

1      **Socio-spatial heterogeneity in participation in mass dog**  
2                                   **vaccination campaigns, Arequipa, Peru**

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12     **Short title:** Socio-spatial heterogeneity in mass dog vaccination

13     **Keywords:**

14     Community participation, Disease outbreaks, Dog diseases, Immunization programs,

15     Mass vaccination, One Health, Rabies, Vaccination coverage, Zoonoses.

16     **Abstract**

17     To control and prevent rabies in Latin America, mass dog vaccination campaigns

18     (MDVC) are implemented mainly through fixed-location vaccination points: owners have

19     to bring their dogs to the vaccination points where they receive the vaccination free of

20     charge. Dog rabies is still endemic in some Latin-American countries and high overall

21 dog vaccination coverage and coverage evenness are desired attributes of MDVC to halt  
22 rabies virus transmission. In Arequipa, Peru, we conducted a door-to-door post-campaign  
23 survey on >6,000 houses to assess the placement of vaccination points on these two  
24 attributes. We found that the odds of participating in the campaign decreased by 16% for  
25 every 100 m from the owner's house to the nearest vaccination point ( $p=0.041$ ) after  
26 controlling for potential covariates. We found social determinants associated with  
27 participating in the MDVC: for each child under 5 in the household the odds of  
28 participating in the MDVC decreased by 13% ( $p=0.032$ ), and for every ten more years  
29 living in the area, the odds of participating in the MDVC increased by 9% ( $p<0.001$ ),  
30 after controlling for distance and other covariates. We also found significant spatial  
31 clustering of unvaccinated dogs over 500m from the vaccination points, which created  
32 pockets of unvaccinated dogs that may sustain rabies virus transmission.  
33 Understanding the barriers to dog owners' participation in community-based dog-  
34 vaccination programs will be crucial to implement effective zoonotic disease preventive  
35 activities. Spatial and social elements of urbanization play an important role in coverage  
36 of MDVCs and should be considered during their planning and evaluation.

## 37 **1. Introduction**

38 The city of Arequipa is in the midst of a dog rabies outbreak. The introduction of rabies  
39 virus into the city has been ascribed to the transport of rabid dogs from the rabies-  
40 endemic state of Puno during human migration [1-3], and it is likely that the persistence  
41 of transmission is due to low coverage in the annual city-wide dog vaccination campaigns  
42 [3]. Following the detection of the outbreak in Arequipa city in 2015, the Ministry of

43 Health of Peru (MOH) initiated additional vaccination campaigns in the city with varying  
44 intensity [4]. These additional efforts have not quelled the epidemic: more than 150 rabid  
45 dogs have been detected as of 2019.

46

47 Epidemics of dog rabies are ongoing in major urban centers across Latin America and  
48 worldwide [1,5-8]. Since bites from rabies-infected dogs cause 99% of human rabies  
49 deaths [9], the control and elimination of dog-mediated human rabies is based on a  
50 population-wide animal-centered strategy: mass dog rabies vaccination [8,10,11]. Dog  
51 vaccination has dramatically decreased the global burden of human rabies since 1955  
52 [5,12,13] and specifically in the Americas, national programs centered around mass dog  
53 vaccination have achieved enormous advances [8,14,15], reducing the incidence of dog  
54 rabies by 98% since 1983 [14]. In most rabies-affected countries, the official health  
55 organizations (e.g. MOH) organize annual MDVC that are held in outdoor settings. These  
56 campaigns are usually free of charge and voluntary [8,16] and campaign promotion  
57 varies greatly in format, content and intensity [1,17,18]. There are three non-mutually  
58 exclusive strategies to implement MDVC: fixed vaccination posts, mobile teams setting  
59 up temporary mobile post or conducting ‘street vaccination’, and door-to-door  
60 vaccination. For the fixed-point strategy the vaccinators wait for the dog owners to bring  
61 the dogs to a unique place. For the mobile team strategy, the vaccinators move from one  
62 location to another, waiting for the dog owners to bring the dogs to these moving  
63 locations. For the door-to-door strategy, vaccinators knock on doors asking for dogs to  
64 vaccinate. Locations of the fixed vaccination sites are typically determined by a  
65 combination of convenience and prominence of the location (e.g. the entrance to a health

66 post) [11]. In Peru, routes for door-to-door and mobile team approaches may or may not  
67 be decided in advance, and teams may move during the course of the day looking for  
68 high-demand locations.

69

70 The fixed-point strategy has been extensively used in Latin America and Africa, even  
71 though it has frequently failed to reach the appropriate coverage [1,8,19-23]. The main  
72 reasons for its extensive application is that fixed-point vaccination is easier to implement  
73 and less costly than other strategies [18]. However, in many cases fixed-point is  
74 combined with other strategies. The use of multiple strategies becomes more common  
75 when initial activities are unsuccessful [19,23,25]. However, high dog owner  
76 participation in MDVC and other dog-centered health campaigns (e.g. de-worming dogs  
77 to prevent human hydatid disease) has proven difficult to achieve in many areas [23,24].  
78 It is necessary to understand barriers to community-based control strategies targeting dog  
79 populations in dog rabies-affected countries where coverage does not reach the minimum  
80 70% recommended by the World Health Organization to attain herd immunity [11], much  
81 less the 80% recommended by the Pan-American Health Organization for the region [25].

