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Demography of domestic dogs in rural and urban areas of the Coquimbo region of Chile and implications for disease transmission

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ABSTRACT

A cross-sectional household questionnaire survey was conducted along two transects (80 and 45 km long) from Coquimbo and Ovalle cities to the Fray Jorge National Park (FJNP) in the Coquimbo region of Chile in 2005–2007 to investigate the demography of dogs in the context of a study of canine infectious diseases. Data were collected on the number of dogs per household, fecundity, mortality, and sex and age distribution. The results from 1021 households indicated that dog ownership was common, with a higher proportion of households owning dogs in rural areas (89%), than in towns (63%) or cities (49%). Dog density ranged from 1380 ± 183 to 1509 ± 972 dogs km^{-2} in cities, from 119 ± 18 to 1544 ± 172 dogs km^{-2} in towns, and from 1.0 ± 0.4 to 15.9 ± 0.4 dogs km^{-2} in rural sites. The dog population was estimated to be growing at 20% in cities, 19% in towns and 9% in rural areas. The human:dog ratio ranged from 5.2 to 6.2 in cities, from 2.3 to 5.3 in towns, and from 1.1 to 2.1 in rural areas. A high percentage of owned dogs was always allowed to roam freely in the different areas (27%, 50% and 67% in cities, towns and rural areas, respectively). Observations of free-roaming dogs of unknown owner were reported from a greater proportion of respondents in cities (74%), followed by towns (51%) and finally by rural areas (21%). Overall only 3% of dogs had been castrated. In addition, only 29% of dogs were reported to have been vaccinated against canine distemper virus (CDV) and 30% against canine parvovirus (CPV). The higher population size and density, higher growth rate and a higher turnover of domestic dogs in urban than in rural areas and the poorly supervised and inadequately vaccinated dog populations in urban areas suggest that urban areas are more likely to provide suitable conditions for dogs to acts as reservoirs of pathogenic infections.

1. Introduction

The domestic dog (*Canis familiaris*) is the most numerous carnivore in the world (Daniels and Bekoff, 1989). Dogs are recognised to play a role in about 100 zoonotic diseases (WHO, 1987; WHO/WSPA, 1990). They have also been implicated as the source of infection for several disease outbreaks affecting wild carnivores, including canine distemper virus (CDV) and rabies (Funk et al., 2001; Cleaveland et al., 2002), which have caused epidemics in wild populations (CDV in lions: Roelke-Parker et al., 1996; Rabies in Ethiopian wolves: Haydon et al., 2006).

The demographic characteristics of host populations have a profound impact on the transmission and maintenance of microparasites (Grenfell and Dobson, 1995; Thrusfield, 2005). Large contiguous populations are more likely to maintain short-lived pathogenic infections, such

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as rabies and CDV, than small or isolated populations in which the probability of contact between infected and susceptibles, and rate of replenishment of susceptibles, is too low for persistence (Black, 1966; Anderson and May, 1991; Dobson and Hudson, 1995; Dye et al., 1995; Grenfell and Bolker, 1998; Begon et al., 2003). In addition, high fecundity and immigration rates will facilitate persistence through the introduction of susceptible hosts to the population at risk (Dye et al., 1995).

A difference between urban and rural areas has been reported for pathogenic infections affecting humans, for instance, measles, in the 'city–village' model (Anderson and May, 1991). Regional analysis of historical data in England and Wales indicates that measles diffuses from mega cities to rural areas, showing an endemic state in large populations and fade-out in small ones (Cliff et al., 1993; Grenfell and Bolker, 1998). Whether similar difference in disease transmission between urban and rural sites exist for pathogens transmitted by domestic dogs is unknown and could be of relevance when trying to design strategies to control infectious disease. Urban areas may favour the maintenance of dog pathogens as a result of high dog densities, low levels of vaccination and the existence of high numbers of neighbourhoods with stray dogs which are allowed to roam freely (WHO/WSPA, 1990). In this context, the study of dog ecology and related anthropological aspects of pet ownership are critical for understanding the epidemiology of canine infectious diseases and also to make decisions in the planning and implementation of dog population management schemes for the control of zoonotic diseases (WHO, 1987; WHO/WSPA, 1990; Perry, 1993; Patronek and Rowan, 1995) or diseases that are of conservation interest (Funk et al., 2001; Cleaveland et al., 2002).

Studies of dog ecology and demography have been conducted in many regions of the world including in Africa, Asia and Latin America (Cleaveland, 1996; Butler and Bingham, 2000; Cleaveland et al., 2000; Kitala et al., 2001; Butler et al., 2004; Kongkaew et al., 2004; Fiorello et al., 2006; Ortega-Pacheco et al., 2007; Knobel et al., 2008). In Chile, there have been only a few studies that have tried to estimate the dog population size in urban or rural areas (Morales et al., 1992; Ibarra et al., 2003; Ibarra et al., 2006a, 2006b); however none has studied in detail the demography of domestic dogs.

This paper describes a study of dog ecology conducted in the Coquimbo region of Chile in 2005–2008, where there are no reliable data about urban or rural dog populations. The region is of interest because an outbreak of CDV involving two free-ranging fox species, chilla (*P. griseus*) and culpeo (*P. culpaeus*) foxes, occurred in the region in 2003 (Moreira and Stutzin, 2003; Acosta-Jamett, 2009), and questions have been raised about the role of domestic dogs in the epidemiology of this disease. The objectives of this study were to estimate the size and distribution of the dog population and compare the different demographic characteristics between urban and rural areas in the context of understanding the maintenance and transmission of infectious canine diseases and risks for wildlife.

