presence of domestic dogs might be caused by the effects of multiple and varied interacting factors that are species- and site-specific, such as defense mechanisms of native species, aggressiveness and ranging behavior of domestic dogs, and matrix composition that facilitates detection of native species (Gehring & Swihart 2003; Swihart et al. 2003; Cardillo et al. 2004; Debinski 2006; Muntifering et al. 2006; Vanak & Gompper 2009).

Few responsible dog owners live in rural areas in tropical areas like the Ecuadorian Andes. A common practice is to abandon or mistreat dogs, and neglect to feed and vaccinate them. Under these circumstances, domestic dogs often become free-ranging or even feral, and represent a significant threat to native wildlife (Salem &
Rowan 2007; Silva-Rodríguez & Sieving 2011). No dog population size estimates are available for the Ecuadorian Andes, and the time period in which dogs became a problem for wildlife in the region is unknown. However, human and dog population sizes generally are strongly correlated (Hughes & Macdonald 2013; Gompper 2014). The human population in the Ecuadorian Andes, approximately 7 million, is already the densest (100 people/km²) in the entire Andean region of South America (Instituto Ecuatoriano de Estadísticas y Censos 2014). The Ecuadorian Andes may have a relatively large population of poorly managed domestic dogs compared to other areas across the region. However, at least 40 million people live in the Tropical Andes (Josse et al. 2009), and our results might represent an alarm call for other areas where similar human activities occur (Lecaros 2008; Young 2009), and where systematic management of domestic dogs is not common.
Table 2-1. Variables of habitat loss and fragmentation and other measures of human disturbance. Site scale (20-m radial distance from camera trap), home range scale (1000-m radial distance for small species, 5000-m for large species), and landscape scale (400-km² study area). Asterisks show variables retained for occupancy analyses.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Acronym</th>
<th>Explanatory Set</th>
<th>Scale</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to nearest patch of native vegetation &gt; 1 km²</td>
<td>DPNPV</td>
<td>Fragmentation</td>
<td>Landscape</td>
<td>Baquero et al. 2004</td>
</tr>
<tr>
<td>Proportion of native habitat (plot radius of 1,000 and 5,000 m)</td>
<td>PRONH*</td>
<td>Habitat loss</td>
<td>Home range</td>
<td>FRAGSTATS 3.0</td>
</tr>
<tr>
<td>Number of patches (plot radius of 1,000 and 5,000 m)</td>
<td>NUMPAT*</td>
<td>Fragmentation</td>
<td>Home range</td>
<td>FRAGSTATS 3.0</td>
</tr>
<tr>
<td>Total edge (plot radius of 1,000 and 5,000 m)</td>
<td>TOTEDG</td>
<td>Fragmentation</td>
<td>Home range</td>
<td>FRAGSTATS 3.0</td>
</tr>
<tr>
<td>Land cover/land use (six categories, native and non-native)</td>
<td>LANCOU*</td>
<td>Habitat loss</td>
<td>Site</td>
<td>Ground assessment</td>
</tr>
<tr>
<td>Patch size (if camera trap located in native vegetation)</td>
<td>PATSIZ</td>
<td>Fragmentation</td>
<td>Site</td>
<td>FRAGSTATS 3.0</td>
</tr>
<tr>
<td>Distance to nearest patch (if camera trap in non-native vegetation)</td>
<td>DISNPAT</td>
<td>Fragmentation</td>
<td>Site</td>
<td>Baquero et al. 2004</td>
</tr>
<tr>
<td>Distance to nearest road</td>
<td>DISROA*</td>
<td>Other disturbance</td>
<td>Landscape</td>
<td>IGM 2011</td>
</tr>
<tr>
<td>Distance to nearest house</td>
<td>DISHOU*</td>
<td>Other disturbance</td>
<td>Landscape</td>
<td>IGM 2011</td>
</tr>
<tr>
<td>Occupancy rates of domestic dogs</td>
<td>DOG*</td>
<td>Other disturbance</td>
<td>Site</td>
<td>Camera traps</td>
</tr>
</tbody>
</table>
Table 2-2. Correlation coefficients among the variables measured for occupancy models of Andean carnivores and domestic dogs. Acronyms for variables are defined in Table 1. Asterisks show significant correlations (* $p < 0.05$; ** $p < 0.01$).

<table>
<thead>
<tr>
<th>Variable</th>
<th>DNPNV</th>
<th>PRONH</th>
<th>NUMPAT</th>
<th>TOTEDG</th>
<th>PATSIZ</th>
<th>DISNPAT</th>
<th>DISNROA</th>
<th>DISNHOU</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNPNV</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRONH</td>
<td>-0.541**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUMPAT</td>
<td>-0.538**</td>
<td>-0.025</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTEDG</td>
<td>0.055</td>
<td>0.262</td>
<td>0.681**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PATSIZ</td>
<td>-0.435**</td>
<td>0.288</td>
<td>-0.575**</td>
<td>-0.387*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISNPAT</td>
<td>0.518**</td>
<td>0.516**</td>
<td>0.367*</td>
<td>0.263</td>
<td>-0.364*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISNROA</td>
<td>0.167</td>
<td>0.128</td>
<td>-0.197</td>
<td>0.124</td>
<td>-0.040</td>
<td>0.062</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DISNHOU</td>
<td>0.135</td>
<td>0.169</td>
<td>-0.054</td>
<td>0.133</td>
<td>-0.070</td>
<td>0.276</td>
<td>0.359*</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2-3. Top three models (occupancy, $\Psi$; detectability, $p$) for domestic dogs.

<table>
<thead>
<tr>
<th>Species/Study area</th>
<th>Models</th>
<th>$K$</th>
<th>AICc</th>
<th>$\Delta$AICc</th>
<th>$w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DISROA) $p$(MOON)</td>
<td>4</td>
<td>481.20</td>
<td>0.00</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(LANCOU) $p$(MOON)</td>
<td>4</td>
<td>483.14</td>
<td>1.94</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISHOU) $p$(MOON)</td>
<td>4</td>
<td>483.74</td>
<td>2.54</td>
<td>0.17</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DISHOU) $p$(.)</td>
<td>3</td>
<td>498.92</td>
<td>0.00</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISROA) $p$(.)</td>
<td>3</td>
<td>501.11</td>
<td>2.19</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(LANCOU) $p$(.)</td>
<td>3</td>
<td>501.11</td>
<td>2.19</td>
<td>0.21</td>
</tr>
<tr>
<td>Guaytaloma</td>
<td>$\Psi$(DISROA) $p$(MOON)</td>
<td>4</td>
<td>488.72</td>
<td>0.00</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISHOU) $p$(MOON)</td>
<td>4</td>
<td>490.81</td>
<td>2.09</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(NUMPAT) $p$(MOON)</td>
<td>4</td>
<td>491.11</td>
<td>2.39</td>
<td>0.23</td>
</tr>
<tr>
<td>El Morán</td>
<td>$\Psi$(DISHOU) $p$(.)</td>
<td>3</td>
<td>495.48</td>
<td>0.00</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISROA) $p$(.)</td>
<td>3</td>
<td>497.68</td>
<td>2.20</td>
<td>0.22</td>
</tr>
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<td></td>
<td>$\Psi$(LANCOU) $p$(.)</td>
<td>3</td>
<td>498.32</td>
<td>2.84</td>
<td>0.14</td>
</tr>
<tr>
<td>Fuya-Fuya</td>
<td>$\Psi$(DISHOU) $p$(.)</td>
<td>3</td>
<td>485.62</td>
<td>0.00</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISROA) $p$(.)</td>
<td>3</td>
<td>487.81</td>
<td>2.19</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(NUMPAT) $p$(.)</td>
<td>3</td>
<td>488.96</td>
<td>3.34</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Table 2-4. Estimated $\beta$ coefficients for the top ranked models of occupancy and mean estimated occupancy ($\Psi^* \pm 95\%$ CI) for domestic dogs.

<table>
<thead>
<tr>
<th>Species/Study area</th>
<th>$\Psi$ top ranked models</th>
<th>DISROA $\beta$ (SE)</th>
<th>DISHOU $\beta$ (SE)</th>
<th>$\Psi^*$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DISROA)</td>
<td>-1.05 (0.22)</td>
<td>---</td>
<td>0.53</td>
<td>0.09</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DISHOU)</td>
<td>---</td>
<td>0.97 (0.32)</td>
<td>0.64</td>
<td>0.14</td>
</tr>
<tr>
<td>Guaytaloma</td>
<td>$\Psi$(DISROA)</td>
<td>0.46 (0.13)</td>
<td>---</td>
<td>0.71</td>
<td>0.11</td>
</tr>
<tr>
<td>El Morán</td>
<td>$\Psi$(DISHOU)</td>
<td>---</td>
<td>1.24 (0.43)</td>
<td>0.73</td>
<td>0.13</td>
</tr>
<tr>
<td>Fuya-Fuya</td>
<td>$\Psi$(DISHOU)</td>
<td>-0.69 (0.24)</td>
<td>---</td>
<td>0.69</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Table 2.5. Summed AIC weights \( (w_+) \) for the variables included in the occupancy models of domestic dogs.

