Methodologies for Dog Population Estimation

Version 1, March 2026

United Against Rabies

1.0. Using this document

Dog population estimation is an important component of planning and implementing mass dog vaccination campaigns for rabies control. Accurate estimates help to determine resource needs, optimise vaccination strategies, and evaluate campaign effectiveness.

Vaccination planners may rely on census data from livestock departments; however, these data tend to be incomplete due to underreporting by owners and limited access to households in urban and semi-urban areas. This document outlines alternative methodologies for estimating dog populations, and provides guidance on their implementation, suitability, and associated advantages and disadvantages.

However, **a lack of precise dog population estimates should not delay the initiation of mass dog vaccination campaigns**. Vaccination campaigns are essential for controlling rabies and should be prioritised even when comprehensive population data are unavailable.

Using published human-to-dog ratios (HDRs) provides a simple and accessible baseline estimate to support initial vaccination planning. The section on this methodology also describes the repository of ratios and estimates available through the United Against Rabies (UAR) website. The alternative methodologies described in this document require additional data collection but are justified where greater precision is needed. The most appropriate methodology will depend on data collection capacity across the area of interest, analytical capacity, the ownership status of the local free-roaming dogs, and the level of precision required. A summary of the methodologies covered is provided in the summary table.

Dog population estimates are most useful when they also provide information on dog demographics relevant to vaccination planning. Factors such as ownership status and roaming behaviour influence the choice of vaccination delivery strategy (e.g. central point, door-to-door, or capture-vaccinate-release) and whether parenteral or oral rabies vaccines should be used.

Dog population turnover, including the birth of rabies susceptible puppies and the death or removal of vaccinated dogs, reduces vaccination coverage over time. These demographic processes can be mitigated through humane dog population management. Whether or not dog population management is in place, vaccination coverage and campaign frequency must be sufficient to sustain herd immunity despite turnover. Annual vaccination campaigns reaching at least 70% coverage of the susceptible dog population are recommended. Susceptible dogs are those at risk of infection from other dogs, particularly free-roaming dogs. The methods described in this document provide limited information on demographic processes; detailed assessment of the population dynamics requires longitudinal studies, which is beyond the minimum data requirements for vaccination planning.

This guide will be updated regularly by members of the UAR Forum. Users are encouraged to provide feedback and suggest additional resources or evidence to support the methodologies described.

Several tools referenced in this document are provided as examples only and do not represent endorsement by WOAH or the UAR Forum. Users are encouraged to consult the UAR Toolbox for a list of tools.

The UAR Forum is a community of rabies experts available to provide technical assistance in estimating dog populations. For more information, please contact globalrabiescoordinator@woah.org

Acknowledgements:

- Aniruddha V. Belsare, Auburn University College of Forestry, Wildlife & Environment
- Elly Hiby, International Companion Animal Management coalition (ICAM)
- Tamara Kartal, Four Paws
- Karma Rinzin, World Organisation for Animal Health (WOAH)
- Maganga Sambo, Ifakara Health Institute
- Ricardo Castillo Neyra, University of Pennsylvania
- Ryan Wallace, United States Centers for Disease Control and Prevention

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2.0. Summary Table of Methodologies

The following summary table indicates the methods that are covered in detail in chapter 4.

Methodology	When to Choose	Resource intensity	Advantages	Disadvantages
Using Published Human-to-Dog Ratios (HDRs)	Initial estimates are sufficient, with planned refinement using with post-vaccination surveys. Reliable human census data are available.	Low	Quick and inexpensive.	Dependent on the availability and quality of previous research in similar settings. Likely to be inaccurate in countries with high variability in dog ownership.
Household Surveys	The majority of free-roaming dogs are owned dogs that roam without supervision. Reliable human census data available.	Medium	Provides direct data on owned dogs and allows collection of additional information (e.g. vaccination status, confinement).	Excludes unowned dogs; insufficient in settings where community or unowned dogs are common. Resource-intensive.
Direct Street Counts	Areas with large numbers of free-roaming dogs, including unowned/community-owned and owned roaming dogs.	Medium	Simple and cost-effective.	Underestimates population if not corrected for detection probability.
Capture-Mark-Recapture	A precise estimate of the abundance of free-roaming dogs is required. To estimate detection probability to correct estimates from direct street counts.	High	Produces precise estimates. Depending on method of marking this can be non-invasive with minimal handling required.	Most resource intensive method presented; typically applied only in small areas. Requires expertise in capture-mark-release.
Post Vaccination Survey (Mark-Resight)	Following vaccination campaigns with systematic data collection on vaccinated and marked dogs (owned and unowned), including confinement status and location.	Low-Medium	Simple and cost-effective.	Typically underestimates dog population size. Results are sensitive to loss of vaccination marks and to the vaccination strategy used.

3.0. Study design for dog population estimates

Dogs of Interest

To choose the right method—or combination of methods—it is important to think carefully about which dogs are being targeted. Free-roaming dogs are the most epidemiologically relevant for rabies, because they have the greatest contact rate with other dogs, placing them at highest risk of rabies transmission. They are therefore the primary targets for vaccination campaigns. Free-roaming dogs are defined as any owned or unowned dogs that is without direct human supervision or control (WOAH Terrestrial Code). This implies that methods focusing on estimating the size of the free-roaming dog population (direct counts and mark-resight methods) are most valuable for vaccination planning.

However, many free-roaming dogs are owned dogs that are allowed to roam, and accessing dogs via their owners is often the most cost-efficient route for vaccine delivery. In countries where most free-roaming dogs are owned, and the proportion of truly unowned dogs is very low, a household survey alone may be sufficient to estimate the number of owned dogs that roam and therefore provide a sufficiently close estimate of the total free-roaming dog population. Note that the proportion of truly unowned free-roaming dogs is commonly overestimated. In settings where unowned free-roaming dogs are more common, or where studies characterising free-roaming dog populations have not yet been conducted, a combination of free-roaming dog-focused methods and household surveys is likely to be more appropriate.

Area of interest

An "area of interest" is the geographic region where the dog population is to be estimated. For large areas of interest (such as a city, state or country) an estimation method can be applied to a sample of locations with results extrapolated to the entire area of interest.

