Sociodemographic factors which predict low private rabies vaccination coverage in dogs in Blantyre, Malawi

Stella Mazeri,1,2 Andrew D Gibson,1,2 Barend Mark de Clare Bronsvoort,2 Ian G Handel,2 Fred Lohr,1 Jordana Burdon Bailey,1 Dagmar Mayer,1 Luke Gamble,1 Richard J Mellanby3

Although rabies kills approximately 60,000 people globally every year, vaccination of over 70 per cent of the canine population has been shown to eliminate the disease in both dogs and human beings. In some rabies endemic countries, owners are able to vaccinate their dogs through private veterinary clinics. However, uptake of dog vaccinations through private veterinary clinics is often low in many rabies endemic countries. In this study, the authors examined the sociodemographic factors which predicted low private rabies vaccination coverage in Blantyre, Malawi. Data on 23,205 dogs were recorded during a door-to-door rabies vaccination programme in 2016. A multivariable logistic regression model was built to identify factors associated with private rabies vaccination. Negative predictors of private vaccination included increasing poverty levels, higher housing densities, male dogs, pregnant or lactating dogs, and puppies and dogs allowed to roam. In contrast, neutered and healthy dogs had greater odds of being privately vaccinated. The present study demonstrated that low private rabies vaccination coverage can be accurately predicted by sociodemographic factors. This information may help inform public health interventions which deliver mass vaccination programmes in rabies endemic countries.

Introduction
Rabies is a neglected disease that kills approximately 60,000 people annually, with death rates per capita being highest in the poorest countries of sub-Saharan Africa. The disease has a myriad economic impacts, both to governments and individuals, resulting in an estimated US$8.6 billion in losses globally each year. People are most often infected through a bite from a rabid dog, with deaths in children and those living in poverty being over-represented. Once clinical signs begin, death is widely considered inevitable and reports of survival following intensive treatment remain rare. Despite significant regional and international healthcare intervention initiatives, no African country has been reported rabies-free to date.

Mass dog vaccination is the single most effective strategy to eliminate rabies among human beings and dogs across most rabies endemic regions. To effectively eliminate rabies from canine and human populations, a critical requirement of mass dog vaccination programmes is to ensure that a sufficiently high proportion of dogs are vaccinated. Empirical and mathematical modelling data have shown that a vaccination coverage of 70 per cent is sufficient to eliminate rabies from dog and human populations. This has resulted in the recommendation by the World Health Organization that rabies vaccination programmes should vaccinate at least 70 per cent of all dogs.

In many countries in Europe and America, private veterinary infrastructure provides year-round opportunity for owners to pay for their dogs to be immunised against rabies. However achieving widespread and high dog vaccination coverage in sub-Saharan African countries typically requires the provision of free dog vaccination through annual intensive dog vaccination campaigns implemented by governmental or non-governmental organisations. These campaigns are often characterised by limited, finite resources, necessitating the prioritisation of areas with the greatest need.
private vaccination where a small amount of additional vaccination effort could increase vaccination coverage to over 70 per cent, or areas of low private vaccination coverage where there is an unambiguous need to vaccinate many more dogs. In either scenario, an ability to predict which areas are likely to have low vaccination coverage will be helpful in the planning and delivery of efficient public health campaigns.

The sociodemographic factors which predict private rabies vaccination in dogs are largely unknown in sub-Saharan Africa. In this study, the authors investigated the sociodemographic factors which were associated with private rabies vaccination in dogs in Blantyre, Malawi. In May 2016 data for 23,205 dogs were recorded during a door-to-door vaccination campaign as part of a city-wide vaccination programme. During this vaccination campaign, the authors were able to establish the prevalence of privately vaccinated dogs and investigate the sociodemographic factors which were predictive of owners privately vaccinating their dogs.

**Methods**

**Study site**

This study was conducted in Blantyre City, the second largest city in Malawi with an estimated human population of 8,81,074 in 2015. The city’s dog population in 2015 was estimated to be 45,526 based on mark resight methods. The city covers an area of 220 km², which is divided into 25 administrative wards. The campaign took place throughout the whole city of Blantyre.

**Vaccination campaign: SP and D2D**

The vaccination campaign has been previously described in detail. Briefly, the city was divided into 204 working zones and their sizes were subjectively dictated according to an area that could be covered by a vaccination team in one day. Each zone was assigned a land type based on appearance on Google satellite maps: (1) housing category (HS) 1 (small houses-high density), (2) HS 2 (small houses-medium density), (3) HS 3 (small houses-low density), (4) HS 4 (medium houses-ordered), (5) HS 5 (large houses-medium/low density), (6) industrial/commercial and (7) agriculture/open space. For the purposes of the regression analysis described below, these were regrouped in high (1), medium (2, 4) and low (3, 5, 6, 7) housing density areas.