<table>
<thead>
<tr>
<th>Species/Study area</th>
<th>PRONH</th>
<th>NUMPAT</th>
<th>LANCOU</th>
<th>DISROA</th>
<th>DISHOU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filo Curiquingue</td>
<td>0.16</td>
<td>0.21</td>
<td>0.41</td>
<td>0.53</td>
<td>0.31</td>
</tr>
<tr>
<td>San Marcos</td>
<td>0.31</td>
<td>0.15</td>
<td>0.12</td>
<td>0.29</td>
<td>0.44</td>
</tr>
<tr>
<td>Guaytaloma</td>
<td>0.10</td>
<td>0.33</td>
<td>0.11</td>
<td>0.50</td>
<td>0.32</td>
</tr>
<tr>
<td>El Morán</td>
<td>0.10</td>
<td>0.16</td>
<td>0.24</td>
<td>0.31</td>
<td>0.55</td>
</tr>
<tr>
<td>Fuya-Fuya</td>
<td>0.12</td>
<td>0.23</td>
<td>0.18</td>
<td>0.38</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Table 2-6. Top three models (occupancy, $\Psi$; detectability, $p$) for Andean carnivores.

<table>
<thead>
<tr>
<th>Species/Study area</th>
<th>Models</th>
<th>$K$</th>
<th>AICc</th>
<th>$\Delta$AICc</th>
<th>$w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DISROA) $p(.)$</td>
<td>3</td>
<td>472.91</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DOG) $p(.)$</td>
<td>3</td>
<td>474.82</td>
<td>1.91</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(PRONH) $p(.)$</td>
<td>3</td>
<td>475.87</td>
<td>2.96</td>
<td>0.16</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DOG) $p(.)$</td>
<td>3</td>
<td>467.53</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISHOU) $p(.)$</td>
<td>3</td>
<td>470.52</td>
<td>2.99</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>$\Psi$(DISROA) $p(.)$</td>
<td>3</td>
<td>470.84</td>
<td>3.31</td>
<td>0.09</td>
</tr>
<tr>
<td>Andean fox</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DOG) $p$(MOON)</td>
<td>4</td>
<td>437.26</td>
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<td></td>
<td>$\Psi$(DISHOU) $p$(MOON)</td>
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<td>0.00</td>
<td>0.39</td>
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<td></td>
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<td>2.91</td>
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<td>2.96</td>
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</tr>
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<td>Fuya-Fuya</td>
<td>$\Psi$(DOG) $p$(MOON)</td>
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<td>442.67</td>
<td>0.00</td>
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<td></td>
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<tr>
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<td>$\Psi$(DOG) $p(.)$</td>
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<td>422.23</td>
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<td></td>
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</tr>
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<td>S. hog-nosed skunk</td>
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<td></td>
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<td>402.23</td>
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<td>Guaytaloma</td>
<td>$\Psi$(DOG) $p$(MOON)</td>
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<td>$\Psi$(DISHOU) $p$(MOON)</td>
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<td>0.21</td>
</tr>
<tr>
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<td>0.13</td>
</tr>
<tr>
<td>Species/Study area</td>
<td>Models</td>
<td>$K$</td>
<td>AICc</td>
<td>$\Delta$AICc</td>
<td>$w_i$</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------</td>
<td>-----</td>
<td>-------</td>
<td>---------------</td>
<td>-------</td>
</tr>
<tr>
<td>El Morán</td>
<td>$\Psi$(DOG) $p$(MOON)</td>
<td>4</td>
<td>481.57</td>
<td>0.00</td>
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<tr>
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<td>$\Psi$(DISHOU) $p$(MOON)</td>
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<td>1.44</td>
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</tr>
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<tr>
<td>Fuya-Fuya</td>
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<td>4</td>
<td>488.99</td>
<td>0.00</td>
<td>0.39</td>
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<td></td>
<td>$\Psi$(DISHOU) $p$(MOON)</td>
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<td>491.15</td>
<td>2.16</td>
<td>0.22</td>
</tr>
<tr>
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<td>$\Psi$(DISROA) $p$(MOON)</td>
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<td>492.31</td>
<td>3.32</td>
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Table 2-7. Estimated β coefficients for the top ranked models of occupancy and mean estimated occupancy ($\Psi^\wedge \pm 95\%$ CI) for Andean carnivores.

<table>
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<tr>
<th>Species/Study area</th>
<th>$\Psi$ top ranked models</th>
<th>DISROA $\beta$ (SE)</th>
<th>DOG $\beta$ (SE)</th>
<th>$\Psi^\wedge$</th>
<th>95% CI</th>
</tr>
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<tbody>
<tr>
<td>Puma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DISROA)</td>
<td>1.64 (0.37)</td>
<td>---</td>
<td>0.29</td>
<td>0.08</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.59 (0.37)</td>
<td>0.22</td>
<td>0.06</td>
</tr>
<tr>
<td>Andean fox</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.18 (0.45)</td>
<td>0.46</td>
<td>0.14</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.03 (0.32)</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>Guaytaloma</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.44 (0.26)</td>
<td>0.37</td>
<td>0.13</td>
</tr>
<tr>
<td>El Morán</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.29 (0.41)</td>
<td>0.34</td>
<td>0.12</td>
</tr>
<tr>
<td>Fuya-Fuya</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-0.87 (0.31)</td>
<td>0.29</td>
<td>0.10</td>
</tr>
<tr>
<td>Andean bear</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.61 (0.43)</td>
<td>0.26</td>
<td>0.09</td>
</tr>
<tr>
<td>San Marcos</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.36 (0.29)</td>
<td>0.19</td>
<td>0.08</td>
</tr>
<tr>
<td>S. hog-nosed skunk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Filo Curiquingue</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-0.93 (0.21)</td>
<td>0.51</td>
<td>0.11</td>
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<tr>
<td>San Marcos</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.37 (0.28)</td>
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<td>0.13</td>
</tr>
<tr>
<td>Guaytaloma</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-1.15 (0.33)</td>
<td>0.42</td>
<td>0.10</td>
</tr>
<tr>
<td>El Morán</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-0.68 (0.34)</td>
<td>0.48</td>
<td>0.11</td>
</tr>
<tr>
<td>Fuya-Fuya</td>
<td>$\Psi$(DOG)</td>
<td>---</td>
<td>-0.99 (0.27)</td>
<td>0.45</td>
<td>0.12</td>
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Table 2-8. Summed AIC weights ($w^+$) for the variables included in the occupancy models of Andean carnivores.

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<th>Species/Study area</th>
<th>PRONH</th>
<th>NUMPAT</th>
<th>LANCOU</th>
<th>DISROA</th>
<th>DISHOU</th>
<th>DOG</th>
</tr>
</thead>
<tbody>
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<td>Puma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filo Curiquingue</td>
<td>0.28</td>
<td>0.17</td>
<td>0.16</td>
<td>0.35</td>
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<td>0.30</td>
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<td>0.15</td>
<td>0.20</td>
<td>0.20</td>
<td>0.37</td>
<td>0.47</td>
</tr>
<tr>
<td>Andean fox</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Filo Curiquingue</td>
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<td>0.18</td>
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<tr>
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<td>0.32</td>
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<td>S. hog-nosed skunk</td>
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<tr>
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<td>0.35</td>
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Figure 2-1. Map of the northern Ecuadorian Andes showing the location of the study areas (a, El Morán; b, Fuya-Fuya; c, Filo Curiquingue; d, San Marcos; and e, Guaytaloma), and protected areas (1, Cotacachi-Cayapas Ecological Reserve; 2, El Ángel E.R.; 3, Cofán Bermejo E.R.; 4, Cayambe-Coca National Park; 5, Antisana E.R.; and 6, Sumaco-Napo-Galeras N.P.).
Figure 2-2. Threshold responses of A) puma and B) Andean bear to occupancy rates of domestic dogs in San Marcos and Filo Curiquingue respectively ($\Psi_b$, occupancy of domestic dogs at breakpoint ± CI 95%; $\beta_2$, slope after the breakpoint).
CHAPTER 3
FERAL DOGS REDUCE ABUNDANCE AND ALTER ACTIVITY PATTERNS OF NATIVE MAMMALS IN THE HIGH ANDES OF ECUADOR

Overview

Domestic cats (*Felis silvestris catus*) and dogs (*Canis lupus familiaris*) are the most ubiquitous introduced carnivore species on the planet. Although the vast majority of cats and dogs are owned as pets, a large percentage of them range freely and many have become feral (i.e., individuals completely wild and independent of human sources of food; Campos et al. 2007; Vanak et al. 2009; Hughes & Macdonald 2013). The negative impacts of feral cats have drawn a lot of attention, and their role in species extirpations and extinctions, especially on islands, have been well documented (Nogales et al. 2004; Medina et al. 2011). Comparatively little is known, however, about the global distribution, population size, and ecological impacts of feral dogs. Most of our knowledge about the impact of dogs comes from free-ranging populations restricted to urban and periurban areas (e.g., Macdonald & Thom 2001; Silva-Rodríguez et al. 2009; Young et al. 2011). Feral dog populations have been reported worldwide, and in many localities where native predators have been extirpated or are absent, they function as apex predators (Vanak & Gompper 2009; Allen et al. 2013; Vanak et al. 2014).

