**RESEARCH ARTICLE**

**Dog health and demographic surveillance survey in Western Kenya: Demography and management practices relevant for rabies transmission and control [version 1; referees: awaiting peer review]**

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**Abstract**

**Background:** Domestic dogs transmit 99% of the estimated 59,000 human rabies deaths occurring globally annually. To achieve the global target of zero human deaths from rabies by 2030, effective mass dog vaccination campaigns that break rabies transmission cycles in dog populations are required. This study describes the design of a dog health and demographic surveillance study established within a human health and demographic surveillance study in Western Kenya. Using baseline data from the dog cohort study, we quantify demographic parameters and describe management practices relevant for rabies transmission.

**Methods:** All dogs in 1213 households participating in a linked human and animal health syndromic surveillance study were recruited. Data on household demographics, dog ownership, dog age and sex ratios, reproductive indices, rabies vaccination, management practices, dog movement and health status were collected at least monthly.

**Results:** 460 of 1213 (38%) of the study households owned dogs (mean 2 dogs/household), and 526 (70%) of those without dogs had owned dogs previously. 802 dogs were recruited into the study, more than half (52%) of those with known ages were ≤ 1 year old. The dog:human ratio in the study population was 1:7, the dog density 54 dogs/km², and the female: male dog sex ratio was 1:1.3. Rabies vaccination was low (5% coverage), and only 48 (12%) male dogs and 13 (5%) female dogs were castrated and spayed, respectively. Dogs were predominantly local breed (99%), mainly kept for security purposes, almost always (97%) left to scavenge for leftovers and 61% roamed freely.

**Conclusion:** Low vaccination coverage, unrestricted dog movement, and high dog population turnover with a large proportion of dogs below one-year-old...
support endemic rabies circulation in this population. These gaps present opportunities for the design of effective dog rabies control plans to break rabies transmission cycles in this part of Kenya.

**Keywords**
Dog, demographics, ecology, Kenya, rabies

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**Author roles:** Kwoba EN: Data Curation, Formal Analysis, Methodology, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing; Kitala P: Supervision, Writing – Review & Editing; Ochieng L: Data Curation, Software; Otiang E: Supervision, Writing – Review & Editing; Ndung’u R: Writing – Review & Editing; Wambura G: Writing – Review & Editing; Hampson K: Conceptualization, Formal Analysis, Funding Acquisition, Methodology, Resources, Writing – Review & Editing; Thumbi SM: Conceptualization, Funding Acquisition, Project Administration, Resources, Supervision, Writing – Review & Editing

**Competing interests:** No competing interests were disclosed.

**Grant information:** SMT is an affiliate of the African Academy of Sciences. This work was supported by the Wellcome Trust [110330/Z/15/Z to SMT, 207569/Z/17/Z to KH]. Funding support for the linked human-animal health surveillance platform in Western Kenya on which the dog-cohort study was conducted was through the Paul G Allen School for Global Animal Health, Washington State University.

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**How to cite this article:** Kwoba EN, Kitala P, Ochieng L et al. Dog health and demographic surveillance survey in Western Kenya: Demography and management practices relevant for rabies transmission and control [version 1; referees: awaiting peer review] AAS Open Research 2019, 2:5 (https://doi.org/10.12688/aasopenres.12902.1)

**First published:** 07 Feb 2019, 2:5 (https://doi.org/10.12688/aasopenres.12902.1)
Introduction
Rabies kills an estimated 59,000 people annually, mostly in Asia and Africa and among rural populations. In Africa, the domestic dog is the reservoir host for the rabies virus and the main source of human rabies cases. The control and elimination of rabies in domestic dogs is critical for eliminating human deaths from rabies. The low basic reproductive number for rabies in dogs supports the feasibility of controlling rabies through vaccination. Mass dog vaccination, reaching 70% of the dog population, is recommended as a cost-effective way to interrupt the transmission cycle and thereby eliminate human deaths due to dog-mediated rabies. However, high dog population turnover leads to rapid declines in herd immunity between vaccination intervals as new susceptible dogs are introduced to the population and immunized dogs leave the population through death. Knowledge of dog population demographic rates and local ecology is critical in designing rabies elimination programmes, including the frequency of mass dog vaccination campaigns.