82

83 In cities, the social and spatial aspects of urbanization can facilitate the emergence of dog  
84 rabies and complicate its control [26-28]. In Arequipa, the locations of rabid dogs have  
85 been associated with urban structures [26], and dog owners from areas with different  
86 levels of urbanization have reported distinct factors associated with vaccinating their  
87 dogs against rabies [1]. The changing urban landscape and social processes in rapidly  
88 growing cities have been associated with uptake of health-related services [29-32] and

89 may be related to the low dog vaccination coverage in Arequipa. The objectives of the  
90 present study were to quantitatively assess the effect of distance to a vaccination point on  
91 dog owner participation in mass dog vaccination campaigns in an urban setting and to  
92 evaluate the effect of such distance on overall vaccination coverage and evenness.

## 93 **2. Methods**

### 94 **2.1. Ethics statement**

95 Ethical approval was obtained from Universidad Peruana Cayetano Heredia (approval  
96 number: 65369), Tulane University (approval number: 14–606720), and University of  
97 Pennsylvania (approval number: 823736).

98

### 99 **2.2. Study setting**

100 The study was conducted in the Alto Selva Alegre (ASA) (human population for 2015:  
101 82,412; density: 11,902 people/km<sup>2</sup>), one of the 14 districts of the city of Arequipa.  
102 Arequipa, Peru's second largest city, is home to 969,000 people and is situated at ~2,300  
103 meters above sea level. The first detection of a rabid dog in the city of Arequipa occurred  
104 in March 2015 in ASA. By June 2016, when our data were collected, 43 rabid dogs had  
105 been detected in 8 districts, but it is assumed that number represents a small fraction of  
106 the total number of cases [26]. The city of Arequipa comprises communities spanning  
107 different stages of urbanization and different migration histories, from old established  
108 neighborhoods, to young neighborhoods, to recent invasions [33]. Within this gradient of  
109 development, young neighborhoods and recent invasions are often located on the

110 periphery of the city (peri-urban area) and the older localities are nearer to the center  
111 (urban area) [33]. Compared to the urban area, peri-urban areas generally have lower  
112 socioeconomic status, fewer community resources, more security problems, and often  
113 more rugged and uneven terrain (Figure 1). As new neighborhoods mature into  
114 established neighborhoods with wealthier residents, homes are improved with better  
115 quality construction material and permanent utility connections, and connectivity with the  
116 rest of the city increases with better sidewalks, roads, and transportation access. ASA  
117 transects the city, running from the center to the periphery, and the district continues to  
118 grow towards the outskirts of the city. In our study, participants represented either the  
119 urban or peri-urban areas of the city of Arequipa. We included 21 urban neighborhoods  
120 founded many decades ago, and 9 peri-urban neighborhoods that originated around 2000  
121 or later.

122

123 In ASA, the MOH conducted a mass dog vaccination campaign in June 2016. A detailed  
124 description of the mass dog vaccination campaigns can be found elsewhere [1], and the  
125 dog population estimator used in Arequipa can be found in [26].



126  
127  
128  
129

**Figure 1.** Study communities represent landscape heterogeneity. A: Urban area. B: Peri-urban.

130

### 131 **2.3. Data collection**

132 In collaboration with the MOH, we georeferenced every stationary and mobile  
133 vaccination team during the three weekends when the campaign was implemented in  
134 ASA. Due to volunteer assistance, some dogs were vaccinated in weekdays during the  
135 campaign; we did not georeference the location of those volunteering vaccinators, mainly  
136 because their schedule was haphazard and unpredictable. We started door-to-door  
137 surveys immediately after the vaccination campaign.

138

139 The door-to-door survey was designed based on the rabies literature and based on our  
140 qualitative studies on local communities, where we found specific barriers at the  
141 household level [1]. We collected household variables (e.g. number of household  
142 members; number of children under 5 years old), dog owner or interviewee variables (e.g.  
143 gender; educational attainment), and dog variables (e.g. vaccination status; age). All  
144 houses in the study localities were geocoded and the survey data were linked to the  
145 household coordinates. We estimated the Euclidean distance between households and the  
146 closest vaccination point (fixed, mobile, or either).

### 147 **2.4. Statistical Analysis**

148 We estimated the total vaccination coverage in the study area and compared the coverage  
149 in urban vs. peri-urban localities with chi-squared test. We estimated the human to dog  
150 ratio and bootstrapped it 10,000 times to estimate its confidence interval. To evaluate the  
151 baseline characteristics of households and dog owners by participation in the MDVC, we

152 defined an ordinal outcome for houses with dogs: *no participation* (no dog vaccinated in  
153 the house), *partial participation* (some, but not all dogs in the house, vaccinated), and *full*  
154 *participation* in the MDVC (all dogs in the house vaccinated). We used a chi-square test  
155 to compare categorical variables with 10 or more observations per group, Fisher's exact  
156 test for categorical variables with fewer than 10 observations in any subgroup, and  
157 Mann–Whitney U test for age of the dog owner or interviewee, which did not follow a  
158 normal distribution and was truncated at 18 years. We compared the individual  
159 characteristics of vaccinated and unvaccinated dogs with chi-square for categorical  
160 variables and with Mann–Whitney U test for dog's age.