Large predators have an important ecological role in structuring food webs and maintaining ecological processes that impact entire ecosystems (Terborgh et al. 2001; Estes et al. 2011). This structuring role occurs through lethal (e.g., predation) and non-lethal (e.g., fear) interactions (Paine 1966; Lima 1998; Luttbeg & Kerby 2005). The presence of large predators results in density effects on prey caused by the removal of individuals and risk aversion that is manifested through behavioral changes of prey. Fear may lead to reduced fitness by altering activity and habitat use patterns, increasing
vigilance, reducing foraging time, and lowering mating success (Preisser et al. 2005; Creel & Christianson 2008). Although lethal and non-lethal impacts have been documented for numerous carnivores, until recently, studies of introduced predators have focused on lethal effects (Silva-Rodríguez et al. 2010; Gerber et al. 2012; Hughes & Macdonald 2013; Vanak et al. 2014).

The Ecuadorian Andes have long been occupied by people, and threats to biodiversity such as habitat loss and fragmentation are widely recognized and well documented (e.g., Hofstede et al. 2002; Sarmiento 2002). On the other hand, threats posed by introduction of exotic animal species have been overlooked until recently (Olmedo & Montoya 2011). Free-ranging and feral dogs have become a problem for conservation, animal welfare, and public health in vast areas of the Ecuadorian highlands, as a result of human population growth, poor waste management practices, absence of responsible dog ownership, and low awareness of zoonotic disease issues (Hofstede et al. 2002; Sarmiento 2002; Olmedo & Montoya 2011). The current geographical distribution of feral dogs in the Ecuadorian Andes is unknown; but, free-ranging and feral dogs are believed to be widely distributed along the Ecuadorian Andes, including areas that otherwise would be considered pristine. Feral dogs are the largest mammalian predators in several protected areas (Olmedo & Montoya 2011). However, dogs as top predators are different from most native predators because they usually occur in relatively high population densities and form packs (Vanak & Gompper 2009; Vanak et al. 2014).

Our objective was to assess the effects of feral dogs on the abundance and behavior of native mammals of the high Andes in northern Ecuador. We carried out our
work in Cayambe-Coca National Park, the second largest protected area in the Ecuadorian Andes, because this area is relatively free of other anthropogenic disturbance and has areas where dogs are present and absent. Of the 16 mammal species (>1 kg) recorded in the study area, eight are endemic to the Tropical Andes, and five are categorized as endangered in the IUCN Red List of Threatened Species (IUCN 2013). We predicted that in areas with similar ecological conditions, the abundance of native mammals in areas with feral dogs would be lower than areas without feral dogs, and that native mammals would show differences in their activity and habitat use patterns between areas with and without feral dogs to avoid encountering them. An understanding of the interactions between feral dogs and the unique fauna of the Tropical Andes is crucial for the design of conservation and management interventions for this region and, in a broader conservation context, for the conservation of biodiversity in areas where feral dog populations have been established.

**Methods**

**Study Area**

We conducted field work in the páramo highlands of Cayambe-Coca National Park (~4,000 km²), which straddles the north-south oriented eastern cordillera of the northern Ecuadorian Andes (Figure 3-1). The páramo is a mosaic comprising high altitudinal grasslands (grass páramo), interspersed with patches of shrub páramo, cushion páramo, and Andean forests (Baquero et al. 2014). Climate is highly aseasonal (average annual precipitation approximately 2,500 mm, with more than 250 rainy days; average monthly temperatures, 4 to 10 ºC; Josse et al. 2011). Our study site encompassed an area of approximately 25 x 75 km (extending from 00°31’N to 00°28’S and 77°39’W to 78°06’W) with altitude ranging from 3,400 to 3,900 m. The site is a
plateau, entirely covered by native páramo vegetation, divided by a deep gorge (Huataringo River). No hunting occurs in the park. Law enforcement in the area is high because the main water supply for Quito, the capital city of Ecuador, comes from glacial lakes in the park. Park rangers of the Ecuadorian Ministry of the Environment and staff of the water utility company control human access to the area. The same páramo vegetation, other ecological characteristics, and protection levels occur north and south of the Huataringo River, but feral dogs have not colonized the park north of the river, yielding an ideal comparative design. The domestic dogs in the area were considered feral based on the following elements: 1) the closest human settlement was more than 50 km away, 2) the dogs showed avoidance and aggressiveness towards people, and 3) the dogs were in relatively good body condition compared to free-ranging dogs associated to human settlements.

The ensemble of large mammal species (>1 kg) in the páramo of Cayambe-Coca National Park is representative of the high altitude fauna of the Tropical Andes, is probably the least known group of Neotropical mammalian species (Tirira, 2007), and includes eight endemic species: Andean white-eared opossum (*Didelphis pernigra*), quichua porcupine (*Coendou quichua*), mountain paca (*Cuniculus taczanowskii*), Colombian weasel (*Mustela felipei*), mountain coati (*Nasuella olivacea*), mountain tapir (*Tapirus pinchaque*), little red brocket deer (*Mazama rufina*), and northern pudu (*Pudu mephistophiles*). More widely distributed species include the tapití (*Sylvilagus brasiliensis*), pampas cat (*Leopardus pajeros*), puma (*Puma concolor*), Andean fox (*Lycalopex culpaeus*), Andean bear (*Tremarctos ornatus*), long-tailed weasel (*Mustela frenata*), striped hog-nosed skunk (*Conepatus semistriatus*), and white-tailed deer
(Odocoileus virginianus). Five species are of conservation concern (IUCN 2013): Andean bear (Vulnerable), Colombian weasel (Vulnerable), mountain tapir (Endangered), little red brocket deer (Vulnerable), and northern pudu (Vulnerable); and two are considered Data Deficient (Kichwa porcupine and mountain coati).

**Survey Methods**

From October 2010 to July 2011, we assessed abundance, habitat use, and activity patterns of native mammals and feral dogs in three randomly located survey sites in the southern part of the study area with dogs and three sites in the northern area without dogs (Figure 3-1). These sites (each 100 km²) were separated by a minimum of 10 km, and thus were spatially independent samples, except for species with the largest home ranges (puma and Andean bear). Each of the six sites contained the four habitat types (grass, shrub and cushion páramo, and Andean forest). To confirm differences in the presence of dogs between dog and no-dog sites, we established six four-km transects in each of the six survey sites in grass páramo. Transects were surveyed between 06:00 – 10:00 hrs at weekly intervals for four weeks. We walked the transects slowly (~1 km/h), and recorded dogs sighted, sighting (radial) distance, sighting angle, and location along the transect. When dogs were observed in groups, estimation of the distance to the geometric center was difficult, so the perpendicular distance to all individuals detected was recorded, and existence of the group was ignored (Buckland et al. 2010; Thomas et al. 2010).