Mass dog vaccination across the city was carried out between April 30 and May 25, 2016 using two approaches: static point (SP) and door-to-door (D2D). Using eight vaccination teams working simultaneously, SP vaccinations were conducted on weekends, followed by D2D vaccinations in the same area on the following Monday, Tuesday and Wednesday. Data used for this study were collected during the D2D campaign. All dogs encountered during the campaign were recorded.

**Data collection**

During the D2D campaign data were collected on every dog encountered using the Mission Rabies (MR) smartphone app. Relevant data for this study included the dog’s age and sex, health status, pregnancy status and lactation status, confinement level, global positioning system (GPS) location, and whether the dog has been vaccinated previously by someone other than MR, which was confirmed, where possible, by visual inspection of vaccination certificate. Puppies were defined as dogs less than three months of age. In terms of health status, data recorders classified any dog with any obvious health issues (including but not limited to being underweight, having any obvious skin problems, lesions or wounds, lame) as unhealthy. Distance from household to private veterinary clinic was not recorded as the authors were not able to secure reliable data on the locations of private veterinary clinics in the Blantyre region.

**Other data sources**

Poverty data were sourced from two WorldPop raster data sets ‘mwi11povcons125.tif’ and ‘mwi11povcons200.tif’ (http://www.worldpop.org.uk/), where 2010–2011 estimates of the proportion of people per grid square living in poverty, as defined by $1.25 a day and $2 a day thresholds, respectively, are available. Land cover data were sourced from the MASDAP Malawi Landcover 2010 Scheme I raster data set (http://www.masdap.mw/). Land use data were sourced from OpenStreetMap data downloaded on April 10, 2017 (www.openstreetmap.org).

**Data analysis**

All data analyses were carried out within the R statistical software environment (R Core Team 2017). Specific packages used are mentioned below.

**Geographic information system data extraction**

GPS coordinates recorded for each dog identified at D2D were used to extract the geographic information system (GIS) data for that dog. The package sp was used to extract data from shapefiles, while the package raster was used to extract data from rasters.

**Multivariable logistic regression model**

A multivariable logistic regression model was built using previous vaccination status as the dependent variable. Dogs recorded to be previously vaccinated by someone other than MR were categorised as ‘previously vaccinated’, and all other dogs were categorised as ‘not previously vaccinated’. This was used as the model’s outcome variable. Explanatory variables included housing density, proportion of the population counted as poor and various dog characteristics.

The data set was split into a training data set (60 per cent), which was used to build the model, and
a test data set (40 per cent), which was used to validate the model using the caret package. Variable selection was carried out using manual forward selection based on the lowest Akaike information criterion (AIC). Fivefold cross-validation was used to confirm the final model selected based on the AUC using the package vtreat. The final model was validated, testing its ability to predict previous vaccination in the test data set by estimating the AUC using the package ROCR.

Results

Dog demographics
A total of 23,205 dogs were recorded during the D2D campaign and were included in the analysis. Despite the fact that 99 per cent of those were owned, only 697 dogs (3 per cent) had been vaccinated independently of the vaccination campaign at a private veterinary clinic.

Risk factors
Data used to build a multivariable logistic regression model predicting the odds of a dog being previously vaccinated included dog-related data recorded during the campaign as well as household-related data extracted from poverty, land use and land type GIS data. A visual comparison of the distribution of each factor in dogs that were previously vaccinated and those that were not is shown in online supplementary figures 1–7. All factors were considered for inclusion in the model.

Multivariable logistic regression model
Figure 1 shows the final multivariable logistic regression model predicting previous dog vaccination. Numerical results of the regression model are shown in table 1. The model shows that increasing poverty and higher housing densities were both negative predictors of a dog being previously vaccinated. Similarly, male dogs, pregnant or lactating females and puppies had lower odds of being previously vaccinated. On the other hand, neutered and healthy animals had greater odds of being previously vaccinated. Lastly, when compared with dogs that are never allowed to roam, dogs that are allowed to roam every day but spend some time confined had lower odds of being previously vaccinated. Dogs that are free at all times had even lower odds of being previously vaccinated.

The procedure used to select the final model is shown in table 2. Using the training data set, the authors estimated each model’s AIC and AUC using a fivefold cross-validation. The best model was selected based on the lowest AIC and confirmed based on the highest AUC.

The predictive ability of the final model was then assessed by using the model to predict whether a dog was previously vaccinated using the test data set. The AUC was calculated as 0.88, indicating that the model was very good at predicting the outcome.

