

# Coverage of pilot parenteral vaccination campaign against canine rabies in N'Djaména, Chad

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**Abstract** Canine rabies, and thus human exposure to rabies, can be controlled through mass vaccination of the animal reservoir if dog owners are willing to cooperate. Inaccessible, ownerless dogs, however, reduce the vaccination coverage achieved in parenteral campaigns. This study aimed to estimate the vaccination coverage in dogs in three study zones of N'Djaména, Chad, after a pilot free parenteral mass vaccination campaign against rabies. We used a capture–mark–recapture approach for population estimates, with a Bayesian, Markov chain, Monte Carlo method to estimate the total number of owned dogs, and the ratio of ownerless to owned dogs to calculate vaccination coverage. When we took into account ownerless dogs, the vaccination coverage in the dog populations was 87% (95% confidence interval (CI), 84–89%) in study zone I, 71% (95% CI, 64–76%) in zone II, and 64% (95% CI, 58–71%) in zone III. The proportions of ownerless dogs to owned dogs were 1.1% (95% CI, 0–3.1%), 7.6% (95% CI, 0.7–16.5%), and 10.6% (95% CI, 1.6–19.1%) in the three study zones, respectively. Vaccination coverage in the three populations of owned dogs was 88% (95% CI, 84–92%) in zone I, 76% (95% CI, 71–81%) in zone II, and 70% (95% CI, 66–76%) in zone III. Participation of dog owners in the free campaign was high, and the number of inaccessible ownerless dogs was low. High levels of vaccination coverage could be achieved with parenteral mass vaccination. Regular parenteral vaccination campaigns to cover all of N'Djaména should be considered as an ethical way of preventing human rabies when post-exposure treatment is of limited availability and high in cost.

**Keywords** Rabies vaccines/administration and dosage; Dogs/immunology; Vaccination/methods; Mass immunization; Pilot projects; Bayes theorem; Chad (*source: MeSH, NLM*).

**Mots clés** Vaccins antirabiques/administration et posologie; Chien/immunologie; Vaccination/méthodes; Immunisation de masse; Projet pilote; Théorème Bayes; Tchad (*source: MeSH, INSERM*).

**Palabras clave** Vacunas antirrábicas/administración y dosificación; Perros/inmunología; Vacunación/métodos; Inmunización masiva; Proyectos piloto; Teorema de Bayes; Chad (*fuentes: DeCS, BIREME*).

Bulletin of the World Health Organization 2003;81:739-744

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## Introduction

In 1998, more than 33 000 human lives were lost worldwide because of rabies (1). Most of these deaths occurred in tropical developing countries (2). In the United Republic of Tanzania, the incidence of rabies in people was shown to be as much as 10–100 times higher than that estimated using the incidence of bites from suspected dogs as an indicator (3). The domestic dog is the most important vector of human exposure (4). An exposed person can be saved through an immediate full-course post-exposure treatment; however, the supply of rabies immunoglobulin is inadequate worldwide, and in developing countries, vaccine often is not available or is of doubtful quality. From an economic point of view, prevention of rabies in humans only by post-exposure treatment is less cost-effective than dog vaccination, since such treatment does not stop the spread of the virus in the animal reservoir (5).

Canine rabies and hence human exposure can be controlled by intervening in the animal reservoir. Effective vaccines against dog rabies are available, and empirical observation and models of the transmission of canine rabies indicate that rabies can be eradicated if 70% of a dog population is vaccinated repeatedly (6, 7). Ownerless dogs that are not accessible to parenteral mass vaccination reduce the coverage achieved. Oral vaccines that could reach stray and ownerless dogs are not yet on the market (8). Non-selective elimination of stray dogs to reduce the vector population is no longer recommended as a strategy against rabies by WHO (9), because it increases population turnover and decreases herd immunity (10), while public opposition to dog removal can lead to the failure of rabies control programmes (11).

Several countries have eliminated canine rabies from their territory. Japan initiated the first urban dog vaccination

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Ref. No. 02-000539

programme in the world and eliminated rabies in 1954 by reducing the urban dog population and by vaccinating dogs (12). In 1982, an epizootic of urban canine rabies in Malaga, Spain, was stopped successfully by vaccination of dogs, and other interventions (13), and in Brazil, a nationwide vaccination programme was especially effective in urban centres (14). In Guayaquil, Ecuador, rabies cases in dogs dropped substantially after an intensive house-to-house vaccination campaign (15). Most industrialized countries of North America and Western Europe have eliminated endemic canine rabies by stopping its urban transmission (11).