For camera trap surveys of all mammal species, each of the six survey sites was subdivided in a grid with 25 cells each 4 km². Three camera traps (Bushnell Trail Sentry STD) were placed randomly in each cell at least 1 km apart for eight consecutive days, for a total of 75 camera traps and 600 trap-nights of survey effort per site. We also
carried out track and sign surveys along five 12-km trails that crossed all the 25 4-km² cells. Each trail was surveyed four times, during a six-week period. We walked the trails looking for mammal tracks and signs (terrestrial bromeliads damaged by Andean bears). Each time we found a track or sign, we recorded the species and the place along the trail where the track or sign was found. We established independence of track and sign observations based on the following considerations (Carrillo et al. 2000): 1) tracks of an animal crossing the trail were considered as one sighting, 2) tracks of an animal following the trail were considered as one sighting, and 3) groups of tracks of gregarious species (e.g., mountain coatis) were considered as one sighting. Tracks were identified following Navarro and Muñoz-Arango (2000) and with the help of local guides. Only those tracks and signs that we could identify confidently to species were counted. The characteristics of the soil (Cryandepts from volcanic ash; Fundación Antisana 1998) were similar in the six survey sites and in all the trails, thus we assumed that differences in occurrence of tracks depended only on mammal abundance. One of the preferred food items of Andean bears is terrestrial bromeliads (*Puya* spp.). Andean bears eat the hearts of the bromeliads leaving clear and characteristic signs of their presence (Peyton 1980; Suárez 1988). In the páramo highlands of the study area, terrestrial bromeliads are abundant and widespread (Miller & Silander 1991). Independence for Andean bear signs was established based on the following considerations: 1) damaged plants were considered as one sighting if they were located at least a 100-m apart, 2) aggregations of damaged plants were considered as one sighting, and 3) damaged plants scattered along a trail were considered as one sighting.
Data Analysis

Population densities of feral dogs were estimated independently for the six survey sites using transect data and DISTANCE 6.0 (Buckland et al. 2001; Thomas et al. 2010). We combined data from all sites to improve estimation of the detection function. Population densities were derived by applying uniform and half-normal key functions, and cosine or simple polynomial adjustment terms as needed (Buckland et al. 2001; Thomas et al. 2010).

To test the effect of the presence of feral dogs on the abundance of native mammal species, for each sampling site we estimated a relative abundance index for each species based on photographic rates in camera traps (number of independent pictures/100 trap-nights; O'Brien et al. 2003; Kelly 2008). In addition, for track and sign data, we used an index based on encounter rates along trails (number of independent tracks or signs recorded for each species/10 km of sampling effort; Carrillo et al. 2000; Reyna-Hurtado & Tanner 2005). Relative abundance indices were used only for intraspecific comparisons because detectability with camera traps and animal signs varies among species. We compared the relative abundance indices between areas with and without dogs using a one-factor analysis of variance. Prior to ANOVA, data were tested for normality and homogeneity of variances with Shapiro-Wilk and Cochran’s C tests respectively (Doncaster & Davey 2007). If vegetation differed between areas with and without dogs, then detectability could differ and effects of habitat and feral dogs on native mammals could be confounded. We performed $\chi^2$ tests of independence to determine whether survey effort of camera traps and track and sign surveys was distributed similarly across the four vegetation types for the six survey sites. Results showed survey effort was distributed similarly across vegetation types for
the six survey sites (camera traps: \(X^2 = 19.52, \text{d.f.} = 15, p = 0.19\); track and sign surveys: \(X^2 = 22.02, \text{d.f.} = 15, p = 0.10\)).

To evaluate the effect of the presence of feral dogs on activity patterns of native mammal species, we used the nonparametric circular Mardia-Watson-Wheeler test to evaluate whether the distributions of activity of native mammals were significantly different in areas with and without feral dogs (Di Bitetti et al. 2009; Gerber et al. 2012). This analysis was restricted to species with \(\geq 30\) independent photographic events in areas with and without dogs. We established the independence of photographic events based on the following considerations (O’Brien et al. 2003): 1) consecutive photos of individuals of the same species taken at least 30 minutes apart, 2) nonconsecutive photos of individuals of the same species, and 3) consecutive photos of different individuals of the same species (only for species where identification of individuals is possible). Data were pooled across survey sites within each section of the study area (with and without dogs). The analysis was performed with Oriana 4.0 (Kovach Computing Services 2012).

If dogs affect habitat use of native mammals, we expected to see shifts in habitat use between areas with and without dogs, including reductions in use of habitats preferred by dogs. For each species, data from camera traps in each section of the study area (with and without dogs) were stratified by the four vegetation types (grass páramo, shrub páramo, cushion páramo, and Andean forest) and analyzed with \(X^2\) goodness-of-fit tests to evaluate the hypothesis of no difference between proportions of habitat available and used. Habitat use by feral dogs also was evaluated. In addition, 90% adjusted Wald confidence intervals (\(\hat{w}\)) for the expected proportions of use were
calculated for each habitat type to determine which habitats were used more than expected based on habitat availability (Agresti 2007). Where the observed proportion ($p_{obs}$) of use of any given habitat did not lie within the expected interval ($p_{exp} \pm \hat{w}$), this habitat was identified as a preferred habitat.

**Results**

**Dog Population Density**

We recorded 156 observations of feral dogs, equivalent to 0.27 sightings/km, in 576 km of transects in the three southern dog sites. In the three northern sites, we did encounter dogs but only six observations were made with a sampling effort of 587 km, a level of presence considered negligible for our study purposes. Average pack size was 9.8 ± 3.3 individuals (mean ± 95% CI). Dog density in the three dog sites was estimated as 0.89 individuals/km² (95% CI = 0.76-1.07), 1.16 ind./km² (95% CI = 1.11-1.32), and 1.09 individuals/km² (95% CI = 0.99-1.24).

**Abundance of Native Mammals**

A total of 13 species of native mammals were recorded in the study area using camera traps, track and sign surveys, or both, including the: Andean white-eared opossum, mountain paca, tapití, puma, Andean fox, Andean bear, long-tailed weasel, striped hog-nosed skunk, mountain coati, mountain tapir, little red brocket deer, white-tailed deer, and northern pudu. All of the species were found at the sites without dogs, but four of the smaller species were absent from areas with dogs. Of these four species, mountain paca (1.8 ± 0.49 pictures/100 trap-nights, mean ± 95% CI, range = 1.16-2.00) and mountain coati (4.4 ± 0.59 tracks/10 km, mean ± 95% CI, range = 3.86-5.07) were relatively abundant in areas without dogs. The long-tailed weasel and northern pudu were recorded in only a few occasions with camera traps ($n = 6$ and $n = 3$, respectively).
Eight species had sufficient data from tracks and signs or camera traps to be included in the assessment of abundance. Data from camera traps were used for species with at least 30 independent photographs in dog and in no dog sites, unless there were more track and sign data for the same species (Table 3-1). For six species (Figure 3-2), relative abundance was significantly higher in areas without dogs: puma ($F_{1,4} = 28.05, p = 0.006$), Andean fox ($F_{1,4} = 54.19, p = 0.002$), Andean bear ($F_{1,4} = 38.46, p = 0.003$), striped hog-nosed skunk ($F_{1,4} = 28.44, p = 0.006$), mountain tapir ($F_{1,4} = 24.75, p = 0.008$), and little red brocket deer ($F_{1,4} = 42.27, p = 0.003$). No significant differences in relative abundance occurred between areas with and without dogs for the Andean white-eared opossum ($F_{1,4} = 5.28, p = 0.083$) and white-tailed deer ($F_{1,4} = 5.97, p = 0.071$; Figure 3-2). Data for all species met the required assumptions for analysis of variance (Shapiro-Wilk test for all species: $W \geq 0.95$, $p > 0.05$; Cochran's C test for all species: $C \geq 0.57$, $p > 0.05$).

**Activity Patterns**

We obtained more than 30 independent photographic events in each section of the study area for seven species of native mammals and the feral dogs (Figure 3-3). Activity patterns of feral dogs were crepuscular between 05:00 and 09:00, and between 16:00 and 20:00 hrs. Three species of native mammals showed significant differences in their activity patterns between areas with and without dogs: Andean bear ($X^2 = 6.34$, d.f. $= 2, p < 0.05$), mountain tapir ($X^2 = 19.64$, d.f. $= 2, p < 0.001$), and little red brocket deer ($X^2 = 14.94$, d.f. $= 2, p < 0.001$). The mountain tapir exhibited activity throughout the day and night in areas with no dogs, and became mostly nocturnal in areas with dogs (Figure 3-3). Both the Andean bear and the little red brocket deer had a bimodal distribution of activity in the absence of dogs, and became more diurnal when dogs
were present. The Andean fox tended to be more nocturnal in areas with dogs, but this difference was not statistically significant ($X^2 = 4.08$, d.f. = 2, $p = 0.12$). Three species did not change their activity patterns in areas where dogs were present: Andean white-eared opossum ($X^2 = 2.76$, d.f. = 2, $p = 0.26$), striped hog-nosed skunk ($X^2 = 2.39$, d.f. = 2, $p = 0.28$), and white-tailed deer ($X^2 = 4.59$, d.f. = 2, $p = 0.11$; Figure 3-3).