To define an area of interest and identify potential survey samples within that area, existing administrative boundaries (such as districts or wards) are often useful. These are particularly useful when they provide available human population data that can be used for extrapolation, such as human density, land use, or housing types. Such boundaries may be obtained as shapefiles or KML files from government GIS departments or online sources, such as the Humanitarian Data Exchange. If such files are unavailable, Google My Maps can be used to draw known administrative boundaries (for example, where only printed versions are available) or to create and export custom boundaries based on landmarks or natural features. An example of how to prepare these boundaries is available online (https://youtu.be/gokcOOQo-yE).

Selecting your survey sample

The survey sample should be representative of the area of interest. For example, if the area of interest is a city, the sample should not be drawn exclusively from the city centre, as this would not represent dog population size in suburban areas. Two commonly used sampling approaches are described below.

Simple random sampling gives all areas an equal chance of being selected. Two methods for selecting a random sample include:

- Assigning a number to each area and using a random number generator to select the sample. In Microsoft Excel, the function 'RANDBETWEEN' generates a random integer between two specified numbers that are provided (lower_limit, upper_limit), and this can be run repeatedly until the required number of areas is selected.

- The ‘checkerboard method’, which both randomises and evenly spaces the sample. All areas within the wider area of interest are coloured using four colours, based on the four-colour theorem, which states that no two adjacent areas share the same colour. One colour is then selected at random, and the areas assigned that colour form the sample (see Annex A for further details).

Stratified random sampling first divides areas into types, or strata, that are expected to differ in dog population and then takes a random sample from within each stratum. This avoids bias that may arise from simple random sampling. When extrapolating estimates using a human-to-dog ratio (HDR), stratifying areas by human density (e.g. high, medium, and low) may be helpful.

For large areas of interest, such as states or countries, multi-stage cluster sampling may be appropriate. This involves first selecting a random or stratified sample of large administrative units (e.g. districts), then selecting sub-districts within those units, followed by towns, villages, and rural areas from within the subdistricts. Repeating these stages produces survey areas of manageable size that remain representative of the wider area of interest.

Sample size

A common question is: what sample size is required? Sample size depends partly on how variable dog populations are between areas. Where dog density varies greatly between locations, a higher proportion of areas will need to be sampled to achieve an accurate estimate. As a general guideline, aim for a sample representing approximately 10-20% of areas.

In general, larger samples yield more accurate and precise estimates and narrower confidence intervals. The number of dogs surveyed across the sample will vary, and this variation can be used to calculate a confidence interval around the final estimate. It is important that confidence intervals are presented alongside population estimates to clearly indicate their level of precision.

Sample size needs to be feasible and realistic given available resources. Initial population estimates can be refined following vaccination campaigns using post-vaccination surveys.

For a more in-depth discussion of sampling, refer to ‘Introduction to Sampling’ by DC Cat Counts. Although written for cat population estimation, the underlying sampling principles are directly applicable to dog population estimation.

Extrapolation

A census involves surveying all households or streets within an area of interest, producing a direct total estimate of the population. This approach requires significant survey capacity or a small area of interest. In most cases, only a sample of areas will be surveyed, producing a count of dogs in that sample. The number of dogs in the remaining unsurveyed areas is then estimated through extrapolation, which, when combined with the sample count, leads to the total population estimate.

The method used for extrapolation depends on the survey approach and may be based on human population size, number of households, or total street length. When planning sampling and extrapolation, it is often useful to use administrative areas for which corresponding human population, household, or street length data are available.

Because survey data form the basis for extrapolation, it is important to avoid introducing bias. Selecting a sample with unusually high or low dog numbers and extrapolating without recognising this bias will amplify error at the population level. To minimise this risk, characteristics that influence dog distribution (such as human density, religion, or urban-rural classification) should be considered during sampling. Stratified random sampling and analysis of relationships between these characteristics and dog numbers can help ensure more reliable extrapolation.

4.0. Detailed Methodologies

Using Published Human-to-Dog Ratios (HDR)

When to use

- Resource-limited settings where observational surveys are impractical.
- To establish an initial estimate before conducting more detailed studies, including refinement of estimates using post-vaccination surveys.
- When published results are available for community-types representative of the area of interest.

Description

Using already published HDR estimates is the simplest method described in this document.

Dogs are reliant on resources provided by people; therefore, the number of people living in an area is a reliable predictor of the number of dogs likely to live there.

However, HDRs are influenced by several factors, including human density and cultural practices related to dog ownership:

In high-density urban areas, particularly where people live in high-rise accommodation, space available for dogs is more limited; therefore there are typically fewer dogs per person than the average HDR for the country would predict. In low density rural areas, where more habitat is available, there may be more dogs per person than national or regional averages would predict.

Levels of dog ownership also vary between cultures. In many Muslim-majority societies, rates of dog ownership tend to be much lower. Dog confinement practices also vary between cultures and are in part influenced by local housing infrastructure. Where fenced yards are uncommon, dogs usually live unconfined and are therefore of relevance to rabies vaccination campaigns.

A repository of human-to-free-roaming-dog ratios and country-wide free-roaming dog estimates is available for download from the United Against Rabies website. This repository includes a worksheet for each region listing countries. For each country estimated ratios are provided for three levels of human density (urban, peri-urban, and rural) and, where relevant, for majority Muslim or non-Muslim areas. These estimates are derived from published data where available or extrapolated from countries within the same region where local data are lacking.

How to conduct

Materials needed:

Human census data; basic statistical software (Microsoft Excel is sufficient); results of local studies or studies in neighbouring countries that provide HDRs; or data from the repository on the UAR Forum website.

Procedure:

1. Obtain human population census data.

2. Create a list of administrative areas with total population figures and urban–rural classification. Where relevant and known, also classify areas as majority Muslim or non-Muslim. If local studies identified additional predictors of HDRs, categorise areas accordingly.

3. Apply published HDRs, adjusting for local context where possible.

4. Divide the human population estimate by the HDR.

For example, applying a 12:1 HDR to a town with 30,000 people results in:

30,000 ÷ 12 = 2,500 dogs.

Other Considerations

Total dog, confined dog, and free-roaming dog ratios may be available in repositories or studies; ensure the correct ratio is applied.

Where available, include standard deviations in calculations to show the likely range of the dog population. These figures remain estimates rather than definitive counts.

If estimating the total dog population using a human-to-free-roaming-dog ratio from the repository, the following formula can be used:

Total dog population = Free-roaming dog population ÷ (1 – % of all dogs confined).