In N'Djaména, the capital of Chad, the annual incidence of canine rabies is 1.4 per 1000 unvaccinated dogs (16). No official and regular intervention strategies against canine rabies exist. Post-exposure treatment often is delayed by the search for cash to buy vaccines, which, moreover, are not always available, and no antirabies serum exists. Mass vaccination of dogs is a logical strategy for preventing human rabies and exposure in this context. This study measured the vaccination coverage achievable after a pilot mass vaccination campaign. We attempted specifically to determine whether dog owners would participate, whether the pilot campaign was feasible from a logistical and organizational point of view, and how many inaccessible ownerless dogs contribute to the dog population in the study area.

## Materials and methods

### Study site

In 2001, a demographic study in N'Djaména estimated the population of dogs at 23 560 (95% CI, 14 570–37 898) (17). For the vaccination campaign, we chose three study zones in the sixth and seventh districts of N'Djaména that had the most cases of rabies and probably the largest dog populations (16, 17). The size of each study zone was determined by our estimated vaccination capacity and the density of the dog population in that district. Zone I covered approximately 0.250 km<sup>2</sup> of the seventh administrative district, and zones II and III covered approximately 1 km<sup>2</sup> each in the sixth administrative district. All zones were well defined by administrative boundaries and were easily accessible on foot.

### Information campaign

The information campaign was limited to the study zones. In the week before mass vaccination, local chiefs who represented traditional authority and the city government in their area went from door to door to invite dog owners to present their dog at the vaccination point, and posters were distributed. The day before the vaccination campaign, we drove several times through each area in a vehicle with a loudspeaker to announce the dog vaccination in Arabic, French, and Ngambai.

### Logistics and equipment of vaccination points

Each vaccination point was operated by two veterinary technicians and a local chief. The local chief organized access to the vaccination point. Two people supervised. We estimated that one dog could be vaccinated, marked, and registered in 10 minutes by the vaccination team, so the daily vaccination capacity of a vaccination point was estimated to be 50 dogs when open for eight hours and 20 minutes. Vaccination points closed at lunchtime for 30 minutes, and a snack was given to the vaccination team. Each vaccination point was equipped with

one register; 60 doses of antirabies vaccine; and 60 syringes, needles, collars, and vaccination certificates. The vaccine was kept on ice in an icebox. A car loaded with additional vaccine, collars, and certificates drove between the vaccination points to ensure a continuously available supply. Chairs and a table for use by the team when documenting the vaccinations and water for washing hands were supplied by the local chief. Each team had a rope or muzzle to prevent dogs from biting. The car that drove between the vaccination points contained a first-aid kit in case someone was bitten.

### Dog vaccination campaign

We had 3000 doses of canine antirabies vaccine (Rabisin, Merial) to vaccinate 400 dogs in a day at eight vaccination points. In study zones I and II, we worked on a Friday and Saturday, and in study zone III, we worked on a Saturday. Every dog that was presented for rabies vaccination was given a free shot of canine antirabies vaccine as long as the animal was old enough to be vaccinated (above about two months). Every vaccinated dog was marked (captured) with a blue plastic collar (Merial), registered with a description of the animal and address of the owner, and given a certificate of vaccination. The registration allowed us to distinguish in the coverage calculation between dogs who originated from the study zone and dogs from elsewhere in the city.

### Household survey

We conducted a household survey with a group of seven interviewers in each study zone in order to register (recapture) marked and unmarked dogs in the owned dog population at the household level. The vaccination points were our starting point, and the direction was chosen randomly. In study zone I, we visited 211 households with dogs, in study zone II, 239 households, and in study zone III, 214 households. A questionnaire was completed for every dog to record whether the animal was marked and whether it was confined to the compound. The vaccination status of unmarked dogs was checked in the vaccination certificate and the reason the animal was not brought to the vaccination point was recorded. Every household was asked to estimate the number of ownerless dogs in their district.

### Transect study

A second recapture of marked and unmarked dogs was carried out in a transect study to estimate the ownerless dog population. In each study zone, we defined a transect line. We chose parallel roads inside the study zone and defined a buffer zone to avoid counting dogs that migrated into the study area. So that we could change direction at the border of the buffer zone and avoid counting the same dogs twice at intersections, one parallel road was skipped. The transects were 2.1 km, 3.4 km, and 4.1 km long for study zones I, II, and III, respectively. Three observers travelled together twice along each transect line — once in the morning and once in the evening on two consecutive days. In study zones I and III, the observers went on foot and in zone II by car. All marked and unmarked dogs seen (recaptured) from the transect were registered.