2. Materials and methods

2.1. Study area and questionnaire survey

The study area comprised an area of ~1600 km^2 of the Coquimbo region in North Central Chile (71°12′ to 71°40′W, 29°58′ to 30°39′S). A cross-sectional study design was used to conduct a questionnaire survey in households of rural and urban areas across along two transects from the Coquimbo and Ovalle city to the Fray Jorge National Park (FJNP). In these transects, eight different sites were chosen, including three towns and four rural areas (Fig. 1). The first transect ran for 80 km north–south from Coquimbo to the FJNP and included Guanaqueros and Tongoy towns (sites B and C, respectively) and the rural sites Lagunillas (A), El Tangue (D), and Punilla (E). The second ran for 40 km east–west transect from Ovalle city to the FJNP. This transect included the rural site Barraza (F) and La Torre town (G). The centroids of each site were evenly spaced out along the transects at intervals of 13 km and a circle of 6.5 km radius drawn at each to demarcate the sampling site (Fig. 1).

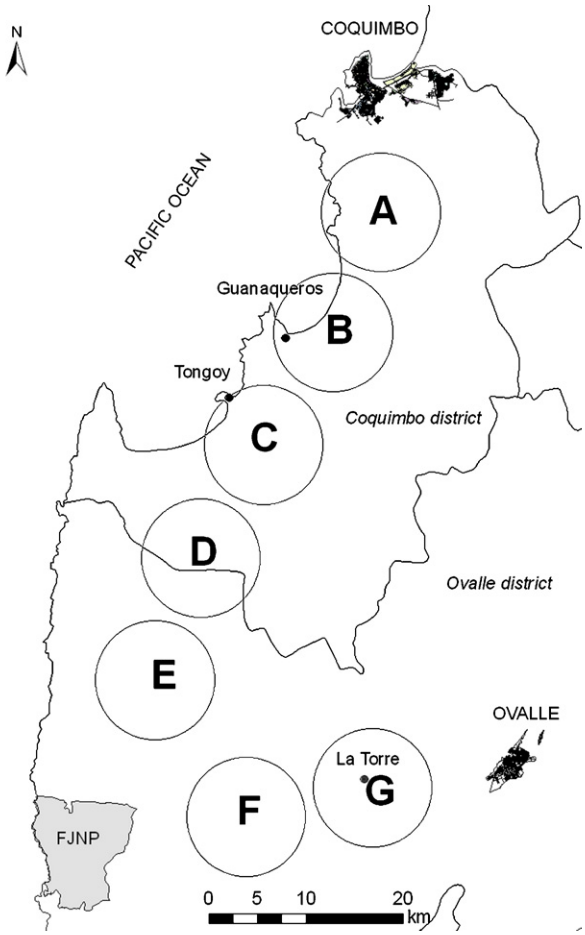

Fig. 1. Study area. Two transects from Coquimbo and Ovalle cities through rural sites are shown. Seven sites were delimited within which the questionnaire survey was conducted. In gray the Fray Jorge National Park. Black dots show small cities in the area.

A questionnaire was developed to obtain detailed information on the demography of domestic dogs in the study area and pre-tested in both rural and urban communities not involved in the study. Questionnaires were carried out in Spanish and data generated at the level of both the household and individual dog. Further details of the questionnaire are given in Acosta-Jamett (2009). Briefly, data were collected at the household level, and dog level. Data at the household level included the owner's name, number of people per household, number of dogs per household, unknown free-roaming dogs seen (always, sometimes, never), methods of feeding, waste disposal methods, education of owners, household condition (e.g. owners, leasing, family home). Also, owners were asked about dogs that had died in the past 12 months and whether they carried out any population control measure.

The dog level questions included the dog's name, age and sex, if dogs where pure breed (yes/no), origin of each animal (i.e. gift, born at home, found), function (e.g. guard), if each animal was allowed to roam freely (always, sometimes, never), number of litters produced by female dogs, information on litters in the last 3 years, vaccination status and whether their dogs have been seen by veterinarians.

2.2. Demographic parameters

2.2.1. Dog ownership patterns

Interviewed households were divided in dog owning (DOHH) and non-dog owning household (NDOHH) (Knobel et al., 2008). DOHH were also analyzed according to the number of dogs reported in each household. Descriptive analyses of the number of people, number of dogs per household, density of dogs, density of humans, free-roaming dogs of unknown origin, function of dogs, source of each animal, number of sterilized animals and restriction were performed for cities, towns and rural sites. The human:dog ratio was estimated by summing the total number of people and dividing by the total number of dogs for each study site. In addition, the average number of dogs per household and per DOHH was estimated (Kitala et al., 2001; Knobel et al., 2008). The effect of site on the frequency of sterilized animals and vaccination coverage was assessed using a Chi-square test to compare the total frequencies of vaccinated and unvaccinated dogs between cities, towns and rural areas.

2.2.2. Reliability of age data

Questionnaires are widely used in epidemiological studies; however, a critical issue is the validation of responses given by interviewees (Bronsvoort, 2003). The age of an individual is a key parameter and the age of dogs was determined by asking owners both the age of the dog and its date of birth. To examine the repeatability of the owner's report, a sample of households was re-visited to repeat the collection of data on the age of the dog (Nespeca et al., 1997). The Wilcoxon Signed Rank Test was used to determine whether there are differences between the two sets of data.