**Habitat Use**

Feral dogs used habitat according to its availability ($X^2 = 6.16$, d.f. = 3, $p > 0.1$), and none of the mammal species included in the analysis shifted their habitat use patterns with the presence of dogs. Four species used habitat according to its availability in areas with and without dogs: Andean white-eared opossum, striped hog-nosed skunk, mountain tapirs, and little red brocket deer (for all species, dogs: $X^2 \leq 7.01$, d.f. = 3, $p > 0.1$; no dogs: $X^2 \leq 6.85$, d.f. = 3, $p > 0.1$). Three species (Andean fox, Andean bear, and white-tailed deer) preferred grass páramo over other habitat types in areas with and without dogs (for all species, dogs: $X^2 \geq 29.83$, d.f. = 3, $p < 0.001$; no dogs: $X^2 \geq 23.70$, d.f. = 3, $p < 0.001$): Andean fox (dogs: $p_{\text{obs}} = 0.69$, $p_{\text{exp}} \pm \hat{w} = 0.47 \pm 0.18$; no dogs: $p_{\text{obs}} = 0.75$, $p_{\text{exp}} \pm \hat{w} = 0.52 \pm 0.19$); Andean bear (dogs: $p_{\text{obs}} = 0.69$, $p_{\text{exp}} \pm \hat{w} = 0.47 \pm 0.12$; no dogs: $p_{\text{obs}} = 0.87$, $p_{\text{exp}} \pm \hat{w} = 0.52 \pm 0.23$); and white-tailed deer (dogs: $p_{\text{obs}} = 0.71$, $p_{\text{exp}} \pm \hat{w} = 0.47 \pm 0.18$; no dogs: $p_{\text{obs}} = 0.85$, $p_{\text{exp}} \pm \hat{w} = 0.52 \pm 0.19$).

**Discussion**

The threat that feral dogs pose to an entire community of native mammals has not been reported previously, though such impacts potentially are widespread given the global distribution of feral dogs. In our study area, the relative abundance and behavior of herbivore, omnivore, and carnivore species differ markedly between areas with and without dogs. Impacts similar to the ones described here have been attributed to
dingoes (*Canis lupus dingo*) in Australia, where this species shows suppressive effects on a wide variety of native and introduced species (Allen et al. 2013). Because our study was observational rather than experimental, the patterns we observed could be related to environmental factors other than the presence of dogs. However, this appears unlikely for several reasons. First, the biophysical characteristics (e.g., vegetation, soils, topography, and rainfall) and protection from human disturbance, including hunting, are similar between areas with and without dogs in our study area. In addition, relative abundance and behavioral data for species that we had sufficient data to assess, were largely congruent. Species that shifted activity patterns and reduced overlap with activity patterns of dogs, also had reduced abundance in the presence of dogs. Density estimates of feral dog populations in the study area (~1 individual/km$^2$) are lower than estimates for free-ranging dogs from other localities worldwide (e.g., 2.5–76.8 individuals/km$^2$; Campos et al. 2007; Lembo et al. 2008), but because feral dogs form packs their impacts may be particularly large. Their role as predators in natural ecosystems is unlikely to be equivalent to those of native predators in systems where native predators are mainly solitary and occur at low population densities, such as the high Andes.

In the study area, two endangered species, the mountain paca and the mountain coati, appear to have been extirpated from the areas with feral dogs. We cannot confirm that these extirpations are related to dogs, but we have no other plausible explanations. In addition, the significantly lower relative abundance in areas with feral dogs for six other species (puma, Andean fox, Andean bear, striped hog-nosed skunk, mountain tapir, and little red brocket deer) suggests that many native species will only persist in
the long-term through the control and eradication of this invasive species. In contrast, the relative abundance of Andean white-eared opossums and white-tailed deer appear not to be affected by the presence of the dogs. Several studies carried out in North America concluded that feral dogs do not prey effectively on white-tailed deer (e.g., Sweeney et al. 1971; Causey & Cude 1980). Also, the mostly arboreal and highly nocturnal behaviors of the Andean white-eared opossum (Gardner 2007) may represent effective means for reducing interference and predation risk.

With the exception of the Andean bear and mountain tapir, prior to this study little was known about the activity patterns of the mammal species from the Tropical Andes (Lizcano & Cavelier 2000; García-Rangel 2012). For at least three native species (Andean bear, mountain tapir, and little red brocket deer), our results suggest that temporal partitioning is an important mechanism for decreasing the risk of encountering feral dogs. These results are congruent with data obtained in Madagascar, where the ring-tailed mongoose (Galidia elegans) changed its activity patterns to avoid exotic species like free-ranging dogs and small Indian civets (Viverricula indica; Gerber et al. 2012). In areas with and without dogs, the Andean fox exhibited little activity during the period when dogs were active in early morning, and nocturnal activity increased slightly in areas with dogs. The three remaining species (Andean opossum, striped hog-nosed skunk, and white-tailed deer) did not show shifts in activity patterns where dogs were present. These patterns might be explained by physiological constraints that preclude shifts in activity patterns, prey naiveté, or the existence of effective mechanisms of defense against the feral dogs, as suggested by the lack of difference in relative
abundance of the Andean white-eared opossum and white-tailed deer between areas with and without dogs (Ashby 1972; Kavanau & Ramos 1975; Sih et al. 2010).

In addition to the temporal shifts in activity patterns, the presence of feral dogs can also lead to changes in habitat use of the native species (Vanak & Gompper 2009; Silva-Rodríguez et al. 2010). However, none of the species included in the analysis shifted their habitat use patterns. Feral dogs used habitat types according to their availabilities, probably making active avoidance through spatial shifts an ineffective strategy. This finding contrasts with other studies in Australia and Europe that have found that native species (e.g., wolves, *Canis lupus*; foxes, *Vulpes vulpes*; bandicoots, *Perameles nasuta*) alter their habitat use patterns to avoid competition and predation by dogs (Boitani et al. 1995; Mitchell & Banks 2005; Carthey & Banks 2012; Krauze-Gryz et al. 2012).

Given the breadth of species that respond to the presence of dogs in our study area, several mechanisms are likely at play (Hughes & Macdonald 2013; Vanak et al. 2014). Shifts in activity patterns can have fitness consequences (e.g., linked to energetics of foraging; Lima 1998; Preisser et al. 2005; Creel & Christianson 2008). Reductions in species abundance also could be related directly to predation as dogs easily kill small prey such as the mountain paca, and packs of dogs also may take offspring of large prey species (e.g., tapir) or even the adults. Feral dogs in our study area also may impact native carnivores through depletion of their prey. Such exploitative competition between dogs and native carnivores generally has not been considered important because free-ranging owned dogs, the subject of most studies, are fed by owners or scavenge on human waste as their primary source of food (Butler
& du Toit 2002; Campos et al. 2007). In our study area, human sources of food are not available and feral dogs rely on native prey. Thus, this mechanism could be relatively more important than previously recognized in areas with feral dogs and low human population, and deserves further attention.

Interference competition, where direct aggression by dogs impacts native carnivores, has been reported as a serious threat to wildlife in numerous parts of the world (Lacerda et al. 2009; Vanak & Gompper 2009; Silva-Rodríguez et al. 2010) and likely is important in the Tropical Andes. During the course of our fieldwork, dogs were observed chasing native species (e.g., Andean fox), and on several occasions killing small carnivores (e.g., striped hog-nosed skunks and mountain coatis) without predating on them. In all cases, dogs had the numerical advantage. This type of intraguild predation without consumption of the subordinate species is common in carnivores (Palomares & Caro 1999; Donadio & Buskirk 2006). One additional mechanism that potentially could cause decline of native species in our study area is disease transmission. The spillover of pathogens resulting from close contact between dogs and native wildlife species is well documented (Murray et al. 1999; Smith et al. 2006). Diseases such as canine distemper and rabies, which have high mortality rates in domestic dogs and affect most wild carnivores, are common throughout the Andes (Young 1997; Ruiz & Chávez 2010).

The effect of feral dogs in our study area is significant, not only because both native predators and prey are affected, but also because many of the native mammal species are endemic to the Tropical Andes and already considered vulnerable to extinction. Currently, the presence of dogs is included as a threat in the assessment for
the IUCN Red List of Threatened Species (IUCN 2013) for only three of 13 species recorded in the study area (Andean fox, little red brocket deer, and northern pudu). Clearly impacts of feral dogs on native species are poorly understood and hugely underestimated for the mammal community of the Tropical Andes and likely many other parts of the world. Moreover, because dogs are generalist species, their impacts may extend to other taxa (Aliaga-Rossel et al. 2012; Rosselli & Stiles 2012) and result in a broad range of secondary impacts that are undocumented. As a result of our findings, the Ministry of the Environment of Ecuador and other organizations are taking a very aggressive approach to managing and controlling feral dogs and their impacts in several protected areas of the Ecuadorian Andes. Actions include feral dog elimination, domestic dog vaccination and sterilization programs in buffer areas, as well as education and communication campaigns. Similar strategies may be needed urgently in other areas where feral dogs and wildlife interact.
Table 3-1. List of species recorded in the study area and survey methods used to register them.