Worked example

Dog population estimates were calculated for three example communities in Guatemala. Human-to-free-roaming-dog-ratios were taken from the repository on the UAR Forum website, which references Moran et al, (2022) as the data source for Guatemala. The estimate of free-roaming dogs includes owned unconfined dogs, community dogs, and unowned dogs, but excludes owned confined dogs. The final two columns include the percentage of owned confined dogs and the resulting total dog population, including owned confined dogs.

Name	Urban-rural classification	Human population from 2018 census	Human-to-free-roaming dog ratio	Estimated free-roaming dogs	Estimated Percent Confined	Total Dog Population
Petatan	Urban	10,850	13	835	23%	1084
Rosario Patulul	Peri-urban	900	8	113	37%	179
Churirin	Rural	623	3	208	14%	241

Household Surveys

When to use

When there is high confidence that the vast majority of free-roaming dogs are owned dogs that roam without supervision.

As defined earlier, free-roaming dogs encompass both unowned and owned dogs that are without direct control human supervision or control (WOAH Terrestrial Code). Rabies virus transmission occurs between free-roaming dogs regardless of ownership status.

Description

A household survey involves visiting (in person or remotely by phone or online) within a selected sample and asking residents how many people live in the household, whether they own dogs, and, if so, how many. The results can be used to determine the human-to-owned-dog ratio within the sample, from which the owned dog population estimate can be extrapolated using the total human population. Alternatively, the survey can estimate the proportion of dog-owning households and the mean number of dogs per dog-owning household for extrapolation. The most appropriate approach depends on the type of human population data available (number of people or number of households).

When residents are also asked about dog confinement and vaccination status, the estimate can be refined to include the number of owned free-roaming dogs, confined owned dogs, and unvaccinated dogs.

How to conduct

Materials needed:

A structured questionnaire; statistical tools to estimate sample size; smartphones for recording responses; data collection platforms; and household data from the government statistics.

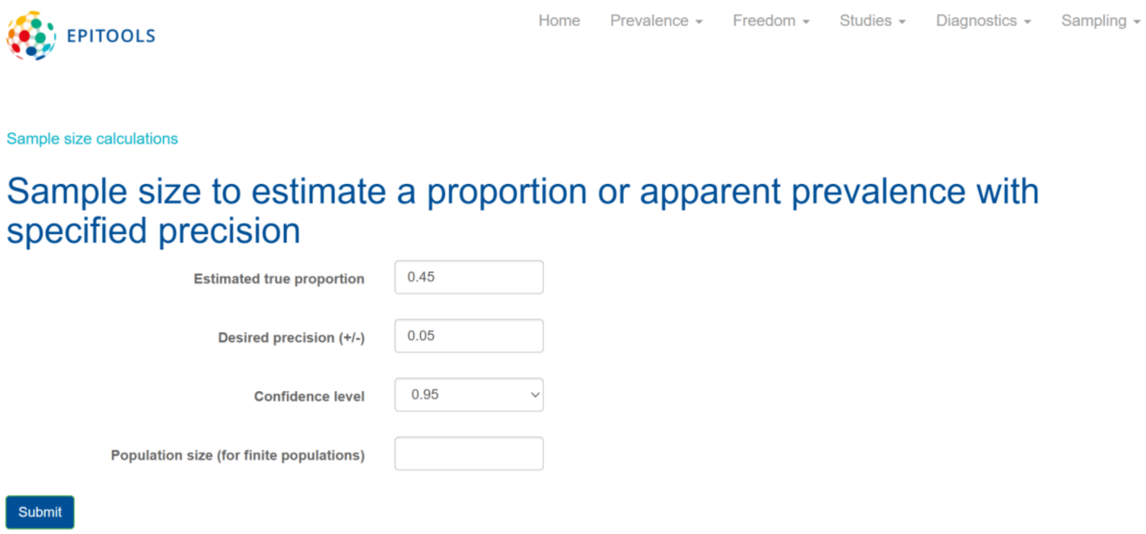
Number of households to be surveyed:

To ensure estimates are sufficiently precise, an appropriate sample size (i.e. the number of households to be surveyed) should be determined using statistical methods. Statistical tools such as EPITOOLS, developed by AUSVET, are freely available online and can be used for this purpose.

Worked example

Worked example of calculating sample size for a household survey:

A household survey is planned for a particular region to estimate the proportion of dog-owning households with 5% precision and a 95% confidence interval in both urban and rural areas. It is assumed that rural households are more likely to own dogs than urban households (60% and 45%, respectively). These assumptions and the desired precision and confidence level are entered into EPITOOLS resulting in a recommended sample size of 381 urban households and 396 rural households.



https://epitools.ausvet.com.au/oneproportion: Screenshot that shows the parameters for urban areas.

Selection of a representative sample of households

As outlined in the section on study design, stratified random sampling and multi-stage cluster sampling may be useful when selecting a sample of households for a questionnaire.

Because rates of dog ownership may vary significantly between rural and urban settings, it is recommended that households across the urban-rural classification are included in the sample to ensure representation of the wider area of interest. This may be achieved through a multi-stage cluster sampling approach:

1. Stratify areas based on urban or rural classification (additional strata, such as peri-urban, may also be included).
2. Randomly select areas within each stratum.
3. Randomly select villages or blocks within selected areas.
4. Randomly select households within selected villages or blocks.

Random selection of households in the field may follow a 'skip pattern', starting at a central point and proceeding along a randomly selected street, interviewing every *n*th household until the required number is reached. If a household declines participation or no one is home, the neighbouring household is selected until a questionnaire is completed, after which the skip pattern resumes.

Clear procedures should be established for selecting households within multi-unit dwellings (e.g. apartments), such as randomly selecting an entrance, floor, and apartment.

Providing interviewers with physical dice or random number generator applications may assist in maintaining random selection procedures.

This multi-stage approach helps ensure the sample is representative and improves the reliability of population estimates.

Survey questionnaire

The questionnaire should collect information on:

- Number of people living in the household
- Whether dogs are owned and, if so, how many
- Vaccination status of each dog
- Confinement status of each dog

If a dog is unvaccinated, follow-up questions should explore barriers to vaccination. These insights will inform both the number of vaccine doses required and the most effective strategy for vaccine delivery.