2.2.3. Sex and age distribution

Chi-square tests were used to determine whether the age and sex distributions differed between cities, towns and rural sites. Ages were classified as a discrete variable by year; where dogs reported in an age class of x years were included in an age class between x and $x+1$ (Cleaveland, 1996). Age-specific parameters (e.g. mortality, fecundity) were calculated to determine within site demography and to compare the demography between rural and urban areas. The Kruskal–Wallis test was used to compare ages between sexes or across all sites.

2.3. Population dynamic data

2.3.1. Population size and density

Combining data from the number of households, the human population size from the human census of 2002 (INE, 2005) and the demographic parameters estimated with our questionnaire survey, we estimated the dog population size and the dog population density for each site. The dog population size was calculated by dividing the human population with the human:dog ratio of the survey for each site (Butler and Bingham, 2000). Finally, the dog population density in each site was obtained by dividing the estimated dog population by the area of the study site, which was calculated by measuring the surface of each site (i.e. area of a polygon whose perimeter is drawn by the lines connecting the most external interviewed households in that site) in Arc View 3.3.

2.3.2. Fecundity

Questionnaire data on female reproduction were used to calculate mean litter size, pup mortality and female fecundity. Fecundity was calculated by the method of Caughley (1977) as the number of female offspring per female per year (m_x). This calculation assumes a 1:1 male:female ratio at birth. *Per capita* birth rates were estimated using data of proportion of mature females (>12 months) in the population and the number of litters/female and the mean litter size/female which were reported in the past 12 months. The Kruskal–Wallis test was used to compare m_x between sites.

2.3.3. Mortality and survivorship

Mortality was estimated from reports of the cause of death occurring in the previous 12 months, given retrospectively by the interviewees. Age-specific mortality was calculated for each specific site depending on the number of dogs of a given age dying in the past 12 months. Age-specific mortality was calculated by dividing the number of dead animals in a given age class in the past 12 months by the number of animals in that age class existing at the time of the interview plus the animals that died during that period.

The effects of age, sex and site on dog death were assessed using a logistic regression analysis where dogs reported as dying were classified as 1 and those surviving as 0. The relationship between these factors and mortality was examined using univariable single logistic regression. Factors with a likelihood-ratio test p-value of <0.25, were considered for entry into a multivariable logistic regression analysis and tested for significance using a likelihood-ratio test ($\alpha = 0.05$). Initially, all selected variables were forced into the multivariable logistic regression model and manual backwards elimination was used for model building, excluding variables with a $P > 0.05$ in the likelihood-ratio test (Dohoo et al., 2003). The presence of confounding was investigated by looking at the effect of each predictor on the coefficient of other variables in the model. Variables were deemed as confounders if the change in the odd ratio for the included variable was 25% or greater (Dohoo et al., 2003). The fit of the logistic regression model was assessed using Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow, 2000), the area under the curve of the receiver-operating characteristic (ROC) and the Pearson's χ^2 statistic. Regression diagnostics to identify covariate patterns were carried out by plotting the Pearson's residual squared ($\Delta\chi^2$), leverage, the influence ($\Delta\beta$), and delta D (ΔD) in order to measure the effect of the covariate on the coefficient and assess the fit of the model. Data were entered into an Excel spreadsheet (Microsoft Excel 2003) and imported into Stata 10 for a windows software package (Stata Corporation, Texas, USA) in which data was analyzed. Descriptive analysis was done in SPSS 12 and Excel (Microsoft Excel 2003).

2.3.4. Life expectancy

Life tables were constructed to estimate life expectancy of dogs at birth (mean age at death) according to Caughley (1977), using age-specific mortality and fecundity (m_x), calculated as described above. Life expectancy in each age group (e_x) was taken as the expected number of years to be lived for dogs in the 0–1 year age interval and was calculated according the following formulas (Newell, 1988): (1) $e_x = T_x/L_x$, (2) $T_x = \Sigma L_x - L_{x-1}$, and (3) $L_x = (l_x + l_{x+1})/2$, where l_x is the survivorship per age class, L_x is the mean life expectancy, which measures the proportion of individuals surviving to the midpoint of age x, and T_x is the total number of age categories left to be lived by all individuals who survive to the beginning of age × category. General Linear Model (GLM) analysis was used for comparing the effect of sites, age and sex on life expectancy. Post-hoc comparisons were performed with Turkey's HD. Statistical analyses were done in Statistica 6.0. Acceptance of significant differences was set at $P < 0.05$.

Table 1
Differences between the number of interviewed dog owning (DOHH) and non-dog owning households (NDOHH).

Households	Overall n (%)	City n (%)	Town n (%)	Rural n (%)
DOHH	619 (61)	266 (49)	163 (63)	190 (89)
No. of dogs				
1	348 (56)	183 (69)	98 (60)	67 (35)
2	151 (24)	56 (21)	45 (28)	50 (26)
3	54 (9)	12 (5)	9 (6)	33 (17)
>3	66 (11)	15 (6)	11 (7)	40 (21)
NDOHH	402 (39)	282 (51)	97 (37)	23 (11)
Total	1021	548	260	213

$\chi^2 = 107$, d.f. = 2, $p < 0.0001$.