### Statistical methods

The main outcome measure of the study was the overall vaccination coverage. This was calculated separately for each zone by dividing the total number of vaccinated (marked) dogs by the overall (owned and ownerless) population of dogs.

A Bayesian model was fitted to estimate the owned dog

population and the ratio of ownerless to owned dogs in each study zone. Bayesian inference takes into account not only the observed data but also any prior information about the model parameters. The observed data was the number of marked owned and unmarked (owned and ownerless) dogs collected in the transect study. Prior information relating to model parameters, such as the total owned dog population in the zone, confinement probabilities for owned dogs and a rough estimate of ownerless dogs, were obtained from the household survey. The initial estimate of the owned dog population was calculated using the Petersen-Bailey formula for capture–recapture with direct sampling (18). In addition, we assumed that confined dogs could not be seen from the transect line as long as the compound was closed. Only unconfined owned dogs and ownerless dogs could thus be recaptured on the transect. Details about the model and parameter estimation are given in Annex 1 (web version only, available at: <http://www.who.int/bulletin>).

Studies on vaccination usually report coverage with reference to owned dogs only, so, for comparison, we also indicate the vaccination coverage of the owned dog population on the basis of the Petersen–Bailey population estimate.

### Data entry and statistical analysis

Data of the household survey were entered and analysed using EpiInfo (version 6.04). The Petersen-Bailey population estimate, vaccination coverage for owned dogs, and the overall vaccination coverage were calculated in Microsoft Excel. The parameters of the Bayesian model, together with their credibility intervals, were estimated with Markov chain Monte Carlo simulation (19) implemented using WinBUGS (version 1.3) (20).

## Results

### Overall vaccination coverage

We vaccinated 427 dogs in study zone I, 468 dogs in zone II, and 324 dogs in zone III. The overall vaccination coverage of the dog population was 87% (95% CI, 84–89%) in zone I, 71% (95% CI, 64–76%) in zone II, and 64% (95% CI, 58–71%) in zone III.

### Bayesian population estimates

The total number of owned dogs was 488 (95% CI, 481–494) in study zone I, 617 (95% CI, 608–626) in zone II, and 460 (95% CI, 452–468) in zone III. The number of dogs per km<sup>2</sup> was 1952 in zone I, 617 in zone II, and 460 in zone III. The ratio of ownerless dogs to owned dogs was 1.1% (95% CI, 0–3.1%) in zone I, 7.6% (95% CI, 0.7–16.5%) in zone II, and 10.6% (95% CI, 1.6–19.1%) in zone III. Table 1 and Table 2 give prior and posterior distributions of recapture and confinement probabilities, respectively.

### Vaccination coverage of owned dogs

Vaccination coverage in owned dogs was 88% (95% CI, 84–92%) in study zone I, 76% (95% CI, 71–81%) in zone II, and 70% (95% CI, 66–76%) in zone III. The owned dog population, including confined and unconfined animals, estimated using the Petersen-Bailey formula was 488 (95% CI, 466–510) dogs in zone I, 617 (95% CI, 578–656) in zone II, and 460 (95% CI, 427–493) in zone III.

### Feasibility of vaccination campaign

We maintained the cold chain for the vaccine everywhere.

Table 1. Prior distribution for recapture and confinement probabilities<sup>a</sup>

Probability	Zone I	Zone II	Zone III
Recapture $p_i^{(i)}$			
$U$ (range) <sup>b</sup>	0.26–0.54	0.11–0.54	0.13–0.54
Coverage	0.41–0.60	0.17–0.60	0.20–0.60
Encountering	0.70–0.90	0.70–0.90	0.70–0.90
Recording	0.90–0.99	0.90–0.99	0.90–0.99
Confinement $c_1^{(i)}$			
Beta $(\alpha, \beta)^{(i)c}$			
$\alpha$	–0.28	–0.25	–0.24
$\beta$	–0.49	–0.54	–0.55
Confinement $c_2^{(i)}$			
Beta $(\alpha, \beta)^{(i)c}$			
$\alpha$	–0.43	–0.33	–0.28
$\beta$	–0.32	–0.43	–0.48

<sup>a</sup> See Annex 1 (available at: URL: [www.who.int/bulletin](http://www.who.int/bulletin)) for an explanation of parameters.