In 2014, Kenya launched a National Rabies Elimination Strategic Plan for the elimination of dog-mediated human rabies by the year 2030. This goal is in line with the global target for zero deaths from human rabies endorsed by the World Health Organization and partners. The Kenya strategy focuses on mass dog vaccinations, timely provision of post-exposure prophylaxis to bite patients, strengthening surveillance for rabies in humans and animals, and public awareness and education. Studies on dog health and demographics can be informative in providing data for effective planning of dog vaccination campaigns that achieve and maintain sufficient herd immunity for rabies elimination.

Here we describe the design of a dog health and demographic study (dog-HDSS) within an existing human health and demographic surveillance study. Using baseline data from the dog cohort study, we quantify demographic parameters and local dog management practices relevant for rabies transmission.

Methods
Study area
The dog-HDSS is set in western Kenya within a linked human health and animal health syndromic surveillance study following > 1500 households in 10 villages regularly collecting health and socio-economic data from people and their animals. The linked human-animal health syndromic surveillance study is itself conducted within a Health Demographics and Surveillance system (HDSS) run by Kenya Medical Research Institute (KEMRI). The HDSS covers 385 villages that lie to the North-East of Lake Victoria covering Alego-Usonga, Rarieda and Gem sub-counties in Siaya County. Figure 1 is a map of the

Figure 1. A map of Asembo showing the study villages and distribution of households with dogs and those without dogs.
study area showing the study villages and distribution of dog owning and non-dog owning households.

**Dog health and demographic surveillance study design**

All households participating in the linked human and animal syndromic surveillance, whether owning dogs or not, were eligible for inclusion into the dog cohort study. Each of the 1500 households is visited at least monthly by a community interviewer that collects information on the health of household members, and that of cattle, sheep, goats and chicken. Households consenting to enroll in the dog-HDSS had their dogs individually enrolled in the study. To allow for each dog to be followed longitudinally, each study dog received a unique identification number. To identify the study dogs, a combination of the dog names as given by the dog owner, sex, age, and coat color were used during the follow-up visits. At recruitment, a questionnaire collecting information on household demographics, dog age and sex, dog management practices, reproductive indices, vaccination status, dog health and dog bite information was administered. New dogs born or brought into the population during the study are recruited into the dog-HDSS during monthly household visits by the community interviewer.

During monthly visits to households, characteristics of each household are monitored such as human-mediated dog movement, any new births or deaths of dogs since the last visit and dog bites that have occurred in the household. Individual data on each dog in the study is also monitored including reproductive and vaccination status that may have changed since the last visit.

In addition to the regular household visits, the participating households have access to a toll-free number that they call to report cases of illnesses or death among their dogs. Following such reports, the veterinary team comprising of animal health assistants and veterinarians respond to these cases within 24 hours by conducting detailed clinical examinations for sick dogs, postmortem examinations of dead dogs, collecting appropriate diagnostic samples and providing veterinary treatments for sick dogs. These clinical visits comprise the third visit type of the dog cohort study. Figure 2 provides a schematic summary of the dog-HDSS study design. Table 1 provides details of the dog information collected at each of the three visit types: recruitment, monthly follow-up visits, and clinical visits.

**Data collection**

The three sets of questionnaires (recruitment questionnaire, follow-up questionnaire and a clinical response questionnaire) were programmed on a personal digital assistant (PDA) to allow for electronic data capture. Data was downloaded from PDAs into a database at the end of each working day and backed up on servers.

**Data analysis**

Data was cleaned and analyzed using R statistical software (version 3.4.1). Number of households, dogs and ages were summarized as means (95%CI) and while dog sex, dog management practices, dog movement as proportions.