Additional information such as age, sex, and neuter status may assist in understanding population dynamics. Households may also be asked whether dogs have died or been acquired in the past year. This can help estimate dog population turnover, which is relevant to determining frequency of vaccination campaigns to maintain herd immunity.

The questionnaire must begin with a consent statement explaining:

- Who is conducting the survey
- How the data will be used and shared
- Whether the data are identifiable (if so, data protection should be considered)
- That participation is voluntary
- Interviewer's contact details for follow-up

A sample survey questionnaire is provided in Annex B.

Once finalised, the questionnaire can be built into a data collection platform that enumerators access via an app on their mobile devices for household-level data collection. The Epicollect5 and Kobotoolbox platforms are good and easy-to-use tools for managing and collecting data on mobile phone or tablets.

Conduct household (door-to-door) survey:

Survey enumerators should be trained in the questionnaire, sampling procedures, and data collection tools before the survey begins.

Trained enumerators visit selected households, record non-responders, and collect responses using the mobile app data collection platform. Where feasible, confinement status may also be observed directly.

Calculating the estimate

Variables measured may include:

- Number of people in per household
- Human-to-owned-dog ratio
- Proportion of dog-owning households
- Mean number of dogs per dog-owning household

- Proportion of owned dogs that roam
- Proportion of owned dogs vaccinated or unvaccinated
- List of reported barriers to vaccination

Extrapolation to owned dog population estimate

In the section on study design, data on the human population are described as a basis for extrapolating from a survey sample to the wider area of interest.

A household survey can provide a human-to-owned-dog ratio, which can be extrapolated using the total human population of the area of interest.

Alternatively, a household survey can estimate the proportion of dog-owning households and the mean number of dogs owned per dog-owning household. Extrapolation to the total owned dog population size is then calculated by multiplying the proportion of dog-owning households by the total number of households to estimate the number of dog-owning households and then multiplying this number by the mean number of owned dogs per household.

The choice of whether to use the HDR or the proportion of dog-owning households and mean dogs per household depends on the available human population data and its accuracy, including how recently it was collected.

Worked examples

Estimation of owned dog population size in a Balinese city
(based on the proportion of dog-owning households and mean number of dogs owned per dog-owning household)

Total number of households surveyed = 1,624 households

Proportion of household owning dogs = 52.7% (854 out of 1,624 households)

Total number of households in Bali in 2023 = 1,144,307 households

Total dog-owning households = 603,050 households (1,144,307 x 0.527)

Average number of dogs per dog-owning household = 1.84

Total owned dogs in Bali = 1,109,612 dogs (603,050 x 1.84)

Proportion of owned dogs not confined/ free-roaming = 19.2%

Roaming owned dogs = 1,109,612 x 0.192 = 213,046 dogs

Estimation of owned dog population size in Bhutan
(based on the human-to-owned-dog ratio)

A total of 1,301 respondents (585 rural and 716 urban) were interviewed, of whom 173 households (24.4%) in urban areas owned 237 dogs, and 238 households (40.8%) in rural areas owned 353 dogs.

Total number of people in surveyed households = 3,865 (urban) and 2,976 (rural)

Total number of dogs in surveyed households = 237 (urban) and 353 (rural)

HDR = 16.31 humans per dog in urban areas and 8.43 humans per dog in rural areas

Human population in the 2012 Census = 254,663 (urban) and 466,017 (rural)

Estimated owned dog population size =
15,663 (254,663 ÷ 16.31) in urban areas
55,281 (466,017 ÷ 8.43) in rural areas

Total owned dog population = 70,944 dogs.

Source: Rinzin *et al* (2016) https://doi.org/10.1016/j.prevetmed.2016.01.030

The household survey can also incorporate principles of mark-resight methodology to estimate the owned dog population size. This involves marking a sample of dogs during an intervention such as rabies vaccination (using collars or temporary non-toxic paint). In the subsequent household survey, the proportion of marked to unmarked dogs observed can be used to infer the total dog population. This approach is further detailed under Capture-Mark-Recapture (using temporary marks).

Recommended tools

Tools for estimating sample size:

EPITOOLS is a suite of epidemiological calculators developed and maintained by AUSVET, including a sample size calculation tool.

There are also sample size calculators developed and maintained by the University of Melbourne.

Tools for data gathering:

Epicollect5 (https://five.epicollect.net/) — A platform owned and maintained by the Centre for Genomic Pathogen Surveillance (CGPS), based at the Big Data Institute, University of Oxford, United Kingdom.

Kobo Toolbox (https://www.kobotoolbox.org/) —A data collection, management, and visualisation platform used globally for research and humanitarian purposes.

Examples from published studies

- Ortega-Pacheco, A., Rodriguez-Buenfil, J. C., Bolio-Gonzalez, M. E., Sauri-Arceo, C. H., Jimenez-Coello, M., & Forsberg, C. L. (2007). A survey of dog populations in urban and rural areas of Yucatan, Mexico. *Anthrozoos,* 20(3), 261-274. http://dx.doi.org/10.2752/089279307X224809

  Estimated the owned dog population size in urban and rural areas of Yucatan, Mexico by multiplying the mean number of dogs per household by the total number of households, using telephone surveys in urban areas and door-to-door surveys in rural areas.

- Dizon, T. J. R., Saito, N., Inobaya, M., Tan, A., Reñosa, M. D. C., Bravo, T. A., Endoma, V., Silvestre, C., Salunga, M. A. O., Lacanilao, P. M. T., Guevarra, J. R., Kamiya, Y., Lagayan, M. G. O., Kimitsuki, K., Nishizono, A., & Quiambao, B. P. (2022). Household survey on owned dog population and rabies knowledge in selected municipalities in Bulacan, Philippines: A cross-sectional study. *PLoS Neglected Tropical Diseases*, 16(1), e0009948. https://doi.org/10.1371/journal.pntd.0009948

  Estimated the owned dog population size in Bulacan Province, Philippines using a human-to-dog ratio (HDR) derived from household survey data and human population estimates from the 2015 census.

- Flockhart, D. T. T., Rowan, A. N., & Boone, J. D. (2022). Owned dog population size and ownership patterns in Costa Rica. *Frontiers in Veterinary Science*, 9. https://doi.org/10.3389/fvets.2022.946603

  Estimated the owned dog population size in Costa Rica using survey questionnaires to determine the proportion of dog-owning households and the mean number of dogs per household.