<table>
<thead>
<tr>
<th>Species</th>
<th>Camera traps</th>
<th>Tracks</th>
<th>Signs</th>
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<tbody>
<tr>
<td>Andean white-eared opossum</td>
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</tr>
<tr>
<td>Mountain paca</td>
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<tr>
<td>Tapiti</td>
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<tr>
<td>Puma</td>
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<td>Andean fox</td>
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<td>Andean bear</td>
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<tr>
<td>Long-tailed weasel</td>
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<td>Striped hog-nosed skunk</td>
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<td>Mountain coati</td>
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<td>Mountain tapir</td>
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<td>Little red brocket deer</td>
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<td>White-tailed deer</td>
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<tr>
<td>Northern pudu</td>
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</table>
Figure 3-1. Map of Cayambe-Coca National Park showing the location of the survey sites (D, areas with dogs; ND, areas without dogs) and neighboring towns. Inset map shows Ecuador and the location of Cayambe-Coca National Park.
Figure 3-2. Relative abundance (overall mean of trails + 95% CI) using A) number of tracks or signs, and B) number of photographs/100 trap nights of 10 native species in areas with and without feral dogs in Cayambe-Coca National Park, Ecuadorian Andes. Asterisks indicate significant differences in abundance between areas with and without feral dogs ($p < 0.05$).
Figure 3-3. Activity patterns of seven native mammals in areas with and without feral dogs based on photographs taken during hourly intervals (percentage of total number of photographs), in Cayambe-Coca National Park, Ecuadorian Andes. The dashed line shows the activity patterns of feral dogs.
CHAPTER 4
CONTROL AND MANAGEMENT OF INVASIVE DOMESTIC DOGS IN SOUTH AMERICA: A REVIEW OF NATIONAL POLICIES

Overview

Worldwide more than 4,000 species have been reported as invasive. Most of these species are plants (78%), with mammals and carnivores accounting for only 3 and 0.9% of the species respectively (IUCN Invasive Species Specialist Group 2005). Although mammals represent a small percentage of the reported invasive species, they are extremely successful when they become invasive (Jeschke & Strayer 2005; Jeschke 2008). Of the 132 mammal species that are considered invasive worldwide, 29 occur in South America, and more than 65% of these species already are successfully established (IUCN Invasive Species Specialist Group 2005). Six species of carnivores are among these, including the domestic dog (Canis lupus familiaris). The introduction and subsequent spread of domestic dogs in South America, as is the case of many other invasive species, has been the result of anthropogenically facilitated dispersal.

Domestic dogs are the most abundant carnivore worldwide. The size of the global dog population has been estimated recently between 700 and 900 million individuals, and at least 60% occur in rural settings (Hughes & Macdonald 2013; Gompper 2014). In South America, knowledge about populations of domestic dogs in urban and rural areas, as well as feral populations is very limited (Escobar-Cifuentes 1988; Jackman & Rowan 2007). However, domestic dogs are ubiquitous throughout South America, and far outnumber all other native carnivore species combined (Young et al. 2011; Hughes & Macdonald 2013). A coarse estimate for South America puts the total domestic dog population at a little bit over 82 million individuals (Gompper 2014). In South America, problems with domestic dogs are not new (Appendix), but many of
their impacts as invasive species have been overlooked until recently (Fiorello et al. 2006; Campos et al. 2007; Whiteman et al. 2007; Lacerda et al. 2009; Silva-Rodríguez et al. 2009, 2010; Torres & Prado 2010; Aliaga-Rossel et al. 2012; Carvalho et al. 2013).

In South America, the vast majority of the dogs range freely, facilitating the formation of feral populations that are not associated with humans (Jackman & Rowan 2007; Silva-Rodríguez & Sieving 2011). In the Ecuadorian Andes for example, in areas above 3000 m that are considered pristine, the feral dog population density has been estimated at approximately 1.15 individuals/km² (see Chapter 2). If densities are similar in other areas of the Andes, this represents a total feral population of 40,000 individuals in the entire Andean region of Ecuador (> 3000 m). The biomass necessary to support this many dogs is considerable. Since feral dogs do not have access to human-derived sources of food, they must gain most of their caloric needs from native wildlife. The per capita needs of an average weight dog (~20 kg) can reach to 4,500 KJ/day (Burguer & Johnson 1991; Mussa & Prola 2005). Therefore, a 20-kg dog would need to consume 0.7 kg/day of meat to satisfy its minimum energetic requirements (Pekins & Mautz 1990; Laundré 2005, 2008). Extrapolating this estimate to the entire feral dog population in the Ecuadorian Andes, the resulting estimated daily consumption rates of 40,000 dogs would be 28,000 kg/day, an amount equivalent to the biomass of 3500 mountain pacas, 1860 little red brocket deer, or 140 mountain tapirs. As a result, the impact of feral dogs on wildlife populations is likely enormous.

In addition to direct predation, feral dogs in wilderness areas have additional varied and complex ecological effects on community dynamics, including direct and
indirect effects that can cascade down several trophic levels (Glen & Dickman 2005; Creel & Christianson 2007; Young et al. 2011). Dogs affect populations of native wildlife through exploitative competition (asymmetric competitive abilities in obtaining limited resources), interference competition (interactions such as spatial exclusion, harassment, and intraguild predation), and by acting as vectors of disease such as canine distemper, parvovirus, and rabies. As a result, domestic dogs have become major threat for wildlife conservation across the globe (Vanak & Gompper 2009; Young et al. 2011; Hughes & Macdonald 2013; Vanak et al. 2014). In addition to the role of dogs as reservoirs for multihost pathogens that can potentially be transmitted to native wildlife (Murray et al. 1999; Smith et al. 2006; Gortázar et al. 2010), dogs transmit at least sixty zoonotic diseases to humans, the most important being rabies, echinococcosis and toxocariasis (Daszak et al. 2000; Matter & Daniels 2000; Taylor et al. 2001; Dudley et al. 2004). For example, dogs are the cause for 99% of the 55,000 human fatalities due to rabies reported yearly worldwide (Knobel et al. 2005).

Political will and policy measures implemented at the local and national levels are required to successfully address the problem of domestic dogs as an invasive species. The Convention on Biological Diversity (CBD; http://www.cbd.int/) is the only global instrument to provide a comprehensive basis for measures to protect all components of biodiversity against invasive species. Every South American country has ratified the CBD and has been involved in the development of national policies for the control and management of invasive species. In this paper, we provide results of a review of national strategies for invasive species in South America conducted to determine whether these countries have policies and strategies designed to mitigate and manage
the impacts of domestic dogs. In addition, we present potential policy options for the management and control of this species.

**Review of National Policies**

We first obtained information on existing policies for invasive species in South America from a web-based, online search of government websites. For several countries, the online search was unsuccessful, and we directly requested information from government officials (Bolivia, Chile, French Guiana, Guyana, Paraguay, Peru, Surinam, and Venezuela). We reviewed a total of 31 official documents and publications for 11 countries (Table 4-1). In addition, we reviewed three publications with a regional focus: Matthews 2005, Ziller et al. 2007, and Schuttler & Karez 2008. We could not obtain any official information or peer-reviewed publications for Paraguay and Surinam. In the case of Surinam, the information apparently does not exist; and in the case of Paraguay, the information is not available to the public. In each national strategy, we examined official listings of invasive species and determined whether domestic dogs were included. When official lists of invasive species were not available, we searched the scientific literature for peer-reviewed papers reporting lists of invasive species for South American countries. In addition, we reviewed the documents to determine whether South American countries have designed and implemented specific control and management plans for domestic dogs, and whether these plans were research-based.

As a result of the increasing concern regarding invasive species and the commitments made by national governments in the context of CBD, a series of official documents regarding the control and eradication of invasive species have been published in recent years for most countries in South America. Seven of the 13 South American countries have prepared and published preliminary or official national policies
regarding invasive species (Argentina, Bolivia, Brazil, Colombia, French Guiana, Guyana, and Uruguay; Administración de Parques Nacionales 2009; Brugnoli et al. 2009; Baudoin et al. 2010; Comissão Nacional de Biodiversidade 2010; De Saint Martin 2010; Environmental Protection Agency 2011; Gutiérrez-Bonilla 2011) and at least another three are currently working on invasive species policies (Chile, Ecuador, and Peru). The existing national policies, and those being prepared, aim to prevent, control and eradicate invasive species. These policies call for implementation of a series of coordinated basic strategic responses: build management and research capacity, promote sharing of information, develop economic policies and tools, strengthen national and international legal frameworks, establish a system of environmental risk analysis, and build public awareness and engagement.