2.3.5. Intrinsic growth rate

In cities, towns and rural areas the intrinsic growth rate, r, was calculated using age-specific survival and fecundity obtained from life tables with the Lotka's equation as follows (Caughley, 1977): $\Sigma l_x m_x e^{-rx} = 1$. Because r cannot be solved analytically (Stearns, 1999) the equation was solved empirically in an Excel spreadsheet by entering successive values for r that approximated the solution of the equation (equalled to 1).

3. Results

3.1. Demography patterns

3.1.1. Dog ownership patterns

A total of 1325 households were interviewed of which 654 (61%) were DOHH and 39% of them NDOHH. DOHH were not randomly distributed across the study areas ($\chi^2 = 107$, d.f. = 2, $p < 0.0001$), with a higher proportion of DOHH found in rural areas and towns (Table 1). Overall, within the DOHH 348 households (56%) owned one dog,

Table 2
Pattern of domestic dog ownership obtained from questionnaire surveys in rural and urban areas in the Coquimbo region of Chile. In parenthesis is the letter given to each site in Fig. 2.

Sites	Number of interviewed households (% of DOHH)	Number of households without response	Overall number of people	Overall number of dogs	Average human:dog ratio	Average number of dogs per household	Average number of dogs per DOHH
Urban							
City							
Coquimbo	326 (48)	49	1409	269	5.2	0.8	1.7
Ovalle	242 (46)	130	996	160	6.2	0.7	1.5
Town							
Guanaquero (B)	81 (52)	6	354	67	5.3	0.8	1.6
Tongoy (C)	147 (59)	78	590	131	4.5	0.9	1.5
La Torre (G)	49 (71)	1	157	68	2.3	1.4	1.9
Rural							
Lagunillas (A)	27 (93)	1	87	68	1.3	2.5	2.7
Tangue (D)	49 (92)	0	156	137	1.1	2.8	3.0
Punillas (E)	53 (96)	4	224	111	2.0	2.1	2.2
Barraza (F)	89 (78)	0	325	157	2.1	1.8	2.3
Total	1063	269	4298	1168			

Table 3
Report of dog management practices in dog owning households obtained from questionnaire surveys in rural and urban areas in the Coquimbo region of Chile.

Sites	Stray dogs (%)[a]	Movement control (%)	Dog function				Source of dogs				Sterilized (%)
			Guarding (%)	Pet (%)	Herding (%)	Hunting (%)	Neighbours (%)	Born (%)	Found (%)	Bought (%)	
City	84 (81–88)	49 (48–55)	33 (29–44)	73 (77–78)	0 (0)	0 (0)	59 (59)	12 (9–15)	14 (13–15)	13 (12–16)	2 (2–3)
Town	83 (66–98)	26 (17–43)	50 (38–57)	63 (58–72)	4 (0–6)	0 (0)	59 (49–63)	8 (5–15)	17 (8–25)	15 (10–23)	7 (0–10)
Rural	47 (22–76)	15 (10–23)	59 (40–77)	32 (20–50)	30 (14–54)	2 (0–4)	54 (45–68)	16 (14–22)	8 (8–24)	7 (5–17)	2 (0–12)
Total	75 (22–88)	30 (10–55)	48 (29–77)	53 (20–78)	14 (0–54)	1 (0–4)	56 (45–68)	13 (5–22)	12 (8–25)	11 (5–23)	3 (0–10)

The number indicates the percentage of animals that were reported for each variable and in parenthesis is the range found within group (n = 758 households questionnaires and 1183 dogs).
[a] Estimated from data at the household level.

151 (24%) two dogs, 54 (9%) three dogs and 66 (11%) owned between 4 and 14 dogs. Within the DOHH in cities and towns, most household had between one and two dogs. In rural areas, similar percentages where found in the number of dogs per DOHH (Table 2).

The number of households visited is shown in Table 2. A lower human:dog ratio was found in rural areas (1:1.7), followed by towns (1:4.1) and cities (1:5.2). The same trend was observed in the average number of dogs per household with a higher number of multidog households in rural areas (2.3), then towns (1.0) and finally cities (0.8) (Table 2). Although we intended to interview all the selected households by doing visits and revisits if no respondents were available at the time of the visit, a high proportion of non-respondents were encountered mainly due to the absence of owners at the time of the visits or by reluctance to participate in the study. The former was more prevalent in urban areas.

Significantly more households in cities reporting seeing free-roaming dogs than in rural areas ($\chi^2 = 100$, d.f. = 2, $p < 0.0001$) by interviewees. Significant differences between sites were found in the number of owners that reported to control the movement of each dog ($\chi^2 = 134$, d.f. = 2, $p < 0.0001$), with a higher percentage of dogs within cities than in towns or rural areas (Table 3).

Overall, the main function of dogs was reported as pets and guard duty and relatively few as herding or hunting dogs (Table 3). The proportion of dogs used for guarding was significantly higher in towns and rural areas than in cities ($\chi^2 = 61$, d.f. = 2, $p < 0.0001$), the proportion reported as pets was higher in cities, followed by towns and finally by rural areas ($\chi^2 = 169$, d.f. = 2, $p < 0.0001$). Herding ($\chi^2 = 204$, d.f. = 2, $p < 0.0001$) and hunting ($\chi^2 = 8.3$, d.f. = 2, $p = 0.02$), were functions mostly reported in rural areas (Table 3).