- Rinzin, K., Tenzin, T., & Robertson, I. D. (2016). Size and demography pattern of the domestic dog population in Bhutan: Implications for dog population management and disease control. *Preventive Veterinary Medicine*, 126, 39–47. https://doi.org/10.1016/j.prevetmed.2016.01.030

  Estimated the owned dog population size in Bhutan using both the mean number of dogs per household and a HDR derived from door-to-door household surveys and national census data.

Direct Street Counts

When to use

- A significant proportion of free-roaming dogs are unowned or community owned and would not be captured through household surveys.
- Many owned dogs are unconfined in populated areas (e.g. around houses, slaughterhouses or waste disposal sites).
- Dogs are visible on streets at one or more times during the day.
- The area of interest is too large for full coverage using Capture-Mark-Recapture (CMR) methods.
- An approximate estimate of the free-roaming dog population is acceptable and may later be refined using post-vaccination surveys.
- Resource constraints require a lower-cost method compared with household surveys or mark-resight approaches.
- The objective is to monitor population-level indicators rather than generate a highly precise population estimate (for more accurate estimates, use CMR methods).

Description

This is a low-cost direct observational survey suitable for urban, suburban, and rural reas. Sampling design may differ depending on setting and survey team size, but protocols and technological requirements remain similar.

Free-roaming dogs are commonly associated with streets, which provide space for movement, rest, and access to food resources. Both owned and unowned dogs rely on resources associated with human activity. Observational surveys counting dogs along all streets within selected sample areas, or along defined route samples, provide an estimate of dog density (dogs per kilometre), which can then be extrapolated to estimate total population size.

This method is accurate and inexpensive, though not necessarily precise. For initial rabies vaccination planning, it may be sufficient, with refinement through post-vaccination surveys.

Materials Needed

Recording animal sightings on paper can lead to data loss and increase the time commitment and capacity needed to collect, process and analyse data. To increase accuracy and accountability between surveys over time, mobile applications have proven to be vitally important. They record dogs in a standardized way, as well as record individual dogs' GPS locations and other details.

Mobile data collection apps tested and recommended for dog surveys are Talea street survey app or WVS data collection app. Both applications require a short training and require only a novice smartphone user expertise to be operated accurately. Both conform to GDPR regulations.

These mobile apps have a web-based application for set-up, design and management of survey teams, and a mobile app for data collection. The mobile apps can work offline during surveying, sending data once reconnected, with data stored in cloud-based databases. Once data is collected, it can be accessed and downloaded from the web-based management application, providing the data in excel, kml and other formats, which improve data analysis and the development of indicators of impact.

How to conduct

Direct observational surveys of free-roaming dogs are conducted along streets in a defined and demarcated sample of areas (sampling units: hotspot or routes). To generate total dog estimates, the survey follows either all streets or a pre-determined, unbiased kilometre of streets within the chosen sample of areas.

Hiby & Hiby (2017) propose that when monitoring changes in the dog population over time, direct count methodologies that provide indicators of abundance and welfare state are sufficient and meaningful to intervention managers and communities. These methods are simpler and quicker than those required for calculating a total estimate. However, establishing a total estimate may be necessary for planning an intervention. The procedure described in this section is designed to produce an estimate and can also be repeated over time to monitor changes using indicators.

Preparation:

Before conducting a street count, the area of interest must be defined (see section Survey Design). If this area is too large to survey in its entirety, a random or stratified sample of smaller areas will need to be selected within the wider area of interest. For example, a sample of wards within a city may be selected, either randomly or using stratification to ensure that different regions are represented.

Once the area is defined, surveys may be conducted along all streets within the selected sample area. However, exhaustive searches can be time consuming. An alternative approach is to use routes along a sample of streets within the sample areas. Routes can be drawn in Google My Maps and exported as KML files. If routes rather than all streets are surveyed, the selected routes must be unbiased with respect to known dog densities; and cover a variety of land-use and/or human density.

Dogs are not evenly distributed across an area; they tend to cluster. By covering a wide range of land-use, human density and other characteristics that may influence clustering, the selected streets are more likely to be representative, improving precision of the estimates. When designing routes, street types assumed to be either unsafe or free of dogs (e.g. highways) should be excluded.

Timing is critical. Surveys should be conducted during peak roaming hours—typically dawn and dusk. Test surveys throughout the day will provide insights. Surveys should avoid holidays, weekends, and extreme weather (including low and high temperatures). If monitoring over time, seasonal factors such as breeding periods should be considered, as they may affect dog visibility. In regions with distinct breeding seasons, biannual surveys are recommended: ideally one during and one outside the breeding season.

Questions and answer choices for each dog sighting must be set up in the selected mobile application. Talea and WVS apps provide pre-set datasheets for rabies and dog and cat management surveys. These allow rapid survey set-up with minimal technical expertise. Datasheets can also be altered where additional attributes (e.g. health conditions or collar colours applied during vaccination) are considered important.

Surveyors must be trained in using the chosen mobile data collection apps, dog classification (e.g. puppy vs adult; vaccinated vs unvaccinated; see table below), and safety protocols. Practice runs and inter-observer reliability checks are encouraged to ensure consistency. This applies to both one-time estimates and repeated monitoring. Where monitoring over time is the objective, additional emphasis should be placed on route consistency, seasonal timing, and inter-observer reliability, and other potential confounding variables that may influence dog counts.

Execution:

Surveys are typically conducted by teams of two surveyors: one person focuses on navigation (and driving, where applicable), while the other observes and records data. On foot, a team can cover 6–7 km per hour; by vehicle or bicycle, 10–15 km per hour. A 2–3-hour session therefore allows coverage of 10–30 km per team, depending on mode of transport. Surveys can be shorter depending on the route length and team capacity.

For each dog sighted, the minimum characteristics required for rabies projects are age (adult or puppy) and vaccination status (marked or unmarked). Additional characteristics relevant to dog population management include sex, reproductive status (e.g. lactating, sterilised), health indicators (e.g. body condition score; sick or healthy) and evidence of ownership (collar, bandana, etc). Recording should take no more than 10 seconds per dog. Examples are provided in the table below.

If the project scope includes welfare issues, welfare indicators should be recorded. Body condition scores (5-point scale) and visible skin disease have proven useful. These indicators are described in the ICAM guidance document "Are We Making a Difference?" and can support longer-term evaluation of dog population interventions beyond rabies control.