<sup>b</sup> Factored in three components: coverage, encountering, and recording.

<sup>c</sup> Mean confinement calculated as  $\alpha/(\alpha + \beta)$ .

The daily vaccination capacity of all vaccination points was higher than our initial estimate of 50 dogs. Some vaccination points vaccinated more than 100 dogs a day. Availability of vaccine, collars, and certificates was maintained with the reserve materials in the circulating vehicle. Dogs unwilling to follow their owner to the vaccination point were transported in wheelbarrows or bicycles or were carried. With very few exceptions, all dogs could be handled for vaccination and marking. No major injuries from dog bites were reported at the vaccination points during the campaign.

### Reasons for not bringing the dog to the vaccination point

Among the reasons owners gave for not vaccinating their dog during the campaign included: not being able to handle their animal (19–35% of owners) and other dog-specific reasons (18–35%) — such as age, recent birth of puppies, illness, or escape from home on the vaccination day. Owner-specific reasons — such as not being informed of the campaign or lack of time — were mentioned by 11–26%. Recent vaccination was given as the reason by 10–17% of owners. In study zone III, 31% of owners stated that vaccination points had run out of vaccine when they presented their dogs.

## Discussion

In N’Djaména, dog rabies vaccination is available at the veterinary clinic, and vaccination coverage of owned dogs before the campaign was 19% (17). Dog owners perceived the price of the vaccine and long distances to the clinic as major obstacles to regular vaccination (17).

Our vaccination campaign attained at least 70% coverage of owned dogs in all study sites, which meets the WHO-recommended threshold level for rabies eradication (6). Unfortunately, not enough vaccine was available to fully saturate zone III, which had the lowest coverage of the three zones. Dog owners participated enthusiastically in the free mass vaccination campaign, and no major logistical problem

Table 2. Posterior estimates for recapture and confinement probabilities<sup>a</sup>

Probability	Zone I	Zone II	Zone III
Recapture $p_i^{(j)}$			
$T_1$	0.59 (0.46–0.75) <sup>b</sup>	0.29 (0.22–0.38)	0.32 (0.24–0.41)
$T_2$	0.35 (0.31–0.44)	0.23 (0.19–0.31)	0.29 (0.23–0.37)
$T_3$	0.34 (0.31–0.41)	0.25 (0.20–0.34)	0.24 (0.22–0.30)
$T_4$	0.53 (0.41–0.68)	0.22 (0.19–0.29)	0.32 (0.24–0.41)
Confinement			
$c_1^{(j)}$	0.71 (0.65–0.77)	0.47 (0.47–0.60)	0.48 (0.37–0.60)
$c_2^{(j)}$	0.74 (0.63–0.84)	0.46 (0.29–0.63)	0.38 (0.22–0.55)

<sup>a</sup> See footnote <sup>a</sup>, Table 1.

<sup>b</sup> Values in parentheses are 95% credibility intervals.

reduced the feasibility of the campaign. Basic equipment for documentation at vaccination points was sufficient and iceboxes were adequate to maintain the cold chain. The vaccination capacity of one vaccination point was about 100 dogs per day. Transportation of dogs to the vaccination point sometimes was not easy, but this was not a drawback, as people transported their dogs with the help of different vehicles or they simply carried the animal.

Our study zones represented typical residential areas of N'Djaména where many dogs are kept. An extension of the programme to the whole city should be possible, because awareness of dog vaccination against rabies was high, as evidenced by the fact that >50% of the dogs vaccinated at our vaccination points were brought from areas of the town without an information campaign. Ownerless dogs are not accessible for parenteral vaccination and the proportion of such animals significantly influences the success of mass vaccination campaigns by reducing their maximal coverage. The difference in overall vaccination coverage between study zone I and zone II might be caused by the larger ownerless population in the later. In contrast with Kumar's findings about stray dogs in India (21), ownerless dogs in our study contributed much less to the overall dog population and the overall vaccination coverage remained high. Similarly, high vaccination coverage has been reported for campaigns in the Philippines and in Guayaquil, Ecuador (22, 23). In a study in Sri Lanka that used Bayesian methods, Matter et al. found 19.3% ownerless dogs and overall vaccination coverage of 57.6% after mass vaccination (24).