**Ethical clearance**

The study received ethical approval from Kenya Medical Research Institute/Scientific and Ethics Review Unit (SERU) (Ref No. KEMRI/SERU/CGHR/046/3268). A written consent from dog owner’s for participation in the study was obtained.

**Results**

**Dog ownership and demography**

A total of 1213 households consented to participate in the study and were recruited into the study between February and April 2017.
The study households had a median and mean of 5 household members (range 1 – 18). From the households recruited, 460 (38%) owned dogs. For the households without dogs at the time of setting up the study, 526 (70%) reported owning dogs previously. The reasons reported for the loss of their dogs included death due to disease (63%), disappearance (11%) or being killed (19%). The remaining proportion (7%) could not recall what happened to their dogs. For the households that had never owned dogs previously, 44% reported disliking dogs, 23% reported that dogs were expensive to maintain, while the rest did not provide any specific reason. Table 2 provides a summary of dog ownership and management practices.

In total, 802 dogs were recruited into the study. More than half (52%) of the recruited dogs with known ages were ≤1 year. Dog owners did not know the age of 16% of the dogs recruited. The female dog: male dog ratio was 1:1.3. Using the number of household members and number of dogs in the study, we estimated the dog: human ratio at 1:7. The dog density for Siaya County was estimated at 54 dog/km² (range 50–57 dog/km²) using the dog to human ratio and average number of dogs per household. The predominant breed of dogs (99% of the dogs) kept was the local breed. Nearly all households (97%) reported keeping dogs primarily for security reasons, with only a few households’ keepings dogs as pets or for hunting.

Sources of dogs
Most dogs in surveyed households were acquired as gifts (71%) when they were puppies while 21% were born from dogs already owned by the household. The remaining 8% were either bought from elsewhere or owners could not clearly recall their origin. Most of the dogs not born within households were acquired within a radius distance of 5 km (87%); 97% of the dogs were from within a 10km radius, and only 3% of dogs were obtained from beyond a 10km radius.

Dog handling management practices
The majority (35%) of the study dogs were mainly taken care of by women, 31% by men, and 11% by children; with only 9% of the dogs were provided with kennels. Most dogs (97%) were fed on leftovers from family food waste and garbage pits. Scavenging for food from garbage dumping sites was common, with 27% of the respondents witnessing it with their own dogs, 44% with neighbors’ dogs and 29% with unknown dogs.

The majority (61%) of the dogs were allowed to roam freely, 38% had their movement partially restricted while 1% of the dogs had their movement strictly confined within the household all the time. Partial restriction of movement was done mainly during the day only. Only 12 (3%) of the surveyed households had secure fences around their homesteads that could restrict dog movement, whereas 55% and 42% had no fence at all or a partial fence, respectively.

Rabies vaccination and population control
Only 37 (5%) of the study dogs had been vaccinated against rabies at the time of recruitment into the study. Breeding control practices were rare with only 48 (12%) of the 395 male dogs and 13 (5%) of the 291 bitches castrated and spayed, respectively.

Reproduction indices
At recruitment, we obtained information on the one-year reproductive history of female dogs recruited into the study. Out of the 201 female dogs above 8 months at recruitment, 92 (46%)
had whelped in the year preceding the recruitment visit. The mean whelping per year was 1.4 and the average litter size in the last whelping was 4.8 (range 1–12) puppies per bitch.

**Discussion**

Here we present the design of a dog health and demographic surveillance study established within an existing human health and demographic surveillance study (HDSS), and using baseline data from the dog-HDSS we quantify key demographic parameters and management practices that underlie rabies transmission in rural western Kenya.