The most common source of dogs was acquisition from neighbours with no significant differences when comparing between sites ($\chi^2 = 1.8$, d.f. = 2, $p = 0.41$). The percentage of dogs that were born of a bitch from the surveyed households was lower in towns than in cities or rural areas ($\chi^2 = 9.7$, d.f. = 3, $p < 0.01$) and the number of dogs found abandoned ($\chi^2 = 14.1$, d.f. = 2, $p < 0.001$) or bought ($\chi^2 = 14.6$, d.f. = 2, $p < 0.001$) was lower in rural areas than in towns or cities (Table 3). Finally, only 3% of dogs had been castrated, with a higher percentage reported in towns than in the other sites ($\chi^2 = 15.0$, d.f. = 2, $p < 0.001$; Table 3).

Overall, only 29% of dogs were reported to have been vaccinated against CDV and 30% against CPV. Significant differences were found in the number of dogs vaccinated to CDV or CPV between sites ($\chi^2 = 37.5$, d.f. = 2, $p < 0.0001$). Higher percentage of vaccinated animals was found in towns (CDV and CPV: 38%), followed by cities (CDV: 23% and CPV: 24%), and rural areas (CDV: 18% and CPV: 19%).

3.1.2. Reliability of age data

When comparing the reported age of the sub sample of dogs at the first interview (median 4.5 years, range 1.2–21) with the second interview (median 4.5 years, range 0.7–20) to determine the repeatability of owners' reports of age, no statistically significant differences where found (Wilcoxon Signed Rank Test, $z = 0.34$, $p = 0.73$; $n = 116$).

3.1.3. Sex and age distribution

There was a predominance of male dogs in the study area ($\chi^2 = 79.9$, $p < 0.001$) with 56% in cities ($n = 420$), 74% in towns ($n = 257$) and 83% in rural areas ($n = 479$) (Fig. 2). The overall median age of the population was 3.0 years (range 0.1–20) and was 3.0 years (range 0.1–20) for males and 2.5 years (range 0.1–14) for females.

Statistically significant differences were found when comparing the overall reported age of males [median 3.0 years (range 0.1–20)] and females [median 2.5 years (range 0.1–14)] (Mann–Whitney U-test, $z = -3.55$, $p < 0.001$). However, significant differences within sites were only detected in rural areas [males: median 3.0 years (range 0.1–20), females: median 3.0 years (range 0.1–20) (Mann–Whitney U-test, $z = 3.55$, $p < 0.001$)], but not in cities [males: median 3.0 years (range 0.1–20), females: median 2.0 years (range 0.1–14) (Mann–Whitney U-test, $z = 1.43$, $p = 0.15$)] nor towns [males: median 3.0 years (range 0.1–17), females: median 2.8 years (range 0.1–12) (Mann–Whitney U-test, $z = 1.38$, $p = 0.17$)] (Fig. 2). Finally, no differences were found when comparing the overall age of dogs reported in cities, towns and rural areas (Kruskal–Wallis test, $H_{2,1156} = 5.9$, $p > 0.05$; Fig. 3).

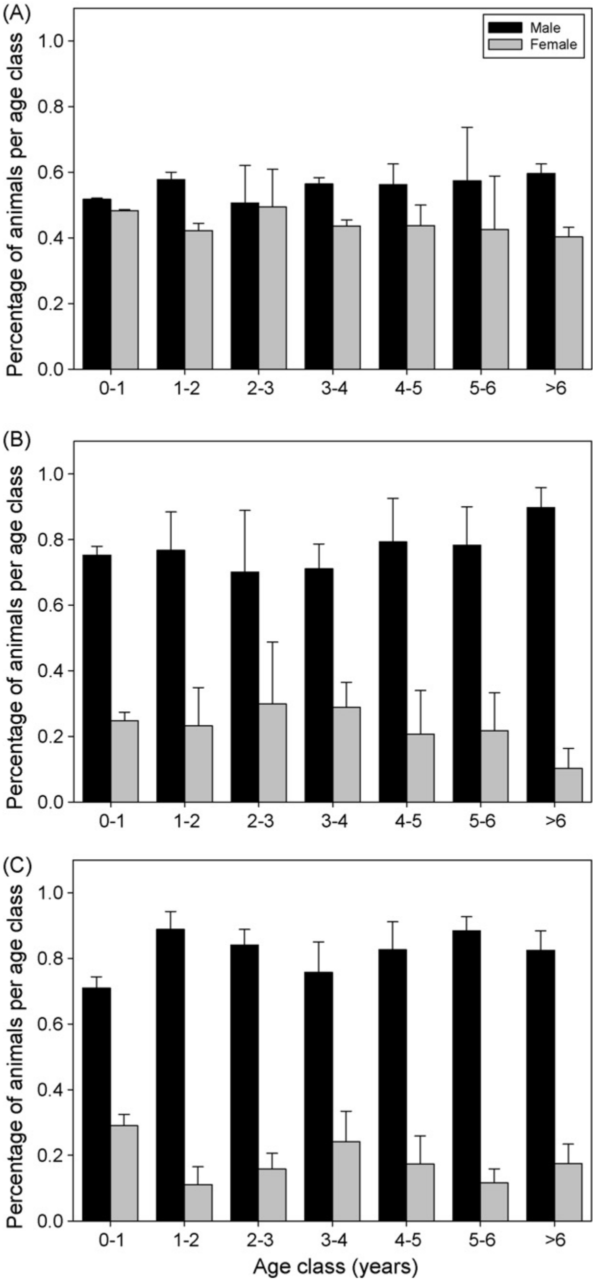

Fig. 2. Sex distribution per age class in cities (A), towns (B) and rural areas (C). Bars indicate SE.