The domestic dog is officially listed as an invasive species in eight countries: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, and Venezuela (Novillo & Ojeda 2008; Rico 2009; Coradin & Tortato 2006; Iriarte et al. 2005; Baptiste et al. 2010; Olmedo & Montoya, 2011; Soubeyran et al. 2011; Ojasti, 2001). However, published research about their ecological impacts has been restricted to Bolivia, Brazil, and Chile (e.g., Fiorello et al. 2006; Silva-Rodríguez et al. 2009, 2010; Carvalho et al. 2013). Seven South American countries have prioritized invasive mammal species in their national policies (Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay, and Venezuela), but only three have prepared specific action plans for them. Argentina and Chile have a binational plan for the control of the North American beaver (*Castor canadensis*; Ramadori et al. 2009). Chile has control and management plans for muskrat (*Ondatra zibethicus*), European hare (*Lepus europaeus*), European rabbit
(Oryctolagus cuniculus), and wild boar (Sus scrofa), and Uruguay has a plan for wild boar (Amaro et al. 2010; Agüero et al. 2012). The remainder of the South American countries have not yet prioritized any species (Bolivia, French Guiana, Guyana, and Peru), nor have they included mammals among their priorities (Brazil, Colombia, Ecuador, and Venezuela). Currently, no country in South America has control and management plans for the domestic dog or other species of invasive carnivores. More than 70% of the current control and monitoring programs of invasive species in South America focus on plants and insects.

The national plans developed in South America provide a general framework for invasive species control and management. However, more species-specific strategies are needed to plan and coordinate management activities of individual invasive species like domestic dogs. Although national governments are considered the main responsible parties for invasive species management, regional and local governments will be important for developing control programs. Because of their association with humans, domestic dogs are different from most invasive species, and efforts to control and manage this species will be helped or hindered by the behavior of dog owners, especially in rural areas. In rural areas there is no strong tradition of keeping dogs as companion animals. Feral dog populations are initially formed with domestic dogs that have been abandoned, mistreated or chased away by their owners, and as a result have moved into wild habitats and switched from a diet based on human-derived sources of food to predation on wild species (Salem & Rowan 2007; Hughes & Macdonald 2013). Dogs that are well fed or kept close to human settlements prey less on wildlife (Salem & Rowan 2007; Silva-Rodríguez & Sieving 2011).
For the vast majority of invasive mammal species in South America, including domestic dogs, basic information about population sizes, geographic distribution, and effects on native species are lacking. In most areas direct evidence of the ecological and economic impacts of dogs does not exist, resulting in little information for making management decisions at local and national levels. Invasive species policies tend to focus on other species with more easily recognized impacts such as economic losses, diminished food security, and public health issues (e.g. water mould, *Phytophthora* spp.; giant African snail, *Achatina fulica*; and Asian tiger mosquito, *Aedes albopictus*). Thus, in the short term, national policies for controlling and managing domestic dogs as an invasive species are unlikely to be developed in South America. Reasons include political, economic and cultural issues such as lack of national prioritization schemes for invasive species, the relatively small economic impacts dogs have on human property, a lack of understanding of the ecological impacts of dogs, the growth of animal rights movements, and the very close relationship humans and dogs have had for several millennia.

**Policy Options for the Control and Management of Domestic Dogs**

According to both economic and ecological analysis, the best way to address the impacts of invasive species is to prevent their introduction into new areas (Vitousek et al. 1997; Donlan & Wilcox 2007; Meyerson & Mooney 2007; Lambertini et al. 2011). For the domestic dog, the most effective ways to prevent introductions into wilderness areas and reduce their impacts on all native ecosystems, include reduction of population size through sterilization programs in urban and rural areas, elimination of individuals without owners, prevention of free-ranging activity, vaccination programs to reduce the potential
for disease transmission, and improved feeding and care (Escobar-Cifuentes 1988; Salem & Rowan 2007; Silva-Rodríguez & Sieving 2011; Vanak et al. 2014).

Current guidelines for dog population management (World Society for the Protection of Animals 1999; World Health Organization 2005) recommend a combination of vaccination and sterilization. The objectives of these guidelines are primarily to reduce human health issues, the spread of zoonotic disease, and reduce dog population size. The World Health Organization (WHO) and the World Society for the Protection of Animals (WSPA) advise that killing of free-ranging and feral dogs is not successful in achieving these goals. Wildlife conservation concerns are not considered in the existing guidelines for dog population control, and the lethal control of feral dogs should be considered as a short-term response to their impacts on native wildlife. Effective cooperation with animal protection groups is often difficult when discussing lethal removal. Animal protection groups differ in their views on how dog populations should be controlled and managed. Most accept sterilization (neutering of males and spaying of females) as vital for population control, but do not accept that lethal control most of the times is unavoidable.

The scope of a national policy in Ecuador should be to control and manage free-ranging and feral dog populations. The policy should be based on three main premises: 1) invasive domestic dogs pose serious ecological impacts and human health problems; 2) because the impacts of invasive domestic dogs are linked to human population density and human activities, control of domestic dogs has to be accompanied by changes in human behavior to be effective; and 3) the promotion of responsible dog ownership can significantly reduce the number of free-ranging and feral dogs and the
extension and intensity of their negative impacts. A program for the control and management of invasive domestic dogs should include the following objectives: 1) eliminate feral dog populations; 2) reduce the number of free-ranging dogs; 3) implement neutering, sterilization and vaccination campaigns; 4) promote responsible ownership of domestic animals; and 5) develop and enforce legislation related to dog ownership to prevent cruelty and abandonment. Before designing strategies, the source of the problem need to be understood. The local traditions need to be taken into account, and potential impacts of education of dog owners need to be assessed.

Education is probably the most important element of a policy designed to reduce the impacts of invasive domestic dogs. Education should target children and dog owners. Children have a natural affinity for animals and are receptive to ideas about caring for them. Information provided to them should include basic care such as feeding and providing shelter. Dog owners, on the other hand, should be provided with information on vaccinations, anti-parasite treatments, neutering and spaying, and their legal obligations to register and limit the freedom of their dogs. In addition, communication programs need to be developed to educate and engage people about the ecological impacts of domestic dogs on native species and their potential impacts on human health. How people perceive dog-wildlife interactions will be fundamental to attempts to manage the extent to which dogs are allowed to roam freely. If people see such interactions as a problem, then it would be easier to address the issue and minimize the impacts that dogs have on native ecosystems. The responsible parties for educational and communication programs should be local governments and animal protection groups.
A regulatory framework from the local to the national scale is needed to help authorities establish an effective program for the control and management of invasive domestic dogs. This framework should include the following components: 1) registration and identification of owned dogs; 2) limits to the number of dogs a person/family can own; 3) licensing of dog breeders; 4) licensing of dog shelters; 5) creation of neutering, sterilization and vaccination programs; and 6) identification of responsible parties for the management and control of domestic dogs (e.g., local governments, environmental authorities, health authorities, NGOs).

In most parts of the world, dogs are valued for their role as guardians of property, the herding of livestock, hunting aides, and as companions. However, cross-cultural differences in human attitudes towards dogs result in enormous differences and contradictions in the manner they are kept (Hughes & Macdonald 2013). These differences and contradictions need also to be understood before policies for control and management of domestic dogs are developed. It is important to develop long-term, sustainable strategies to deal effectively with free-ranging and feral dog populations. For example, in countries like Australia, New Zealand, Great Britain and Germany, there are strict laws about the keeping of domestic dogs with concurrent local regulations allowing local authorities, farmers and hunters to impound or kill dogs which are not within a specific area or under human control. Free ranging dogs are rare in those countries, although feral populations still exist (Fleming et al. 2001; Veitch 2002). In Italy, where feral and free ranging populations also are present, the killing of free ranging dogs is not permitted and they must be captured for retention in public kennels (Genovesi and Dupre 2000). Although in most of the United States there are strict dog control laws,
free-ranging and feral dog populations occur in extensive areas (Daniels & Bekoff 1989).

The experience of these countries suggest the eradication of invasive domestic dogs requires a comprehensive and coordinated program of owner education, registration and identification of owned individuals, controlled reproduction and the prevention of over production of pets through regulated breeding and selling, neutering and sterilization, and lethal control of feral populations (World Society for the Protection of Animals 1999). There is no easy solution to the problem of feral dogs, and no single organization or government agency can do it alone. In many regions, management of domestic dogs likely can be lobbied most effectively in the context of human health and safety with additional benefits for native ecosystems. In South America, conservation initiatives that take into account control and management strategies for domestic dogs will assume increasing importance, given the expected increase in human populations and the consequent increase in number of domestic dogs.
Table 4-1. List of reviewed documents for 11 countries in South America.