A large number of owned dogs that missed the campaign for dog-specific reasons (e.g., young age, recent birth, or illness) or owner-specific reasons (e.g., absence from home during the campaign) could be vaccinated later, if a vaccination service were maintained as well as the regular campaign. The veterinary technician of the administrative district could provide dog vaccination on request in his district.

The success of dog vaccination contrasts with the post-exposure treatment of people, which is not assured because of shortages of vaccine, the high cost of treatment, and the lack of rabies immunoglobulin. This makes interventions in the animal reservoir even more urgent.

Our model assumed that each dog in its group had an equal probability of being captured. In the Petersen-Bailey model, we had one group of owned dogs. In the Bayesian model, we distinguished between "invisible" confined dogs and "probably visible" owned and ownerless free-roaming dogs.

The assumption that confined dogs were not visible was based on the fact that most houses are compounds that are surrounded by walls. From the street, it would not be possible to see a dog confined in such a compound. A critical point is the assumed equal probability of encountering owned and ownerless dogs on the transect, although unmarked owned and ownerless dogs cannot be distinguished. Nevertheless, WHO recommends capture–mark–recapture studies to estimate the size of dog populations (6). Further assumptions were that the population between the times of marking and recapturing was closed and that no markers were lost (25). This is plausible because the maximum number of days between marking and the last recapture was five days.

## Conclusion

In N'Djaména, for the first time in a Sahelian city, vaccination coverage high enough to interrupt rabies transmission was reached by a pilot parenteral mass vaccination of dogs. Participation of dog owners was high, and the technical organization of the mass vaccination campaign was thoroughly feasible. The proportion of inaccessible ownerless dogs was low, and the overall vaccination coverage in the study population was high. We suggest that regular parenteral vaccination campaigns against rabies in dogs that cover the whole city would be an ethical and effective way of preventing human rabies in N'Djaména. ■

## Acknowledgements

The study was financed by the Swiss Federal Veterinary Office, Swiss Agency for Development and Cooperation, EMDO Foundation, and Zürcher Hochschulverein. We thank these institutions for their support. Merial donated the canine antirabies vaccine to the campaign, for which we are grateful. Our appreciation goes to all the collaborators of the vaccination campaign who worked with a lot of motivation. Many thanks also to the collaborating institutions for the fruitful intercultural collaboration. Finally, we thank Dr Hans Matter from Swiss Federal Public Health Office for his assistance with the study design. Several authors of this work (JZ, RM, and YN) are supported by the National Centre for Competence in Research North-South "Mitigating syndromes of global change" (Individual Project 4 "Health and wellbeing"), which is funded by the Swiss National Science Foundation and the Swiss Agency for Development and Cooperation.

**Conflicts of interest:** none declared.

## Résumé

### Couverture d'une campagne pilote de vaccination antirabique parentérale des chiens à N'Djaména (Tchad)

On peut lutter contre la rage canine, et donc l'exposition de l'homme à cette maladie, en procédant à la vaccination massive du réservoir animal, si les propriétaires de chiens veulent bien coopérer. Les chiens errants, sans propriétaire et inaccessibles, réduisent néanmoins la couverture qu'il est possible d'atteindre dans ce type de campagne. L'étude avait pour objet d'estimer la couverture vaccinale des chiens dans trois zones de N'Djaména (Tchad) après une campagne de vaccination antirabique gratuite. Nous avons utilisé une procédure de capture-marquage-recapture pour les estimations de la population, avec une méthode bayésienne Monte Carlo par chaînes de Markov pour estimer le nombre total des chiens ayant un propriétaire et la proportion de chiens errants par rapport aux premiers pour calculer la couverture vaccinale. Lorsque nous avons tenu compte des chiens errants, les couvertures vaccinales des populations canines étaient de 87 % (intervalle de crédibilité à 95 % : 84 % – 89 %) dans la zone I de l'étude, 71 % (64 % – 76 %) dans la zone II et 64 %

(58 % – 71 %) dans la zone III. La proportion de chiens errants par rapport aux chiens ayant un propriétaire était respectivement de 1,1 % (0 % – 3,1 %), 7,6 % (0,7 % – 16,5 %) et 10,6 % (1,6 % – 19,1 %). Les couvertures vaccinales dans les trois populations de chiens ayant un propriétaire ont été de 88 % (84 % – 92 %) dans la zone I, 76 % (71 % – 81 %) dans la zone II et 70 % (66 % – 76 %) dans la zone III. On a observé une forte participation des propriétaires de chiens à la campagne gratuite et un faible nombre de chiens errants inaccessibles. La vaccination parentérale de masse a permis d'obtenir des couvertures vaccinales élevées. Il convient donc d'envisager des campagnes régulières de vaccination parentérale couvrant toute la ville de N'Djaména car, compte tenu de la faible disponibilité du traitement post-exposition et de son coût élevé, elles représentent un moyen éthique de prévention de la rage chez l'homme.