161

162 Our main objective was to assess the effect of distance to the vaccination point on  
163 participation in the MDVC. For distance to the vaccination point, we used the Euclidean  
164 distance from the dog's house to the closest vaccination point, either fixed or mobile. For  
165 participation in the MDVC we used the ordinal values described above: *no participation*,  
166 *partial participation*, and *full participation*. We compared proportional odds logistic  
167 regression (POLR), non-proportional odds logistic regression, and multinomial  
168 regression. The ordinal models were superior to the multinomial regression, and the  
169 proportional odds assumption holds for most of the covariates. Given that the categories  
170 of participation are inherently ordinal and that providing one point estimate per covariate  
171 is more interpretable, the POLR model was favored. To adjust the model, based on the  
172 recent literature, we chose this set potential of covariates: having a dog leash at home,  
173 number of children under 5 years old at home, time living in the area, rabies status of the  
174 last place they lived in before living in the study area, number of dogs at the house, age



175 and gender of the dog owner, and educational attainment. We considered transformed  
176 distance to capture non-linear effects and interactions between distance and having a  
177 leash. The fit of the alternative models to the data was compared with Akaike's  
178 Information Criteria (AIC). We also attempted building a hierarchical model to take into  
179 account the spatial autocorrelation within locality. However, given that within each  
180 locality there was at most one vaccination point, the variable distance from the house to  
181 the vaccination point would be unidentifiable under such hierarchical model. The final  
182 POLR model fitted with the R package MASS (REF) was:

$$183 \quad \ln \left\{ \frac{\text{Odds}(Y \leq k)}{\text{Odds}(Y > k)} \right\} = b_0 + b_1 \cdot \text{distance} + b_2 \cdot \text{leash} + b_3 \cdot \text{children} + b_4 \cdot \begin{matrix} \text{time living} \\ \text{in the area} \end{matrix} + b_5 \cdot \begin{matrix} \text{rabies status of} \\ \text{previous residence} \end{matrix} + \varepsilon$$

184 Where  $k$  takes the values 0 (no participation), 1 (partial participation), and 2 (full  
185 participation). All statistical tests were 2-sided, and significance level was 0.05.

186

187 We tested the spatial pattern of vaccinated and unvaccinated dogs in relation to  
188 vaccination tents for clustering using the bivariate cross K-function. This function  
189 estimates spatial dependence between two types of points (i.e. unvaccinated dogs and  
190 vaccination points) by measuring the expected number of points of type  $i$  within a given  
191 distance to a point of type  $j$  divided by the overall density of the points of type  $i$ . We used  
192 the Kcross function in the R package spatstat [34] to estimate deviations between the K  
193 function estimated for our data and the theoretical K function corresponding to a  
194 completely random Poisson point process for vaccinated dogs to tents and unvaccinated  
195 dogs to tents. Deviations greater than the theoretical K function indicate that the mean  
196 point count is higher than expected under complete spatial randomness (CSR) and thus  
197 some degree of clustering is present between the two event types at the indicated

198 distance. Similarly, deviations less than the theoretical K function indicate that the mean  
199 point count is lower than expected under CSR which therefore indicates that some degree  
200 of dispersion is present between the two event types at the indicated distance.

201

202 In order to investigate the effect of geolocation on the odds of canine vaccination we  
203 fitted Generalized Additive Models (GAMs) to our data using the R package MapGAM  
204 [39]. GAMs are an extension of linear regression models in which both parametric and  
205 non-parametric terms are used to estimate the outcome of interest. We used a two-  
206 dimensional locally weighted smooth (LOESS) of latitude and longitude for our non-  
207 parametric term. The LOESS smoother fits each data point by weighting it towards  
208 nearby points, where weighting is based on the distance to the point being fitted. The  
209 percentage of data points in the region that will be used to predict a particular point is  
210 referred to as the span. The optimal span size used for smoothing was determined by  
211 minimizing Akaike's Information Criterion. We mapped the odds ratio for each point on  
212 pre-specified grids of each locality (from polygon data) and next tested the null  
213 hypothesis that the odds of each points' vaccination status did not depend on geolocation  
214 using permutation tests. For each test, the paired latitude and longitude coordinates were  
215 randomly permuted but vaccination status was held fixed. 1000 permutations were run  
216 for each locality and contour lines encircle areas with significantly increased or decreased  
217 vaccination odds as indicated by point wise p-values computed from the permutation  
218 ranks. All models and figures were created with R [35].