A proven and easy to implement survey protocol is described in Hiby & Hiby (2017). For repeated surveys, the same routes, timing, and data collection protocols should be followed to allow meaningful comparisons across survey events.

Calculating the estimate

Variables measured by the sample if using the minimum datasheet:

- Free-roaming dogs per km of street surveyed (if using routes)
- Free-roaming dogs per sample area (if counting all streets)
- Proportion of vaccinated (marked)/unvaccinated (unmarked) free-roaming dogs
- Proportion of puppies

Extrapolation to free-roaming dog estimate

When representative routes are used, the average number of dogs per kilometre of street can be extrapolated using total street length to estimate number of dogs visibly roaming on public streets at the time of the survey. This extrapolation may be applied to the entire area of interest, or the first to survey areas and then extended to the wider area using human-to-free-roaming-dog ratios.

Dogs are strongly associated with streets, which provide habitat for movement and rest, and access to food resources. Street length therefore serves as a proxy for available habitat. Because street density is highly variable (many streets per km^2 in urban areas and few in rural areas), extrapolation by area tends to be less reliable than extrapolation by street length.

Total street length may be obtained from government road or mapping departments, or from online sources such as ArcGIS or OpenStreetMap. These provide breakdowns of street and path types. Road classes such as "footway", "steps" or "service" should be excluded from calculations, as they run alongside other street types and may lead to double counting. Road classes excluded from routes because they are unsafe assumed to have zero free-roaming dogs (e.g. "motorway") should also be excluded.

This approach estimates the number of observable dogs and therefore underestimates the total population, as some dogs will not be detected. Estimates should therefore be corrected for imperfect detection. Detection probability is the likelihood that a free-roaming dogs present during a survey is observed and recorded. For example, a detection probability of 0.5 indicates that half of free-roaming dogs present are observed. Where possible, Capture, Mark, Recapture surveys should be used to estimate detection probability for the area of interest. If not possible, a suitable detection probability may be selected from the table provided in this chapter. Detection probability varies with habitat and human-dog interactions; therefore, values in the table should be regarded as suggested rather than accurate for every location type. If no comparable location is available, it is recommended to use a detection probability of 0.4.

Location type	Country	Detection Probability	Source
Sub-urban	Bulgaria	0.42	Kartal et.al. (in prep)
Rural	Bulgaria	0.41	Kartal et.al. (in prep)
Urban	Romania	0.39	Kartal et.al. (in prep)
Urban	Cambodia	0.43	Kartal et.al. (in prep)
Rural	Cambodia	0.43	Kartal et.al. (in prep)
Sub-urban	Moldova	0.48	Kartal et.al. (in prep)
Urban	Kosovo	0.58	Kartal et.al. (in prep)
Rural	Kosovo	0.37	Kartal et.al. (in prep)
Urban	Nepal	0.44	Hiby E. et al. (2016)
Urban	India	0.4	Hiby L. (2014) internal HSI report
Rural	Pune, India	0.33	Tiwari et.al. (2018)
Rural and sub-urban	Pescara, Italy	0.11-0.41	Smith et.al. (2022)
Urban	Lviv, Ukraine	0.07-0.16	Smith et.al. (2022)
Urban	Guatemala	0.19-0.87	Moran et al (2022)
Sub-urban	Guatemala	0.12	Moran et al (2022)
Urban	Zambia	0.07 - 0.59	Chazya et al (2025)
Urban	Haiti	0.03-0.78	Beron et. al. (pending)
Sub-urban	Haiti	0.09-0.59	Beron et. al. (pending)
Rural	Haiti	0.15-0.29	Beron et. al. (pending)

Worked example

Kathmandu mid-project evaluation for ManuMitra in Kathmandu following both street counts and household survey (Hiby et al., unpublished).

In March 2016, a mark-resight survey was conducted to estimate the detection probability of free-roaming dogs. Dogs were marked on Day 1 using non-toxic paint spray applied with an agricultural backpack sprayer, and resighting on Day 2). Detection probability was calculated at 44%. This means that during a morning street survey, approximately 44% of dogs roaming on that street at some point during the day are likely to be observed, and approximately 56% are likely to be missed.

This estimate of detection probability was combined with the number of dogs observed per kilometre of street surveyed (average dog density of 14.2 dogs per km, ranging from 8 to 27 dogs per km) and the total street length across eight zones (total street length of Kathmandu is 733 km). This resulted in an estimate of just under 22,000 free-roaming dogs.

Importantly, this estimate represents the total roaming dog population, comprising community dogs, unowned dogs, and owned dogs allowed to roam unsupervised by their owners. Owned roaming dogs may have lower detection probability because they spend part of the day within houses or yards.

Examples from published studies

- ICAM (2015). Are We Making a Difference? A Guide to Monitoring and Evaluation of Dog Population Management Interventions. https://www.icam-coalition.org/download/are-we-making-a-difference/

  Provides guidance on monitoring and evaluating dog population management interventions, including recommended indicators and practical methods such as direct street surveys.

- Hiby, E., & Hiby, L. (2017). Direct observation of dog density and composition during street counts as a resource efficient method of measuring variation in roaming dog populations over time and between locations. *Animals*, 7(8), 57. https://doi.org/10.3390/ani7080057

  Demonstrates the use of direct street counts to measure variation in free-roaming dog populations across locations and over time, highlighting the method’s efficiency and cost-effectiveness.

- Kartal, T., et al. (in preparation). Validation of mark–recapture frameworks across various dog population densities and dynamics.

  Comparing various Mark-Recapture methods and tools with empirical data to validate them for various dog population densities and population dynamic complexities across the globe.

- Tiwari, H. K., Vanak, A. T., O'Dea, M., Gogoi-Tiwari, J., & Robertson, I. D. (2018). A comparative study of enumeration techniques for free-roaming dogs in rural Baramati, District Pune, India. *Frontiers in Veterinary Science*, 5, 104. https://doi.org/10.3389/fvets.2018.00104

  Compares several methods for estimating free-roaming dog populations in rural India, evaluating their relative accuracy and precision.

- Hiby, E., Rungpatana, T., Izydorczyk, A., Rooney, C., Harfoot, M., & Christley, R. (2023). Impact assessment of free-roaming dog population management by CNVR in Greater Bangkok. *Animals*, 13, 1726. https://doi.org/10.3390/ani13111726

  Uses street dog counts to monitor and evaluate a large scale free-roaming dog sterilisation programme in Bangkok and compare counts over time.