## Resumen

### Cobertura de una campaña piloto de vacunación antirrábica parenteral de los perros en N'Djaména (Chad)

La rabia canina, y en consecuencia la exposición humana a la rabia, puede controlarse mediante la vacunación masiva del reservorio animal cuando los dueños de los perros están dispuestos a cooperar. Sin embargo, los perros inaccesibles sin dueño reducen la cobertura de vacunación lograda en las campañas de vacunación parenteral. Este trabajo tuvo por objeto calcular la cobertura de vacunación de los perros en tres zonas de estudio de N'Djaména (Chad), después de una campaña piloto de vacunación parenteral masiva gratuita contra la rabia. Empleamos un procedimiento de captura-marca-recaptura para estimar las poblaciones, aplicando un método bayesiano de simulación Monte Carlo de Cadenas de Markov para calcular el número total de perros con dueño, y la proporción entre perros abandonados y con dueño para calcular la cobertura de vacunación. Teniendo en cuenta los perros sin dueño, las coberturas de vacunación de la población canina fueron del 87% (intervalo de credibilidad del 95%, 84%–

89%) en la zona de estudio I, 71% (64%–76%) en la zona II y 64% (58%–71%) en la zona III. Las proporciones de perros sin dueño respecto a perros con dueño fueron de 1,1% (0%–3,1%), 7,6% (0,7%–16,5%) y 10,6% (1,6%–19,1%) en las tres zonas de estudio, respectivamente. Las coberturas de vacunación de los perros con dueño fueron del 88% (84%–92%) en la zona I, 76% (71%–81%) en la zona II y 70% (66%–76%) en la zona III. La participación de los dueños de los animales en la campaña gratuita fue alta, y el número de perros sin dueño inaccesibles fue reducido. La vacunación masiva parenteral permitiría alcanzar altos niveles de cobertura vacunal. La realización de campañas periódicas de vacunación parenteral que abarcaran todo N'Djaména debería considerarse una alternativa ética para prevenir la rabia humana en unas circunstancias en que el tratamiento postexposición está disponible sólo de forma limitada y a un alto costo.

## Annex 1. Model developed to estimate total number of owned dogs and ratio of ownerless dogs to owned dogs in three study zones in Chad

In each study zone, data were collected on the number of marked (vaccinated) and unmarked (unvaccinated) dogs in four passages along the same transect lines, during the transect study.  $X_{1t}^{(i)}$  and  $X_{2t}^{(i)}$  are the number of owned dogs, marked and unmarked, respectively, and  $Y_t^{(i)}$  is the number of ownerless (and unmarked) dogs recaptured in zone  $i$  and on transect passage  $t$ . All marked dogs were owned since ownerless dogs were not brought to the vaccination points. Unmarked dogs included not only owned but also ownerless dogs as it was not possible to distinguish them. Therefore we observed only the number of unmarked dogs  $Z_t^{(i)}$ , instead of  $X_{2t}^{(i)}$  and  $Y_t^{(i)}$ , where  $Z_t^{(i)} = X_{2t}^{(i)} + Y_t^{(i)}$  and  $X_{2t}^{(i)}$ ,  $Y_t^{(i)}$  are latent data. The total number of vaccinated (marked, owned) dogs,  $M_v^{(i)}$ , in each zone  $i$  is known from the register of each vaccination point.