### 219        **3. Results**

220        The vaccination coverage of the MOH MDVC was only 58.1%, and it was low in both  
221        urban and peri-urban localities (58.0% vs. 58.6% respectively,  $\chi^2=0.086$ ,  $p=0.769$ ).  
222        Only 3.4% of dogs were (reportedly) vaccinated in private clinics, bringing our estimated  
223        total coverage to 61.5%. Participation in our survey was higher in the urban area (88.8%)  
224        compared to the peri-urban area (61.6%) (mean= 82.0%,  $\chi^2=6458.5$ ,  $p<0.001$ ). The  
225        total number of dogs in the surveyed houses was 5,292 and the human to dog ratio was  
226        3.78:1 (95% CI: 3.69:1 - 3.89:1). In total, 65.3% of surveyed houses had dogs, but this  
227        number was higher in peri-urban areas (70.0% compared to 64.6% in urban areas,  
228         $\chi^2=6.529$ ,  $p=0.011$ ). For 76.9% of vaccinated dogs in the area, the person who took  
229        them to the MDVC is the person who responded the survey. In our study area the  
230        urbanization process involves new localities being founded and settlers moving in.  
231        Accordingly, we found that the time of residency (or the year people moved in to this  
232        area) was clustered at the locality level. However, we found that people living in or  
233        founding a locality do not necessarily share the same place of origin or previous  
234        residence.  
235  
236        When we compared the distance from each house to the closest fixed vaccination point,  
237        to the closest mobile vaccination point, and to either the closest fixed or mobile  
238        vaccination point, we found a clear gradient with higher average distances for non-  
239        participant houses to houses that partially participated to houses that fully participated  
240        (Table 1). The proportion of households with children under 5 was higher in households  
241        that did not participate of the campaign (36%) compared to houses that participated fully

242 or partially of the campaign (31% and 29% respectively). The proportion of houses with  
243 a dog leash increases from those who did not participate, to those who participated  
244 partially, to those that fully participated of the MDVC. Houses that did not vaccinate their  
245 dogs reported not knowing about the campaign nine times more than houses that  
246 vaccinated all or some of their dogs. There were some differences in MDVC participation  
247 by migration history: people who have lived for longer in ASA tend to report higher  
248 participation in the MDVC compared to those who have lived fewer years in ASA. Also,  
249 there is a slight difference in participation in the MDVC depending on rabies status of  
250 previous residence, with more people participating in the campaign, partially or fully, if  
251 they were migrants from a rabies endemic area (Table 1). Other variables, such as  
252 educational attainment, the proportion of female dog owners or interviewees, and the  
253 proportion of households in urban localities were all similar in those households that  
254 participated fully or partially in the campaign compared to those households that did not  
255 participate of the campaign (Table 1). Having multiple dogs is a prerequisite to be in the  
256 partial participation group; therefore, houses with partial participation had on average  
257 more dogs, but the number of dogs per house was very similar in houses that participated  
258 fully compared to those that did not participate in the campaign (Table 1). Those who did  
259 not participate in the MDVC reported more frequently not knowing about the campaign  
260 before it happened (Table 1), but many of them reported learning about the campaign the  
261 same day it occurred. In S1\_Table, we report the media channels through which they  
262 learned about the campaign either after it occurred or the same day it occurred.  
263

264 **Table 1.** Characteristics of the dog owner population in the study area by participation in  
 265 the MDVC, Arequipa City, Peru, 2016.  
 266

Interviewee/Owner Variables	Vaccinated no dog (n=1,017)	Vaccinated some dogs (n=176)	Vaccinated all dogs (n=1,434)	p
Distance to any closest vaccination point – Mean (SD)	125m (96)	117m (114)	103m (83)	<0.001 <sup>a</sup>
Distance to closest fixed vaccination point – Mean (SD)	501m (479)	490m (420)	461m (422)	0.119 <sup>a</sup>
Distance to closest mobile vaccination point – Mean (SD)	137m (101)	127m (119)	114m (93)	<0.001 <sup>a</sup>
Number of dogs in houses with dogs – Mean (SD)	1.79 (1.10)	2.96 (1.24)	1.80 (1.05)	<0.001 <sup>a</sup>
Houses with children under 5	36.4%	28.9%	30.8%	0.019 <sup>b</sup>
Age of dog owner/interviewee – Median (IQR)	39 years (28 - 52)	40 years (29 - 50)	42 years (30 - 53)	0.024 <sup>c</sup>
Time living in ASA if migrant – Mean (SD)	18.1 years (13.7)	21.2 years (13.9)	22.1 years (14.8)	<0.001 <sup>a</sup>
Area before living in ASA				0.036 <sup>b</sup>
Rabies epidemic (Arequipa)	90.7%	94.1%	89.8%	
Rabies endemic (Puno)	1.6%	2.4%	3.3%	
Rabies free (rest of country)	7.7%	3.6%	6.9%	
Educational attainment				0.509 <sup>b</sup>
Illiterate	0.6%	0.5%	0.6%	
Primary school	11.5%	11.4%	13.6%	
High school	43.2%	48.3%	41.1%	
Technical academy	21.2%	15.3%	20.6%	
University	22.3%	23.3%	23.3%	
Preferred not to respond	1.2%	1.1%	0.7%	
Owens at least one dog leash	51.0%	54.5%	60.1%	<0.001 <sup>b</sup>
Female interviewees/owners	64.6%	73.3%	64.4%	0.032 <sup>b</sup>
Did not know about the campaign before it happened	15.4%	2.3%	1.3%	<0.001 <sup>b</sup>
Live in urban locality (vs. peri-urban)	78.8%	78.1%	79.4%	0.002 <sup>b</sup>

267 *p* values estimated with <sup>a</sup> one-way ANOVA; <sup>b</sup> Chi square test; and <sup>c</sup> Kruskal Wallis test.