3.2. Population dynamic data

3.2.1. Population size and density (Table 4)

Coquimbo city had the highest dog density in the area with 2380 dog km $^{-2}$, followed by Tongoy town (site C), with a density of 1544 dog km^{-2}, and the other two towns in the study (119 and 311 dog km^{-2}). A much lower density was estimated in rural areas, with about 1 dog km^{-2} in all sites, except in sites A and F (7.2 and 23.9 dog km^{-2}, respectively). The total dog population for the study area was estimated to be 38,190 and the overall dog density was estimated to be 87.1 dog km^{-2}.

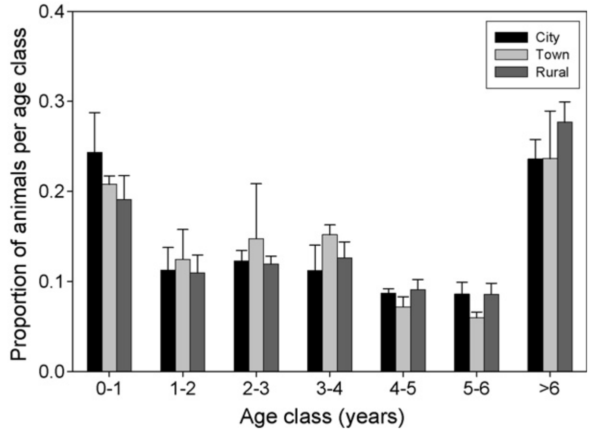

Fig. 3. Proportion of dogs within each class, grouped in cities, towns and rural areas. Bars indicate SE.

3.2.2. Fecundity

Of the 170 female dogs (12 months and older), 47% had whelped at least once with a median litter size of 5.0 (3.14–7.0) puppies. None of the 61 bitches less than 12 months at the time of the interview were reported to have whelped. The median fecundity rate (m_x) was 1.0 (0.44–1.82) female offspring per female per year and tended to be higher in cities (median 1.21, 0.6–1.82) than in towns (median 0.88, 0.44–1.82) and rural areas (median 0.88, 0.44–1.22), with a peak fecundity in all sites between dogs of 4 and 5 years old (Table 5), however no statistical significant differences were detected between sites (Kruskal–Wallis test, $H_{2,9} = 0.1$, $p = 0.95$) nor when comparing the age-specific fecundity between sites (Kruskal–Wallis test, $H_{2,63} = 1.7$, $p > 0.05$).

3.2.3. Mortality and survivorship

Mortality was higher in dogs less than a year in rural areas, with highest mortality reported in young females (Fig. 4). In the univariable analysis all categorical factors (site, sex, age) ($p < 0.25$) were selected for the multivariate analysis and analyzed as categorical predictors. Age

Table 4
Estimated dog population size and density in the study area[a].

Sites	Estimated dog population size	Estimated dog population density (dogs km^{-2})
Urban		
City		
Coquimbo	35,160 ± 2705	2380 ± 183
Ovalle	10,711 ± 691	1509 ± 97
Town		
Guanaquero (B)	440 ± 66	119 ± 18
Tongoy (C)	1125 ± 125	1544 ± 172
La Torre (G)	602 ± 236	311 ± 121
Rural		
Lagunillas (A)	200 ± 169	7.2 ± 6.1
Tangue (D)	137 ± 100	1.3 ± 0.9
Punillas (E)	97 ± 39	1.0 ± 0.4
Barraza (F)	429 ± 143	15.9 ± 0.4
Total	48,901 ± 2643	87.1 ± 9.3

[a] Estimated number ± SE.

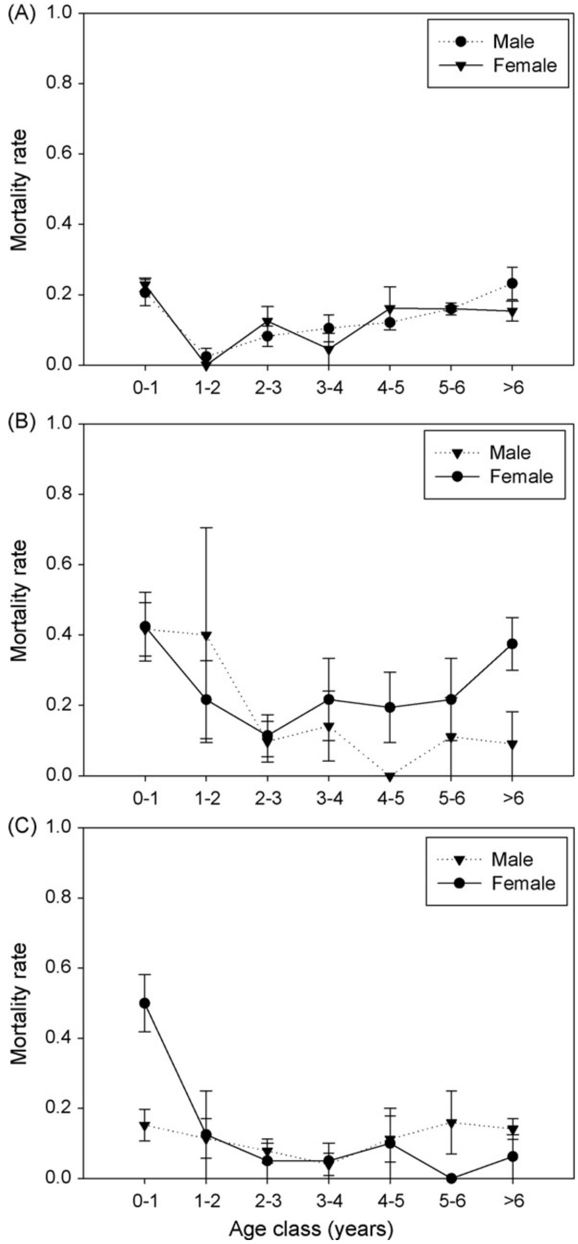

Fig. 4. Age- and sex-specific mortality rates. (A) Cities, (B) towns and (C) rural areas. Bars indicate SE.