We assume that  $X_{1t}^{(i)}$ ,  $X_{2t}^{(i)}$  and  $Z_t^{(i)}$  follow binomial distributions with recapture binomial probabilities,  $p_{11}^{(i)}$ ,  $p_{12}^{(i)}$  and  $p_{13}^{(i)}$ , respectively; that is,  $X_{1t}^{(i)} \sim \text{Bn}((1 - c_1^{(i)}) * M_v^{(i)}, p_{11}^{(i)})$ ;  $X_{2t}^{(i)} \sim \text{Bn}((1 - c_2^{(i)}) * M_u^{(i)}, p_{12}^{(i)})$  and  $Z_t^{(i)} \sim \text{Bn}((1 - c_2^{(i)}) * M_u^{(i)} + N^{(i)}, p_{13}^{(i)})$ , where  $c_1^{(i)}$  and  $c_2^{(i)}$  are confinement probabilities related to zone  $i$  for owned marked and owned unmarked dogs, respectively;  $M_u^{(i)}$  is the total number of unvaccinated owned dogs; and  $N^{(i)}$  is the total number of ownerless dogs in area  $i$ . To reduce the number of parameters of the model, we assumed a common recapture probability,  $p_t^{(i)}$  for all dogs (marked owned, unmarked owned, and ownerless), that is,  $p_{11}^{(i)} = p_{12}^{(i)} = p_{13}^{(i)} = p_t^{(i)}$ .

We estimated the parameters of the model following Bayesian inference implemented by Markov chain Monte Carlo simulation. Prior information about the model parameters was obtained from the analysis of data collected during the household survey. Thus an initial estimate of the total owned dog population  $M^{(i)} = M_v^{(i)} + M_u^{(i)}$  in study zone  $i$  was taken applying the Petersen-Bailey formula for direct sampling on captured (marked) – recaptured data observed during the household survey, that is  $M^{(i)} = M_v^{(i)} * (n_i + 1) / m_i + 1$  and standard error  $(M^{(i)}) = \text{square root} [M_v^{(i)} * M_v^{(i)} * (n_i + 1) * (n_i - m_i) / (m_i + 1) * (m_i + 1) * (m_i + 2)]$ , where  $n_i$  and  $m_i$  are the numbers of recaptured dogs and recaptured marked (vaccinated) dogs in the household survey in zone  $i$ , respectively. These estimates specified the parameters of a normal prior distribution that was adopted for  $M^{(i)}$ .

The parameter  $N^{(i)}$  was expressed as a fraction of the total owned dogs, that is  $N^{(i)} = a_i * M^{(i)}$ . Uniform prior distributions were assumed for  $a_i$ ,  $a_i \sim \text{U}(0, 0.08)$ ,  $\text{U}(0, 0.2)$ ,  $\text{U}(0, 0.2)$  in zone I, II, III respectively. The parameters of the above uniform distribution were chosen by combining the Petersen-Bailey estimate of the owned dogs with a rough estimate of the ownerless dog population per zone obtained from the household questionnaire.

Uniform prior distributions were also adopted for the recapture probabilities  $p_t^{(i)}$ . The parameters of these distributions were chosen by assuming that recapture probabilities were factored in three components: the area covered by the transect line (coverage), the probability to encounter a specific dog provided the area is covered by the transect (encountering), and the probability of the observer to actually record an encountered dog (recording) (21). For each component, uniform priors were adopted as explained below and shown in Table 1. The lower limit for the area coverage was calculated by dividing the area

covered by the transect (allowing 25 m along each side of the line to include a part of the road as well as the yard of the compound next to the road) by the total area of the zone. The upper limit for the area coverage was based on the assumption that more than 50% of the total area was covered, as there was a transect in every second parallel road, most compounds are along the roads, and at intersections parallel streets could be seen. The limits of the uniform prior for the encountering component are based on our observation that many dogs gather around their compound and could therefore be seen. It is, however, a critical point in our assumption. We concluded that recording was very high by comparing the counts of dogs recorded by the three observers who moved together along each transect line.

Finally, beta distributions were adopted for the confinement probabilities  $c_1^{(i)}$  and  $c_2^{(i)}$ . The proportion of dogs that, according to the household survey, spend no time outside of the compound and were in compounds with closed doors during the survey was taken as the mean of the beta distribution. The standard error of this proportion was considered equal to the standard error of the prior. Table 1 shows the prior distributions of confinement probabilities.

A general introduction to Bayesian inference for medical scientists is given by Goodman SN (*A1, A2*).

### References

- A1. Goodman SN. Towards evidence-based medical statistics. 1: the P value fallacy. *Annals of Internal Medicine* 1999;130:995-1004. Available from: URL: <http://www.acponline.org>
- A2. Goodman S.N. Towards evidence-based medical statistics. 2: the Bayes factor. *Annals of Internal Medicine* 1999;130:1005-13. Available from: URL: <http://www.acponline.org>