268

269 Compared to vaccinated dogs, unvaccinated dogs were older, they were more likely

270 females, they had more free access to the street, there was no leash for them at home, and

271 they were less likely to be walked. It seems that multipurpose dogs (dogs reported as

272 guard and company dogs) were more likely to be vaccinated (Table 2). It does not seem  
 273 that dogs from a specific source have higher chances of being vaccinated. If any, dogs  
 274 received as gifts are more likely to be vaccinated and dogs born at home or  
 275 adopted/picked on the street are less likely to be vaccinated (Table 2). Being considered  
 276 purebred or being spayed/neutered was not associated with dog vaccination status (Table  
 277 2).

278 **Table 2.** Dog characteristics by vaccination status in the MDVC (dogs vaccinated  
 279 privately not included).  
 280

Dog Variables	Unvaccinated dog (n=2,019)	Vaccinated dog (n=2,800)	p
Age of dogs – Mean (SD)	24 months (12 – 60)	20 months (10 – 54)	0.039 <sup>a</sup>
Female dogs	42.1%	36.8%	<0.001 <sup>b</sup>
Free access to the street	20.6%	25.7%	0.002 <sup>b</sup>
Leash for the dog	33.8%	45.3%	<0.001 <sup>b</sup>
Dogs that are walked, either with or without leash.	55.9%	66.9%	<0.001 <sup>b</sup>
Dog function			<0.001 <sup>b</sup>
Company	52.0%	49.0%	
Protection	23.4%	20.9%	
Company & Protection	24.6%	29.6%	
Breeder/business	0.0%	0.5%	
Dog source			<0.001 <sup>b</sup>
Gift	51.2%	56.5%	
Bought at market/store	17.4%	18.3%	
Born at home	15.6%	12.3%	
Adopted/Picked on the street	12.3%	10.8%	
Bought from friend/neighbor	2.6%	2.0%	
Do not know	1.0%	0.0%	
Purebred as reported by interviewee	25.7%	24.9%	0.589 <sup>b</sup>
Spayed/Neutered	3.5%	2.6%	0.157 <sup>b</sup>

281 *p* values estimated with <sup>a</sup> Student's t-test; and <sup>b</sup> Chi square test.

282

283 We found that distance to the vaccination site is strongly associated with participation of  
284 the MDVC. The odds of not participating in the MDVC were 16% lower for someone  
285 who lived 100 meters farther from the vaccination point after adjusting for other  
286 covariates and this difference was statistically significant (Table 3). Those having a dog  
287 leash at home had 35% higher odds of participation of the MDVC, either fully or  
288 partially, compared to those who did not have a dog leash after adjusting for other  
289 covariates. The odds of participating in the MDVC, either fully or partially, were 13%  
290 lower for each additional child under 5 years at home after adjusting for other covariates.  
291 The time living in the area was also associated with participation in the MDVC; the odds  
292 of participating in the campaign were 9% higher when we compared people who had  
293 lived 10 years longer in the area with those who moved to the area more recently.  
294 Another component of migration history, the previous residence region, was also  
295 associated with participating in the MDVC: those whose previous residence was a rabies-  
296 free region or was any district within Arequipa were 23% to 32% less likely to participate  
297 of the campaign compared to those whose previous residence was a rabies-endemic  
298 region, after adjusting for other covariates (Table 3). Demographic variables such as  
299 owner's/interviewee's age, gender and educational attainment, and other house-level  
300 variables, such as number of dogs at the house, were dropped during model selection  
301 because they neither improved the fit of the model nor were statistically associated with  
302 participating in the MDVC.

303

304 **Table 3.** Factors associated with participating in the Mass Dog Vaccination Campaign,  
305 Arequipa, Peru.  
306

<b>Variable</b>	<b>OR</b>	<b>95% CI</b>	<b>p</b>
Distance to closest vaccination point (100m)	0.84	0.76 – 0.98	0.041
Having a leash at home	1.35	1.10 – 1.61	0.003
Number of children U5Y at home	0.87	0.78 – 0.97	0.032
Time living in ASA (10 more years)	1.09	1.06 – 1.11	<0.001
Rabies status of previous residence			
Endemic for rabies	Ref.		
Epidemic for rabies	0.77	0.63 – 0.93	0.006
Free of rabies	0.68	0.57 – 0.82	<0.001