explained most of the variation when using three age classes (0–1 years, 1–2 years and >2 years). In the final model, the inclusion of the three variables was associated with an increased risk of mortality ($p < 0.05$) (Table 6). The odds of a dog dying was higher in towns than in cities (OR 2.19, 95% CI 1.61–2.98), but not when comparing cities and rural areas ($p > 0.05$). Additionally, higher mortality was detected in the younger age (<1 year) when comparing to the other age classes ($p < 0.001$). Finally, there were significant differences between sexes with a higher mortality in females than in males (OR 1.51, 95% CI 1.18–1.95).

Causes of death included human activities/actions (i.e. poisoning, motoring accidents, etc., 41%), disease (35%) and old age (12%). During the questionnaire survey some respondents commented that they selectively killed female puppies to avoid overpopulation of dogs, which was most commented in rural than urban areas. Another reported population control measure was the restriction of female movement during oestrus.

3.2.4. Life expectancy

Overall, the life expectancy reduced with age (GLM, $F_{1,119} = 377.2$, $p < < 0.001$) (Fig. 5) and significant differences were found when comparing life expectancy between sites (GLM, $F_{2,119} = 11.0$, $p < < 0.001$). Although no differences were detected when comparing sexes (GLM, $F_{1,119} = 0.7$, $p > 0.05$), the lowest life expectancy was found in females in towns (Tukey HSD test, $p < 0.001$: Fig. 5A).

3.2.5. Intrinsic growth rate

By combining age-specific survival and fecundity and assuming a stable age distribution, the population growth rate, r, was calculated to be $20 \pm 2\%$ in cities, $19 \pm 3\%$ in towns and $9 \pm 4\%$ in rural areas.

4. Discussion

This study demonstrates substantial differences in demographic characteristics of dog populations in urban and rural areas in the Coquimbo region of Chile, which are likely to have important implications in diseases transmission in an urban/rural complex. The range of values for the urban human:dog ratio in this study (4.5:1–6.2:1) is similar to values reported in Santiago, Chile (Ibarra et al., 2003) and Mexico (Flores-Ibarra and Estrella-Valenzuela, 2004; Ortega-Pacheco et al., 2007), but much lower than in urban settings in other parts of the world (Brooks, 1990; WHO/WSPA, 1990; Rautenbach et al., 1991; Matter et al., 2000; Kitala et al., 2001; Kongkaew et al., 2004).

The results found in this study indicate that the sex ratio is skewed towards males, which is consistent with finding from other parts of the world (Beran, 1982; Daniels and Bekoff, 1989; Brooks, 1990; Cleaveland, 1996; Butler, 2000; Butler and Bingham, 2000; Kitala et al., 2001; Flores-Ibarra and Estrella-Valenzuela, 2004; Kongkaew et al., 2004), but is more marked in this study than elsewhere.

The small fraction of sterilized animals is consistent with high rates of growth across the study sites, which is higher than those reported in other similar settings in Africa (Cleaveland, 1996; Kitala et al., 2001). Although the age distribution was skewed toward young dogs, only 20% (range 14–28) of the population was less than 1 year old and the overall median age of the population was 3.0 years (range 0.1–20), which is lower than most African populations (Brooks, 1990; Cleaveland, 1996; Kitala et al., 2001), and consistent with the higher life expectancy than populations in Asia and Africa (when comparing to other studies elsewhere: see Beran, 1982; Beran and Frith, 1988; Wandeler et al., 1988; Cleaveland, 1996; Kitala et al., 2001) and elsewhere in Chile (Morales et al., 1992; Ibarra et al., 2003). The high population growth, the low number of sterilized animals, and high life expectancy found in our

Table 5
Overall fecundity of 105 female dogs from 266 DOHH in cities, 53 female dogs from 163 DOHH in towns and 64 female dogs from 190 DOHH in rural areas.

Site	Age class	Number of females[a]	Number of litters[b]	Pups born[c]	Mean puppies number[d]	m_x[a]
Cities	0–1	29	0	0	0.0	0.0
	1–2	17	5	20	1.2	0.6
	2–3	12	7	33	2.8	1.4
	3–4	13	11	36	2.8	1.4
	4–5	11	10	52	4.7	2.4
	5–6	5	3	12	2.4	1.2
	>6	18	12	34	1.9	0.9
Towns	0–1	11	0	0	0.0	0.0
	1–2	6	4	20	3.0	1.5
	2–3	10	5	31	3.6	1.8
	3–4	12	6	36	1.5	0.8
	4–5	5	3	18	5.0	2.5
	5–6	3	2	7	1.0	0.5
	>6	6	0	0	0.0	0.0
Rural areas	0–1	21	0	0	0.0	0.0
	1–2	5	2	5	1.0	0.5
	2–3	8	3	14	1.8	0.9
	3–4	9	3	9	1.0	0.5
	4–5	4	4	18	4.5	2.3
	5–6	3	1	8	2.7	1.3
	>6	20	14	77	3.9	1.9

[a] $m_x = d/2$, where $d = c/a$ (see Caughley, 1977).