- Moran, D., Alvarez, D., Cadena, L., Cleaton, J., Salyer, S. J., et al. (2022). Heterogeneity in dog population characteristics contributes to chronic under-vaccination against rabies in Guatemala. *PLoS Neglected Tropical Diseases*, 16(7), e0010522. https://doi.org/10.1371/journal.pntd.0010522

  Combines sight–resight surveys and household surveys in urban, semi-urban, and rural communities in Guatemala to estimate dog population size, HDRs, and detection probabilities.

- Smith, L. M., Goold, C., Quinnell, R. J., Munteanu, A. M., Hartmann, S., Dalla Villa, P., et al. (2022). Population dynamics of free-roaming dogs in two European regions and implications for population control. *PLoS ONE*, 17(9), e0266636. https://doi.org/10.1371/journal.pone.0266636

  Uses repeated street surveys and closed population mark–recapture methods to monitor changes in dog population density and turnover in Italy and Ukraine.

- Smith, L. M., Kartal, T., Rawat, S., Chaudhari, A., Kumar, A., Pandey, R. K., et al. (2025). Changes in free-roaming dog population demographics and health associated with a catch–neuter–vaccinate–release program in Jamshedpur, India. *PLoS ONE*, 20(10), e0317636. https://doi.org/10.1371/journal.pone.0317636

  Uses street surveys to monitor demographic and health changes in free-roaming dogs during a CNVR programme, highlighting the role of direct counts for monitoring programme impact.

Capture-Mark-Recapture Method

When to use

- Detection probability needs to be estimated to refine street survey estimates.
- A precise estimate of free-roaming dogs is required within a closed area (i.e. with no, or minimal, immigration and emigration)
- Sufficient resources and technical expertise are available to conduct and analyse Capture-Mark-Recapture surveys.

Description

A sample of dogs is marked (e.g., with collars, non-toxic paint, or by recording natural markings through photographs and descriptions), and subsequent surveys estimate the proportion of marked to unmarked dogs to infer total population size.

A major challenge in estimating the free-roaming dog populations is imperfect detection—many dogs present during surveys go undetected and are therefore missing from counts. Capture-Mark-Recapture (CMR), also referred to as Capture-Recapture, Mark-Recapture, or Mark-Release-Recapture, is a method that explicitly accounts for imperfect detection and has a long-standing history in wildlife and fisheries research.

CMR methods rely on uniquely marked individuals that can be identified across multiple sampling occasions. These generate capture (or encounter) histories for each individual recording whether they were detected (1) or not detected (0) on each occasion. These histories form the basis for estimating key population parameters. The primary observed statistic is the total number of individuals captured, while the key estimated parameter is detection probability—the likelihood that a free-roaming dog present during a survey is observed by surveyors.

By explicitly estimating detection probability through repeated sampling, CMR corrects for imperfect detection and provides robust, precise population size estimates, even when not all dogs are observed.

How to conduct

The basic CMR process involves four steps:

1. Capture a sample of animals from the population.
2. Mark each animal in a recognisable and durable way.
3. Release them back into their environment.
4. Conduct one or more recapture efforts to record the proportion of marked versus unmarked animals.

Important assumptions underlying the marking process are that capture, handling, and marking do not adversely affect survival, movement, or behaviour; that marks are accurately recorded without misidentification; and that marks remain intact and recognisable for the duration of the study.

Marking approaches vary depending on the analysis planned. Generic marks such as collars or paint can be used with Lincoln-Peterson, Chapman or Schnabel estimators, as individual identification is not required. This method is commonly used in post-vaccination surveys. Alternatively, photographic identification can be used to ‘capture’, ‘mark’ and ‘recapture’ dogs based on natural markings, without catching or handling. Photographic methods allow analysis using Beck’s method and Program Mark, but can also be used with Lincoln-Peterson, Chapman or Schnabel estimators, when only prior observation (‘marked’) status is required.

Calculating estimates using different analyses

Closed population CMR models, including the Lincoln-Petersen estimator, are widely applied to free-roaming dog populations. These methods assume demographic and geographic closure – no births, deaths, immigration, or emigration during the study period. Closed population CMR methods allow estimation of both population size and detection probability and can accomodate heterogeneity in detection and variation following initial capture, resulting in less biased estimates of population size.

Lincoln-Petersen estimator

The simplest CMR method involves two sampling occasions. On the first occasion, M individuals are captured, marked (in a durable, but not necessarily individually identifiable way), and released. On the second occasion, C individuals are captured, of which R are marked from the first capture. This method may also be referred to as 'Mark-Resight', as individuals are marked only once and no new marks are added during the second occasion. It forms the basis of post-vaccination survey estimates, where dogs are marked (e.g. with collars or paint) during vaccination.

Under the assumptions of a closed population (i.e. no births, deaths, immigration, or emigration between the two sampling occasions), the Lincoln-Petersen estimator provides an estimate of the total population size (Ñ):

$$\tilde{N} = \frac{MC}{R}$$

Detection probability (P) on the second sampling occasion can be estimated as:

$$P = \frac{R}{M}$$

This estimator assumes equal capture probability among individuals, no mark loss, and complete mixing of marked individuals back into the population before the second sampling. When assumptions are met, the Lincoln-Petersen estimator yields an unbiased estimate of the true population size.

However, these assumptions may not hold true for free-roaming dogs. For example, during vaccination campaigns, dogs that are approachable and easily vaccinated are also more likely to be resighted, whereas difficult-to-catch dogs may also be harder to observe. This overestimates detection probability and leads to an underestimation of the total population.

Worked Example 1

In a village in Tanzania, researchers conducted a Capture-Mark-Recapture study to estimate the free-roaming dog population.

Sampling Occasion 1:
20 dogs were captured, marked, and released.
M = 20

Sampling Occasion 2 (two days later):
28 dogs were captured, of which 9 were previously marked.
C = 28; R = 9

Using the Lincoln-Petersen estimator:

$$\tilde{N} = \frac{MC}{R} = \frac{20 \times 28}{9} = 62.22$$

$$P = \frac{R}{M} = \frac{9}{20} = 0.45$$

The free-roaming dog population is therefore estimated at approximately 62 individuals, with a detection probability of 0.45 (i.e. just under half the dogs present are observed during the survey).