307 Odds ratios estimated with multiple proportional odds logistic regressions.

308

309 The significant effect of distance to the vaccination point on the odds of participating in  
310 the MDVC has consequences for the distribution of unvaccinated dogs in the area. We  
311 observed spatial clustering of unvaccinated owned dogs as a function of the distance from  
312 the house to the vaccination point; that is, unvaccinated dogs are closer to each other than  
313 expected by chance. These pockets of unvaccinated dogs occur at 500 meters from the  
314 vaccination point or further (Figure 2). We also analyzed the spatial odds of participating  
315 in the MDVC, that is, the effect of their specific geolocation with regards to the location  
316 of the vaccination point. For areas served by fixed-point vaccination, there was a clear  
317 smooth spatial effect with higher odds of participating for houses closer to the  
318 vaccination point and a decreasing gradient farther away from the vaccination point. The  
319 spatial effect of the fixed-point vaccination strategy creates two clearly defined zones: a  
320 large zone with statistically significantly high odds of participation in the MDVC and  
321 another large zone with statistically significantly low odds of participation in the MDVC  
322 (Figure 3). For areas served by mobile teams, there were more spots of significant low

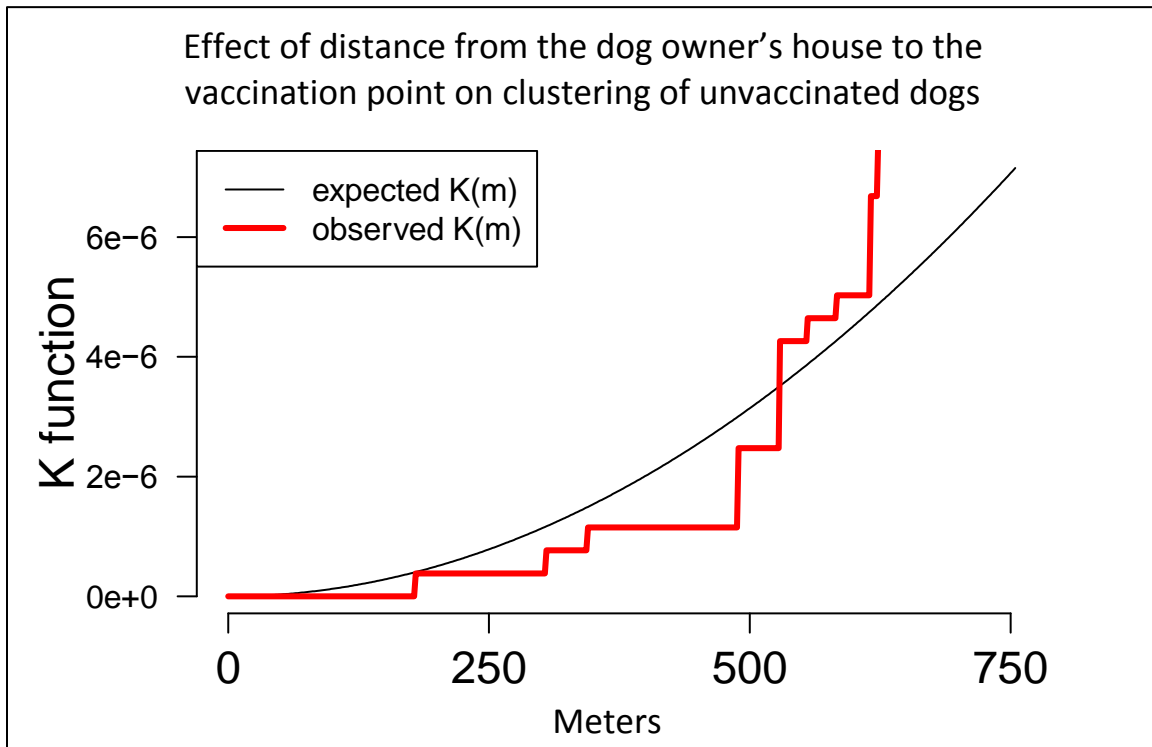


323 and high odds of participation in the MDVC and these spots were spread in the study area  
324 without a clear association between the spots and the locations where the vaccination  
325 teams stopped to wait for dogs or to vaccinate dogs (Figure 3). The spatial odds shown in  
326 maps A and B in Figure 3 are relative to themselves. When the odds found in the area  
327 served by mobile teams were adjusted to the scale of the area served by fixed teams, the  
328 odds of participating in most of the area are similar to the odds of participating for  
329 someone who lives mid-distance from the fixed point in map A.