Table 6
Multivariable logistic regression model of factors associated to dog mortality in the study area ($n = 1687$).

Factor	Coeff.	S.E.	OR	95% CI	p-value
Site					
City			1		
Town	0.78	0.16	2.19	1.61–2.98	<0.001
Rural	0.22	0.15	1.25	0.93–1.69	0.143
Age					
0–1			1		
1–2	−1.34	0.28	0.26	0.15–0.45	<0.001
>2 year	−1.04	0.13	0.35	0.27–0.46	<0.001
Sex					
Male			1		
Female	0.41	0.13	1.51	1.18–1.95	<0.001

AUC: 0.68; Pearson's $\chi^2 = 48.6$ ($p < 0.01$); Hosmer–Lemeshow x^2=33.0 ($p < 0.01$).

study explains the high dog density detected in the study area, particularly in urban settings.

In common with studies elsewhere in central and southern America, Africa, Asia and southern Europe (Beran, 1982; Beran and Frith, 1988; Daniels and Bekoff, 1989; Matter et al., 2000; Butler et al., 2004; Ibarra et al., 2006a; Ortega-Pacheco et al., 2007; Slater et al., 2008), free-roaming dogs were also common in our study. Although dogs were confined in a higher proportion of urban households than rural households, free-roaming dogs of unknown ownership were reported more in urban than rural areas. This suggests that more ownerless ('stray') dogs exist in cities and that, in rural areas, each dog is more easily associated with a household. Given the low rates of confinement overall, the majority of free-roaming dogs, even in urban areas, are likely to be owned dogs that are allowed to roam freely, a view supported by observations in Santiago (Ibarra, personal communication).

One of the important findings that could have consequences on pathogen transmission and maintenance in our study area is the huge difference in the resulting dog density between urban and rural sites, with extremely high dog density in urban centres (Daniels and Bekoff, 1989; Wandeler et al., 1993; Ortega-Pacheco et al., 2007). The higher density of dogs in cities and the free-roaming behaviour of many of these dogs provide ideal conditions for the persistence of pathogenic infections. However, control and management of dog populations pose considerable challenges. Dogs are very important in Chilean culture and protected by their owners. To date, efforts to implement population control through elimination of free-roaming dogs has resulted in confrontation with local people and greater efforts will be needed to engage communities in the humane removal of genuinely stray urban dogs (Ibarra, personal communication).

The low vaccination status of urban dog populations, combined with high population turnover rates, indicates that current vaccination programs are very unlikely to be resulting in effective disease control. Only few attempts have been made to estimate R_0 for CDV in dog populations (Cleaveland, 1996), and these only in rural populations. However, a vaccination coverage of 30% would only

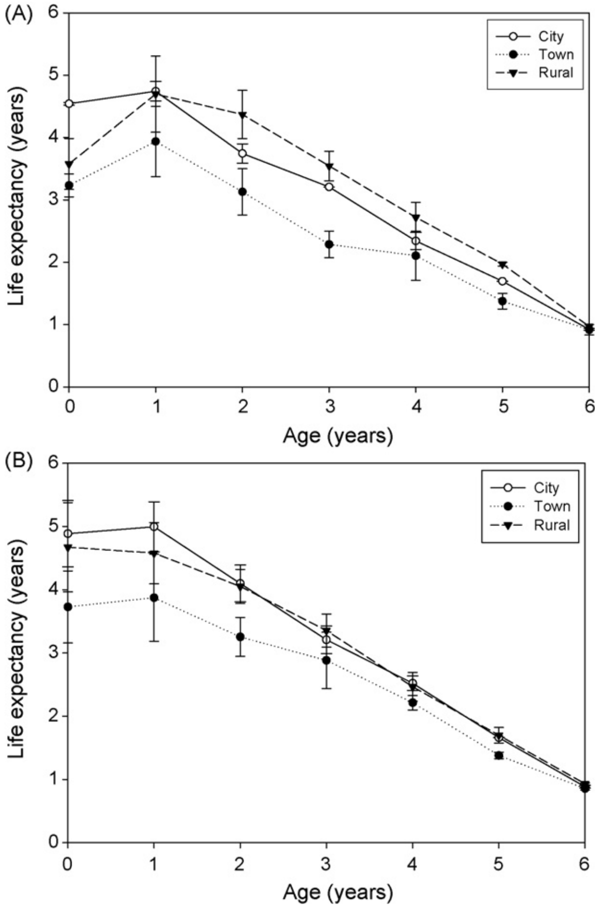

Fig. 5. Age-specific life expectancy for (A) females and (B) males, e_x, determined from life tables calculated from cross-sectional data obtained during questionnaire surveys. Bars indicate SE.

provide sufficient herd immunity to control disease where R_0 is very close to 1.

In summary, the demographic characteristics of domestic dogs in urban and rural communities in Chile show broad similarities to populations from comparable settings in other parts of the world, and suggest consistent patterns of dog ownership, confinement and management in a wide range of countries. In this study, the size and density of dog populations were particularly high in urban areas of Coquimbo and Ovalle, which coupled with a low proportion of vaccinated dogs, suggest that these areas provide ideal conditions for the maintenance of a high and dense population of susceptible hosts that have the potential to act as reservoirs of directly transmitted canine pathogens.

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