Neglected zoonotic diseases such as rabies are responsible for a significant burden of infectious diseases in Africa and Asia. For most of these diseases, good epidemiological data are scant resulting in gross underestimation of disease burden and low

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog owning HH</td>
<td>460 (38%)</td>
</tr>
<tr>
<td>Non-dog owning HH</td>
<td>753 (62%)</td>
</tr>
<tr>
<td>Dogs/HH</td>
<td>0.7 (range: 0.6–0.7)</td>
</tr>
<tr>
<td>Dogs/Dog-owning HH</td>
<td>1.8 (range: 1.7–1.9)</td>
</tr>
<tr>
<td>Total number of dogs owned</td>
<td>802</td>
</tr>
<tr>
<td>Dog density</td>
<td>54 (range 50–57) dogs/km²</td>
</tr>
<tr>
<td>Average number of people/HH</td>
<td>5 (range: 1–18)</td>
</tr>
<tr>
<td>Male: female dogs</td>
<td>1.3:1</td>
</tr>
</tbody>
</table>

**Dog ages**

<table>
<thead>
<tr>
<th>Ages</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>110 (16%)</td>
</tr>
<tr>
<td>Ages &lt;1 year</td>
<td>360 (52%)</td>
</tr>
<tr>
<td>Ages &gt;1 year</td>
<td>332 (48%)</td>
</tr>
</tbody>
</table>

**Non-dog owning households that owned dogs previously (n= 526)**

<table>
<thead>
<tr>
<th>Reason for not owning dogs</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Died from disease</td>
<td>63%</td>
</tr>
<tr>
<td>Lost</td>
<td>11%</td>
</tr>
<tr>
<td>Killed</td>
<td>19%</td>
</tr>
<tr>
<td>Unknown</td>
<td>7%</td>
</tr>
</tbody>
</table>

**Non-dog owning households that have never owned dogs (n=227)**

<table>
<thead>
<tr>
<th>Reason for not owning dogs</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t like dogs</td>
<td>44%</td>
</tr>
<tr>
<td>Dogs are expensive to maintain</td>
<td>23%</td>
</tr>
<tr>
<td>No specific reason</td>
<td>33%</td>
</tr>
</tbody>
</table>

**Dogs confined (n=733)**

<table>
<thead>
<tr>
<th>Type of confinement</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No confinement (free roaming)</td>
<td>61%</td>
</tr>
<tr>
<td>Partial confinement (see time of confinement, below)</td>
<td>38%</td>
</tr>
<tr>
<td>Complete confinement</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Partial confinement (n= 281)**

<table>
<thead>
<tr>
<th>Time of confinement</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime only</td>
<td>55%</td>
</tr>
<tr>
<td>Occasionally</td>
<td>44%</td>
</tr>
<tr>
<td>Nighttime only</td>
<td>1%</td>
</tr>
</tbody>
</table>

HH, household.
The prioritization of their control\cite{12,13}. The lack of reliable population-based health data has led to the establishment of HDSS across low and middle-income countries in Africa and Asia to collect longitudinal epidemiological data within defined populations\cite{14}. These HDSS provide opportunities to not only understand disease in humans but can be extended to include health and demographic data on animals living in close proximity to humans in these HDSS populations.

The design of the dog-HDSS utilized the social units (households) established under the KEMRI HDSS in western Kenya. Working within the HDSS makes it easy to identify households to recruit and to conduct follow-up visits, taking advantage of existing community engagement on surveillance. The International Network for the Demographic Evaluation of Populations and their Health (INDEPTH) Network lists 36 HDSSs in Africa\cite{14}. These provide opportunities to improve epidemiological data on linkages between human and animal health, and establish health and demographic surveillance systems for animals that collect vital events including births, deaths (by age and sex), illness, and causes of death\cite{10,15}.

Reported dog demographics from this study show a dog population with high turnover (half the dog population is under 1 year old). High turnover rates result in rapid declines in herd immunity between vaccination intervals and is the reason for requiring high annual vaccination coverage reaching 70%, even though the basic reproductive number for rabies ($R_0$) is consistently < 2 across settings with varying dog population densities\cite{5}. Interventions that reduce the rate of dog population turnover (reducing fecundity, improving life expectancy) could slow the decline in vaccination coverage between rabies campaigns and increase the probability of rabies elimination\cite{16}.