330

331

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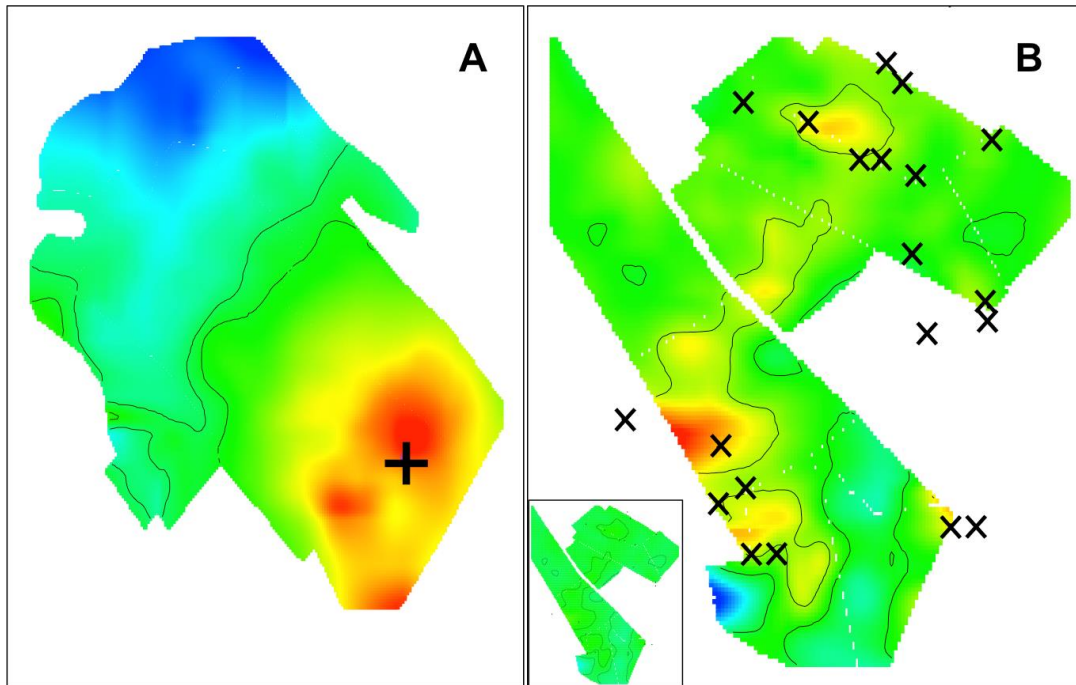
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335 **Figure 2.** Clustering of unvaccinated dogs as a function of distance from the vaccination  
336 point.

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**Figure 3.** Spatial odds ratios for participating in the MDVC in a locality served by a fixed vaccination point (cross in A), and by a mobile team (in B, X's represent locations where the mobile team stopped to wait for dogs or to vaccinate dogs). The insert in B shows the spatial odds for that area after adjusting the odds scale to the scale in A. Contour lines represent areas where the spatial odds were statistically significant.

#### 346 **4. Discussion**

347 In Arequipa, the social and spatial aspects of urbanization facilitate the emergence of dog  
348 rabies and complicate its control. In 21 urban and 9 peri-urban localities in Arequipa,  
349 Peru, we found low vaccination coverage and coverage that was spatially uneven. We  
350 found a strong effect from a more proximal explanation for low participation in the  
351 MDVC: distance to the vaccination point. The unadjusted data show a clear negative  
352 gradient with higher levels of participation in the MDVC at shorter distances to the  
353 vaccination point. After accounting for other important individual- and household-level  
354 variables, distance to the vaccination point remains an important factor associated to

355 participating to the campaign. The effect of distance on participation in the MDVC also  
356 has effects on the spatial coverage of vaccination. We found areas with statistically  
357 significant lower odds of dogs being vaccinated, and the LOESS smoother maps  
358 correlated well with maps of vaccination coverage. Therefore, it seems that both fixed  
359 point and mobile team canine vaccination approaches produced spatially heterogeneous  
360 vaccination coverage. However, we found that vaccination coverage was more “patchy”  
361 coverage in localities served by mobile vaccination teams. This combination of mobile  
362 and fixed points was used also in 2015, but the same localities are not always served with  
363 the same approach (e.g. a locality that was served with mobile teams in 2015 could be  
364 served with fixed point vaccination in 2016). As others have reported [36], there is  
365 potential that in some localities owners in 2016 expected that the MDVC would be  
366 brought to their doors and did not plan or intend to bring the dogs to the fixed points in  
367 their areas. Spatially heterogeneous vaccination coverage is undesirable for dog rabies  
368 control and elimination. Townsend et al. [37] found that such patchy coverage can  
369 "profoundly damage prospects of elimination [...] by creating pockets where rabies could  
370 persist", and modeled patchy coverage within 1 km<sup>2</sup> cell grids. The low coverage  
371 ‘patches’ in our study had smaller areas than 1 km<sup>2</sup>, thus the potential for a threat to  
372 elimination efforts may be different or non-existent. However, in these densely populated  
373 areas it is unknown if these ‘patches’ are large enough to sustain rabies transmission in  
374 the city.

375

376 Many studies have explored logistical, informational, social and structural barriers for  
377 dog rabies vaccination experienced by owners in rabies-affected areas

378 [1,17,18,22,23,36,38-48]. Two of the most common reasons identified are difficulty  
379 handling the dogs [1,22,23,44,45,47,48] and lack of time [1,23,44,45,47,48]. These two  
380 logistical barriers are correlated with a less studied element: the distance to the  
381 vaccination campaigns. Distance to health services has been fairly well studied in terms  
382 of availability of and access to health care and impact on health, especially for maternal  
383 health, treatment and prevention of chronic diseases and treatment adherence for  
384 infectious diseases [49-51], but not as much for preventing infectious diseases. Some  
385 rural studies mention distance as a potential factor for low dog vaccination coverage  
386 [22,52] and two studies directly evaluated the effect of distance on overall rural villages  
387 vaccination coverage [45] and the effect of distance on attendance to the MDVC in Sub-  
388 Saharan Africa [18]. In the sub-Saharan Africa study, researchers found that distance in  
389 dispersed communities have an impact on MDVC attendance [18]. Given the hilly  
390 landscape with rare direct paths between houses and vaccination points, they estimated  
391 the shortest-path distance for their analysis to take into consideration the long and  
392 tortuous routes dog owners had to follow to visit the vaccination sites. In our study area,  
393 with non-dispersed urbanized highly-populated localities and high density of street  
394 intersections that increase walkability, distance is still an important proximal explanation  
395 for low participation in the vaccination campaigns.

