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Dog ownership, abundance and potential for bat-borne rabies spillover in Chile

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ABSTRACT

Rabies is a viral infectious disease that affects all mammals, including humans. Factors associated with the incidence of rabies include the presence and density of susceptible hosts and potential reservoirs. Currently, Chile is declared free of canine-related rabies, but there is an overpopulation of dogs within the country and an emergence of rabies in bats. Our objectives are to determine potential areas for bat-borne rabies spillover into dog populations expressed as a risk map, and to explore some key features of dog ownership, abundance, and management in Chile. For the risk map, our variables included a dog density surface (dog/km^2) and a distribution model of bat-borne rabies presence. From literature review, we obtained dog data from 112 municipalities, which represent 33% of the total municipalities (339). At country level, based on previous studies the median human per dog ratio was 4.8, with 64% of houses containing at least one dog, and a median of 0.9 dog per house. We estimate a national median of 5.3 dog/km^2, and a median of 3680 dogs by municipality, from which we estimate a total population of 3.5×10^6 owned dogs. The antirabies vaccination presented a median of 21% of dogs by municipality, and 29% are unrestricted to some degree. Human per dog ratio have a significant (but weak) negative association with human density. Unrestricted dogs have a negative association with human density and income, and a positive association with the number of dogs per house. Considering dog density by municipality, and areas of potential bat-borne rabies occurrence, we found that 163 (~48%) of Chilean municipalities are at risk of rabies spillover from bats to dogs. Risk areas are concentrated in urban settlements, including Santiago, Chile's capital. To validate the risk map, we included cases of rabies in dogs from the last 27 years; all fell within high-risk areas of our map, confirming the assertive risk prediction. Our results suggest that the use of dog population parameters may be informative to determine risk areas for bat–rabies spillover events. In addition, we confirm that dog abundance is a neglected and emerging public health concern in Chile, particularly within urban areas, which deserves prompt intervention.

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1. Introduction

Rabies is a worldwide-distributed zoonotic viral infection transmitted primarily by bites, where the virus affects the central nervous system causing encephalitis (WHO, 2012). Specific rabies lineages are associated and maintained by particular mammal species (Gordon et al., 2004). However, interspecies cross-transmission is possible, and one species can be infected by other host rabies-lineage (Leslie et al., 2006). This cross-species transmission is defined as spillover, and can be the first step in an outbreak and in the establishment of a new variant in the novel host (Kienzle, 2007).

In developing countries, dogs remain the main source of human rabies (OPS, 2005; Wandeler et al., 2009); although in the Americas, bats have arisen as an important source of rabies spillover transmission to dogs and humans (Páez et al., 2003; Kienzle, 2007; Favi et al., 2008). Because rabies is a density-dependent disease (Ramey, 2005; Kauhala et al., 2006; Zinsstag et al., 2009), dog-overpopulation is critical for potential dog-rabies emergence and perpetuation (Zinsstag et al., 2009).

Given that the transmission of pathogens requires the close juxtaposition of a susceptible and an infected, vector, or reservoir, transmission dynamics are inherently a spatial processes (Ostfeld et al., 2005). Therefore, risk can be expressed in maps, which could be used to guide effective intervention or model future expansions of an emerging infectious disease, reservoir, and vector (Ostfeld et al., 2005; Tatem et al., 2012). In the case of rabies, spatial analyses have been the base for a wide number of studies, including modeling disease patterns (Childs et al., 2000), transmission dynamics (Smith and Yager, 1990; Real et al., 2005), and potential areas for rabies outbreak (Tinline and MacInnes, 2004).

In Chile, after a rabies-free period of more than 10 years, the first detection of rabies in the bat species *Tadarida brasiliensis* occurred in 1985 (Favi and Durán, 1991). Since then, dog-related rabies remains under control meanwhile wildlife-rabies increases, particularly from bats (OPS, 2005; Favi et al., 2008; Escobar et al., 2014). This epidemiological pattern is similar to other countries such as the United States and Argentina (Blanton et al., 2010; Piñero et al., 2012). At the same time, Chile has a neglected problem of domestic dog overpopulation (Acosta-Jamett et al., 2011; Ibarra et al., 2006), with no national program that addresses dog population control, while recent reports declare that, particularly free-ranging dog overpopulation, represents a threat to public health and biodiversity conservation (Cleaveland et al., 2000; Gompper, 2014; Morters et al., 2014a). The objective of this study is to determine the geographic areas at risk of rabies spillover from bats to dogs using dog demography data and bat–rabies potential distribution. Additionally, we explored dog abundance, restriction management, and rabies vaccination in Chile, all relevant elements for rabies outbreaks (Morters et al., 2013, 2014a; WHO, 2012).

2. Methods

In order to obtain dog demography data, from March to July 2013 we conducted a literature review considering scientific articles and theses related to dog demography in Chile. Keywords were "dog demography" and "dog population" in both Spanish and English. For theses, we reviewed the entire available Universities database from Chile. For scientific articles, we used Google Scholar, ISI Web of Science, and Scielo databases. To be selected, literature source had to be original research (not a review) related to dog population and management in Chile. We organized studies according to municipality. For municipalities with several studies, we selected the most recent data.

To describe dog abundance, we used human:dog ratio, number of dogs by house (dog/house), percentage of houses with dogs (%houses_dog), dog density (dog/km^2), and total number of dogs by municipality (dog/muni). To obtain the latter, we multiplied the human:dog ratio by the human population in each municipality. Dog density (dog/km^2) was obtained via dividing the total number of dogs by municipality by the area (km^2) of the corresponding municipality. The dog/house and %house_dog were obtained from the literature review data, the first one as a ratio, and the latter as a proportion, representing the percentage of houses with the presence of at least one dog from the total houses included in the corresponding municipality. The human population data was summarized from a recent census (INE, 2011). For the risk map development, we needed data from all municipalities, not only from the ones included in previous studies. Therefore, for municipalities with lack of available dog data, we used the median human:dog ratio obtained from the total available municipality data, in order to calculate dog population for the neglected municipalities. This human:dog median was only used to develop the risk-map, and to describe national dog population estimates (i.e. national dog/km^2, dog/muni, and total dog population), but not for posterior statistical analysis.

We explored potential factors related to restriction management and dog abundance. We used simple and multiple regression analysis, establishing human density (human/km^2), income, and education values per municipality as independent variables. Only for dog-restriction management, we also included the human:dog ratio and dog/house as potential predictors (Table 1). Human density was obtained from the division of the human population per municipality and its corresponding area measured in km^2 (INE, 2011). Income and education values are continuous variables used to estimate the human developing index (HDI); these values were obtained from the United Nations Program with the National Ministry of Planning (PNUMP, 2003). To explore dog abundance, dependent variables were human:dog ratio, %house_dog, and dog/house. In the reviewed literature, dog-restriction management had diverse definitions, but always expressed as a proportion from the total dog population surveyed. We standardized the unrestricted dog variable as the percentage of dogs allowed to roam freely and unsupervised at any