![Figure 1](image-url)  
**Figure 1** Multivariable logistic regression model predicting previous vaccination. CI, confidence interval.
This finding is consistent with previous research in sub-Saharan Africa, with many studies finding a similarly low level of private vaccination despite almost all the dogs being formally owned in this region. This finding is unsurprising in Malawi, which is one of the world’s poorest countries, ranking 170 out of 188 countries in the Human Development Index (United Nations Development Programme, 2016). Approximately 70 per cent of the population have an income below $1.90/day, making typical private veterinary fees beyond the financial means of most Malawians (United Nations Development Programme, 2016). In addition, there is a lack of private veterinary clinic industry within Malawi, which invariably limits opportunities for owners to vaccinate their dogs outside of the annual mass vaccination campaigns. Healthcare professionals also face frequent difficulties in obtaining reliable rabies vaccines for both canine and human patients in Blantyre, which may also limit the ability of owners to vaccinate their dogs. The authors’ previous work in Blantyre revealed the strong relationship between distance to campaign vaccination clinics and attendance, with very few owners willing to travel more than 1 km to attend an SP vaccination clinic. The authors also found that some owners had difficulties restraining their dogs, which will likely further limit the ability of owners to present their dogs for vaccination at a private clinic.

Studies exploring dog ownership through mass vaccination campaigns in Nigeria and Chad reported low levels of private vaccination in areas of low income and high housing density, while dogs in affluent areas were more likely to be vaccinated. In the current study, the low levels of private vaccination across the population mean that omission of even small regions quickly increases the risk of failure. In the current study, the low levels of private vaccination across the population mean that free supplementary vaccination is still required in all regions if the goal is elimination.

This work has also shown that a simple model including a relatively small number of details about the dog and the sociodemographic circumstances of the owner can accurately predict the vaccination status of the dog. The authors probed the sociodemographic
factors initially in a training data set and then examined the leading predictive factors formally in a test data set. The authors found that owners residing in areas of high housing density and low economic income were less likely to privately vaccinate their dogs. The study also found that puppies were less likely to be vaccinated privately. While much of this effect could be due to the fact that puppies have had less time to be vaccinated than adult dogs, owners may be reluctant to vaccinate puppies due to the mistaken belief that the vaccine is ineffective if administered to young dogs. The authors’ finding that puppies were less likely to be vaccinated is consistent with other studies in sub-Saharan Africa.20-23 There is a clear need for public health initiatives to address this issue since it is well established that a high proportion of young dogs mount an appropriate protective immune response to rabies vaccination.24

Another finding of the present study was that dogs considered to be healthy and dogs which were neutered were more likely to be privately vaccinated. This may indicate that a small proportion of owned dogs received a significant amount of preventive healthcare, which includes neutering, appropriate diet and timely veterinary treatment when required.

Few studies have examined whether private veterinary care for owned dogs can be predicted based on simple, standard details about the owner and the dogs. While the present results cannot be robustly translated to other sub-Saharan countries without further study, the finding that vaccination status can be readily predicted is encouraging and may help public health professionals identify areas of a community which are likely to have low or higher levels of private vaccination coverage. This may help vaccination programmes distribute their finite resources in a more efficient and effective manner. Where possible, the authors confirmed the previous vaccination of the dog through inspection of a vaccination certificate. However, this was not always feasible since the owner did not invariably have ready access to the appropriate certification. In these circumstances, the authors accepted the accuracy of the owners’ assessment of vaccination status at face value. The authors feel this approach is valid since there was no penalty for not having their dog vaccinated; indeed, if their dogs were not vaccinated, the research team had the capacity to readily arrange vaccine administration.

In summary, the authors have found that few dogs are privately vaccinated in Blantyre, Malawi, highlighting the need for public health initiatives to improve rabies vaccination coverage. Importantly, the authors have shown that low private rabies vaccination coverage can be accurately predicted by sociodemographic factors. This information may help inform public health interventions which deliver mass vaccination programmes in areas where there is a low uptake of private rabies vaccination by dog owners.

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Competing interests: None declared.

Ethics approval: Before vaccination of owned dogs, verbal informed consent was obtained from the person presenting the dog for vaccination. In the cases where an owner could not be identified, dogs were vaccinated in accordance with Government Public Health protocol, as the work was part of a public health campaign. The study was part of our mass rabies vaccination campaign which has been approved by The University of Edinburgh Veterinary Ethics Research Committee. Access to rabies vaccination was not influenced by the decision of an owner to participate in the study. © British Veterinary Association 2018. No commercial re-use. See rights and permissions. Published by BMJ.

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