396

397 Our study area consisted of urban and peri-urban localities. Surprisingly, there were no  
398 clear differences in participation in the MDVC between these two groups. However, the  
399 distribution of other proximal rabies-related characteristics is different between them (e.g.  
400 more free-roaming dogs in peri-urban areas, more neutered/spayed dogs in urban areas).

401 There are other social determinants that provide more distal explanations for participation  
402 in the MDVC. In previous focus groups conducted by our team, young females reported  
403 that having a baby at home could prevent them for participating in the campaign [1].  
404 Similarly, we found that households with children under 5 years old were less likely to  
405 vaccinate their dogs compared to houses without children, and each additional child  
406 under 5 reduced the odds of vaccinating the dogs in the house. This knowledge suggests  
407 that redirecting the attention to the dog to protect the household children from rabies  
408 could increase participation in the MDVC for this group of households. There was also a  
409 clear difference in participation between those who lived in a dog rabies-endemic area  
410 before living in Arequipa. A possible explanation for that difference is higher awareness  
411 among that group. In our focus groups, we found low awareness and low perception of  
412 severity among residents of Arequipa. Interestingly, another component of migration  
413 history was also associated with participation in the MDVC: time living in the area. This  
414 phenomenon has been observed for the utilization of other health services in different  
415 settings and populations [53-55]. Migration, settlement and adaptation are processes that  
416 take time and are necessary for the uptake of health services [56-59], and could be  
417 influencing the participation in the MDVC. Importantly, in the peri-urban localities there  
418 are more households with children under 5, more recent migrants, and more people  
419 whose previous residence was in a rabies-affected region.

420

421 Our study has a number of limitations. Other studies have focused attention on dog-level  
422 variables (e.g. sex, age, function) that might be associated to participation in MDVC [18].  
423 We did not analyze these; rather we focus on owner and community characteristics that

424 can be utilized by the health authorities (who rarely have the opportunity to collect  
425 detailed house-by-house information) to increase participation in MDVC. Vaccination  
426 status and access to the street were reported by the owner/interviewee. Given the bad  
427 publicity in the local media about owned free roaming unvaccinated dogs and the  
428 authorities' threats to fine 'irresponsible' dog owners, there is potential for social  
429 desirability bias to inflate our estimate of vaccination coverage and deflate that of the  
430 proportion of dogs that have access to the street. We did not ask the interviewees to show  
431 the vaccination certificate they receive at the MDVC since many of them do not save  
432 these certificates. We used Euclidean distances, which are only a proxy for the real  
433 distance traveled by individuals to a vaccination post.

434

435

436 Dog rabies virus transmission continues in Arequipa, putting at risk millions of people in  
437 the city and the surrounding departments. Dog-focused public health strategies are not  
438 limited to rabies: deworming dogs to prevent human echinococcosis [60], use of  
439 insecticide treatment [61] or vaccines [62] on dogs to prevent human Leishmaniasis or  
440 Chagas disease, are just a few examples. These programs, if they are to be successful,  
441 require high coverage and evenness in their implementation. The same approaches to  
442 reach the appropriate levels of community participation that might have worked in the  
443 1980s are not working today. Understanding the barriers for dog owners' participation in  
444 community-based programs will be crucial to implement effective zoonotic disease  
445 preventive activities. Distance to health services and the heterogeneous social

446 composition of growing cities have to be taken into consideration when designing field

447 programs to protect against zoonotic diseases.

448

449 Supporting information

450

451 S1\_Resumen en Español (Abstract in foreign language).

452

453 S1\_Table. MDVC communication channels interviewees were exposed by participation  
454 level.

How they learned about the campaign	Vaccinate none dog (n=858)	Vaccinated some dogs (n=170)	Vaccinated all dogs (n=1,397)	p
Megaphone	56.9%	64.5%	66.5%	<0.001 <sup>a</sup>
TV	36.4%	33.1%	32.1%	0.842 <sup>a</sup>
Radio	33.9%	23.3%	30.4%	0.122 <sup>a</sup>
Poster/Banner	7.8%	9.9%	7.4%	0.337 <sup>a</sup>
Relative/friend/neighbor	4.8%	8.7%	5.7%	0.027 <sup>a</sup>
Newspaper	1.3%	0.6%	1.1%	0.798 <sup>a</sup>
Flier	1.3%	1.2%	0.7%	0.497 <sup>b</sup>
At municipality	0.6%	0.6%	0.6%	--
Social media	0.1%	0.6%	0.7%	0.066 <sup>b</sup>
Community meeting	0.1%	0.0%	0.0%	0.454 <sup>b</sup>

455 p-values estimated with <sup>a</sup> Chi square test and <sup>b</sup> Fisher exact test.

456

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- 654



A



B





# Effect of distance from dog owner's house to the closest vaccination point on clustering of unvaccinated dogs