<table>
<thead>
<tr>
<th>Country</th>
<th>Documents</th>
<th>Official government publications</th>
<th>Other publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>2</td>
<td>Baudoin et al. 2010; Rico 2011.</td>
<td></td>
</tr>
<tr>
<td>Brasil</td>
<td>4</td>
<td>Coradin &amp; Tortato 2006; Comissão Nacional de Biodiversidade 2010; Ziller 2010; Leão et al. 2011.</td>
<td></td>
</tr>
<tr>
<td>Ecuador</td>
<td>2</td>
<td>Carrión-Gonzales &amp; Palacios 2009; Olmedo &amp; Montoya 2012.</td>
<td></td>
</tr>
<tr>
<td>French Guiana</td>
<td>2</td>
<td>de Saint Martin 2010; Soubeyran et al. 2011.</td>
<td></td>
</tr>
<tr>
<td>Guyana</td>
<td>2</td>
<td>Lilwash 2009; Environmental Protection Agency 2011.</td>
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</tbody>
</table>
CHAPTER 5
CONCLUSION

Below I concisely summarize the main findings of my dissertation:

Current occupancy of four native Andean carnivores, including three habitat generalists (puma, Andean fox, and striped hog-nosed skunk) and one specialist (Andean bear), was best predicted by the presence of domestic dogs, and not habitat loss, fragmentation, and other types of disturbance caused by human activities.

Half of the native carnivore species that should occur in the study region were not detected (pampas cat and Colombian weasel) or were recorded very rarely (long-tailed weasel and mountain coati). With the exception of the long-tailed weasel, all of these species are habitat specialists.

Whether the pampas cat, Colombian weasel and mountain coati have always naturally occurred in very low population densities, or current status is the result of major declines related to habitat loss, fragmentation, and other human disturbance prior to our study is unknown.

The importance of habitat loss and fragmentation as determinants for carnivore occupancy cannot be dismissed. The impacts of habitat loss and fragmentation may have resulted in decline and loss of species in the past, and only the most resistant species remain today.

The existence of thresholds has been recognized as potentially critical to inform conservation and management actions. However, we did not find support for the existence of thresholds as a prevalent response among Andean carnivores.

The relative abundance and behavior of herbivore, omnivore, and carnivore species differ markedly between areas with and without dogs. The threat that feral dogs
pose to an entire community of native mammals has not been reported previously, though such impacts potentially are widespread given the global distribution of feral dogs.

For at least three native species (Andean bear, mountain tapir, and little red brocket deer), our results suggest that temporal partitioning of activity is an important mechanism for decreasing the risk of encountering feral dogs.

None of the species included in the analysis shifted their habitat use patterns. Feral dogs used habitat types according to their availabilities, probably making active avoidance through spatial shifts an ineffective strategy.

Given the breadth of species that respond to the presence of dogs in our study area, several mechanisms are likely at play. Among them, predation, exploitative and interference competition, and disease appear to be the most important.

Few responsible dog owners live in rural areas in tropical areas like the Ecuadorian Andes. A common practice is to abandon or mistreat dogs, and neglect to feed and vaccinate them. Under these circumstances, domestic dogs often become free-ranging or even feral, and represent a significant threat to native wildlife.

The national plans developed in South America provide a general framework for invasive species control and management. However, more species-specific strategies are needed to plan and coordinate management activities of individual invasive species like domestic dogs. Currently, no country in South America has control and management plans for the domestic dog or other species of invasive carnivores.

A program for the control and management of invasive domestic dogs should include the following objectives: elimination of feral dog populations, reduction of the
number of free-ranging dogs, implementation of neutering, sterilization and vaccination campaigns, promotion of responsible ownership of domestic animals, and development and enforcement of legislation related to dog ownership to prevent cruelty and abandonment.
Five hundred years ago, colonization of South America by Spain and other European countries started a massive human immigration, and resulted in the arrival of many exotic invasive species. Among them, dogs were among the first to arrive. Before the Spanish conquest, the dog was already a domestic species of native indigenous peoples in America. Archaeological records suggest that humans in North America had domestic dogs as early as 7,000-8,000 B.P. (Schwartz 1997). However, by the time the Spanish conquistadors reached Mexico and South America, the breeds that native populations had were relatively small (< 10 kg), did not bark, and were used for food, companionship and religious purposes (e.g. xoloitzciuntle in Mexico and viringo in Peru; Brothwell et al. 1979; Valadez 1995). On the other hand, the Spanish brought with them their own dog breeds. These dogs (called “alanos”) were war mastiffs that could stand to 75 cm tall at the shoulder, and weigh more than 45 kg, and were the result of almost a millennia of breed selection (Fernández de Oviedo y Valdés 1526; De Sahagún 1590).

During his second voyage, in 1493, Christopher Columbus brought twenty war mastiffs to America (Dominican Republic). Later, Juan Ponce de León, a former lieutenant under Columbus, used war mastiffs in his campaigns in Puerto Rico in 1506, and Florida in 1513 (Fernández de Oviedo y Valdés 1526). Vasco Nuñez de Balboa, in 1514, introduced the first war dogs to Panama and Colombia (Acosta de Samper 1883); and Hernán Cortez to Mexico in 1518 (Díaz del Castillo 1568). In 1541, Gonzalo Pizarro, Governor of the Kingdom of Quito, transported 900 war dogs from Spain for the conquest of “El Dorado”, expedition that concluded with the discovery of the Amazon
River (Medina 1894). Meanwhile, Diego de Rojas introduced war dogs to Bolivia and Argentina in 1536 and 1543 respectively; and Pedro de Mendoza to Uruguay in 1537 (de Angelis 1832). The Spanish conquistadors used their dogs for battle against native indigenous groups, to put down slave rebellions, and to execute their enemies (execution called in Spanish “aperreamiento”; Poma de Ayala 1615).

An unknown number of war dogs escaped, or were released by their owners and formed packs of feral dogs. By the late 1550’s, there were feral dogs distributed along the northern Andes, the Pampas in southeastern South America, and the Caribbean (de Angelis 1832; Fernández de Oviedo y Valdés 1526; Fiede 1960). Gonzalo Jiménez de Quesada, founder of Bogota and governor of the Viceroyalty of New Granada (corresponding to modern Panama, Venezuela, Colombia and Ecuador), organized the first feral dogs eradication campaigns in 1565. Although the dogs were predating on domestic animals and attacking people, Jiménez de Quesada’s motivations were mainly political. Many indigenous groups were taming feral dogs and managing large packs of them, and the Spanish government was afraid the dogs would be used against them. Also in 1565, Phillip II of Spain created the first regulations limiting ownership of dogs by indigenous people. Only tribal chiefs were allowed to possess dogs, a maximum of two individuals, both males (Poma de Ayala 1615).

For almost 150 years, there was no more mention of dogs in history books until the first outbreaks of rabies occurred in the New World. Although the first recorded description of canine rabies was made in 500 B.C. by Aristotle, and outbreaks were common and periodic throughout the Middle Ages, it was not until 1703 that the first outbreak was reported in Mexico. In South America, the first documented canine rabies
outbreak occurred in Peru in 1803, and the second one in 1806 in Argentina. These first rabies outbreaks were controlled by the governments with the slaughter of dogs in cities and rural areas, and people were discouraged from keeping dogs to avoid further outbreaks. By 1835, most countries in South America had reported canine rabies epizootics, and the disease remains enzootic to this day (Escobar-Cifuentes 1988; Baer 1991; Cliquet & Picard-Meyer 2004; Schneider et al. 2007).
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BIOGRAPHICAL SKETCH

Galo Zapata-Ríos graduated, in 1997, from Pontificia Universidad Católica del Ecuador with a B.Sc. degree in biological sciences, with thesis work on the ecology and biogeography of the ground beetles (Carabidae) of Ecuador. In 2001, he completed his M.Sc. degree in environmental studies and a graduate certificate in conservation biology at Ohio University in Athens with a Fulbright Scholarship. His thesis evaluated the effects of varying levels of connectivity on the long term viability of five large mammal species of the Amazon in Yasuní National Park and Cuyabeno Wildlife Reserve (the two largest protected areas in Amazonian Ecuador).

Since 2001, he has been working in Ecuador for the Wildlife Conservation Society. In different capacities, he has been involved in several research and conservation initiatives. Among other projects, he has coordinated several wildlife management projects with Awá, Kichwa and Shuar communities in Ecuador. In Fall 2006, he began graduate studies at University of Florida in the Department of Wildlife Ecology and Conservation, and pursued a graduate certificate in Tropical Conservation and Development. He plans to continue working on wildlife conservation issues in Ecuador.