Our study reports minimal dog population control (castration of male and neutering of female dogs). There is however little empirical evidence that such population control interventions play a significant role or are cost-effective in reducing dog rabies incidence and subsequent transmission to humans\cite{17}. Indicators of responsible dog ownership in this population including sheltering dogs in kennels, provision of feed to dogs to reduce scavenging, and controlled dog movement to reduce roaming are poor, and similar to those reported elsewhere\cite{16,19}. These characteristics facilitate disease spread and pose a public health challenge as free roaming dogs may increase the likelihood of dog bites to humans, and of accidents on the roads and the potential spread of diseases that are zoonotic\cite{19}.

In the absence of rabies vaccination campaigns, our study reported only a small proportion (5%) of dogs had a history of rabies vaccination. A large population of unvaccinated dogs supports endemic circulation of rabies. Although the majority of the dogs are free roaming, they were owned and are likely to be available for vaccination when campaigns are organized. A review of publications on dog parenteral vaccinations in Africa has reported similar results on dog ownership and accessibility for vaccination\cite{20}. Importantly, the review reported significantly higher vaccination coverage under free-of-charge vaccination schemes compared to vaccination schemes where dog owners paid vaccination costs, indicating vaccination costs may be a more important determinant to vaccination coverage than accessibility of free roaming dogs.

Security was the main reason for dog keeping, and the male dominated sex ratio is in agreement with findings from other studies in Kenya and across the continent\cite{18,20,21}. This may be attributed to several factors including the perception that male dogs make good hunters and guard dogs compared to female dogs, and the stress on female dogs associated with reproduction increasing their mortality rates.

Most of the demographic and ecological studies conducted in Africa are cross-sectional, making it difficult to estimate demographic parameters such as birth rates, death rates and causes of deaths which inform dog population turnover. Our dog-HDSS provides an ideal opportunity to determine health and demographic parameters of a dog population in a rural setting over time. Establishing survival and mortality rates and the associated risk factors related to rabies in such a setting will allow estimation of their impact on rabies control and elimination strategies. The demographic and ecological estimates from such studies are important in parameterizing models to estimate the rabies burden, and to examine rabies dynamics and test the impact of alternative intervention strategies on rabies spread and time to elimination\cite{1,5,22,23}.

To meet the 2030 global target for the elimination of dog-mediated human rabies, epidemiological data on the population dynamics of dogs, incidence of rabies, and impact of rabies intervention strategies are urgently required. Embedding these kinds of studies on existing platforms such as HDSS across rabies endemic regions presents opportunities to improve data availability to answer policy questions and inform the design of effective and sustainable rabies control programs. Parameters such as dog to human ratios are critical to estimating dog population sizes, determining vaccine needs, and estimating post-vaccination coverage. Ultimately, reviewing progress and confirming elimination of human rabies requires surveillance systems that extend beyond health facilities to local communities. Integrated human and animal health and demographic surveillance systems are unexploited opportunities for addressing disease burden associated with rabies and other neglected zoonotic diseases.

**Data availability**

**Underlying data**

OSF: Dog Health and Demographic Surveillance Study (dog-HDSS) in Western Kenya, [https://doi.org/10.17605/OSF.IO/BZ78A]\cite{23}.

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).
Grant information

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This work was supported by the Wellcome Trust [110330/Z/15/Z to SMT, 207569/Z/17/Z to KH]. Funding support for the linked human-animal health surveillance platform in Western Kenya on which the dog-cohort study was conducted was through the Paul G Allen School for Global Animal Health, Washington State University.

Acknowledgements

We thank the dog cohort community interviewers, the veterinary team comprising of veterinarians and animal health technicians and the entire staff at IAHP for actively helping in data collection. Special thanks to James Oigo, Joseph Onyango and Judith Oduol for coordinating the fieldwork. This manuscript is published with the approval of the Director of KEMRI. The findings and conclusions are those of the authors and do not represent the views of the Center for Global Health Research, Kenya Medical Institute of Research.

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