Chapman estimator

When sample sizes are small or recaptures are rare, the Lincoln-Petersen estimate may be biased and associated with wide confidence intervals. The Chapman estimator can improve the estimate:

$$\tilde{N}_{Chapman} = \frac{(M+1)(C+1)}{R+1} - 1$$

How reliable are estimates of population size derived from simple closed population CMR estimators?

To assess reliability, a confidence interval should be constructed around each estimate. A confidence interval provides a statistical range within which the true population size is likely to lie and therefore indicates the precision and reliability of the estimate.

Estimation of free-roaming dog population size and calculation of confidence intervals using two-sample closed population models (e.g. Lincoln-Petersen and Chapman estimators) can be performed using the free interactive web application ShinyCMR (https://anyadoc.shinyapps.io/ShinyCMR/).

Increasing estimator precision: How many dogs should I count?

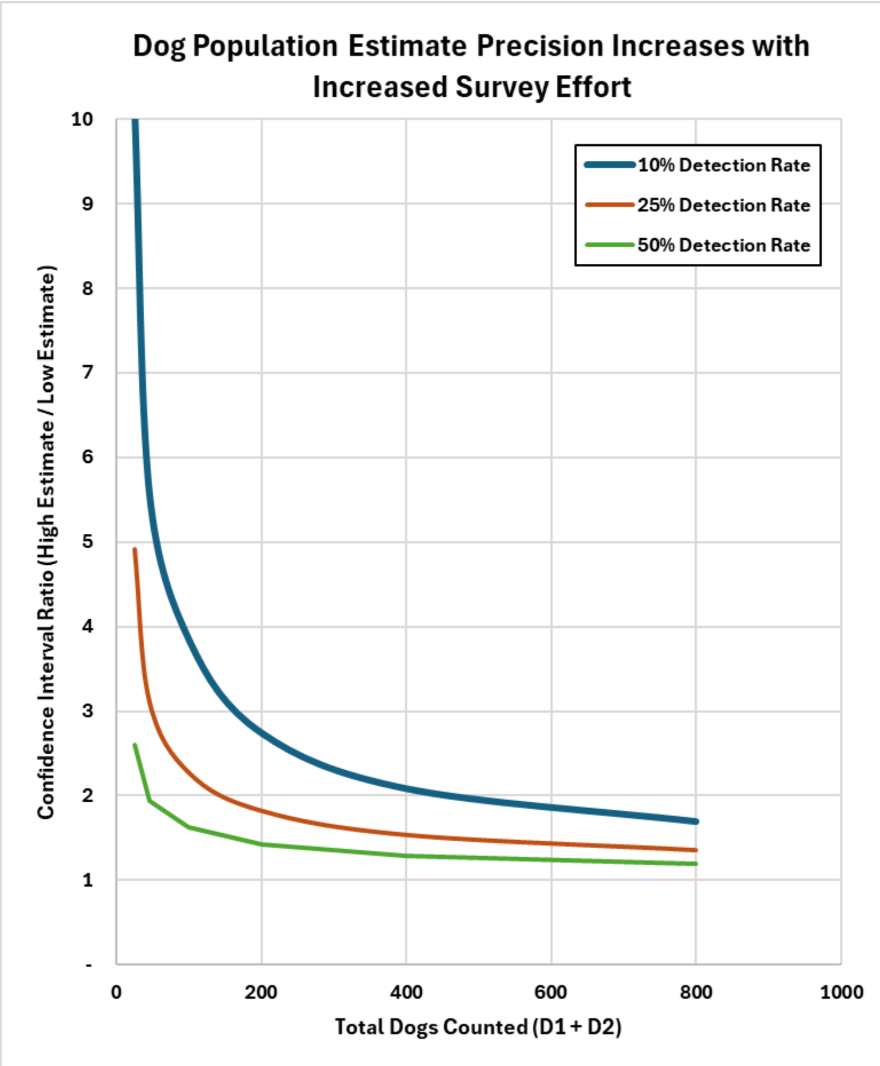
When recapture rates are low, the estimates become less precise, as there is limited information about the proportion of marked individuals in the population. This results in wide confidence intervals which may limit practical use. Precision can be improved by increasing survey effort – both the number of dogs marked on Day 1 and the number of dogs surveyed for recaptures on Day 2. The Day 2 survey area should include a buffer around the original marking area to account for outward movement of dogs. This helps support the assumption of a closed population (i.e. no emigration of your marked dogs). If a HDR is to be calculated, the Day 2 recapture area must align with the area for which human population data are available; the original marking area buffer should fall within this defined recapture area.

The number of dogs that must be counted to obtain sufficient recaptures depends on detection probability. When dogs are difficult to detect, and therefore difficult to recapture, larger samples are required.

The following figure presents simulated data demonstrating how precision improves as the number of dogs counted increases. Precision is shown on the y-axis as the confidence interval ratio (the upper confidence limit divided by the lower confidence limit); lower ratios indicate greater precision. The figure presents three detection probabilities:

- Blue line: low detection probability (10% recaptured on Day 2)
- Red line: intermediate detection probability
- Green line: high detection probability (50% recaptured on Day 2)

These simulations demonstrate that lower detection probabilities require larger sample sizes to achieve precise estimates. As a rule of thumb, counting approximately 100 dogs per day is often necessary to obtain a usefully precise estimate.



An additional approach to addressing imprecise estimates resulting from low numbers of recaptures over two days is to use extended estimators, such as the Schnabel estimator for closed populations or the Jolly-Seber model for open populations.

Schnabel estimator

To address low recapture rates, the Schnabel estimator extends the two-sample Lincoln-Petersen approach to incorporate multiple capture occasions. Rather than relying on only two sampling events, data are accumulated across repeated capture and recapture rounds.

During each sampling occasion, captured individuals are examined for existing marks. All unmarked individuals are marked and released back into the population. Unlike methods requiring individual identification, the Schnabel estimator only requires marks that distinguish between marked (previously captured) and unmarked (never captured). This allows the use of less invasive marking techniques and reduces logistical effort.

By pooling information across repeated sampling events, the Schnabel method increases the precision and reliability of population estimates, particularly when recapture probability is low. It generally produces more robust estimates than two-sample methods.

Worked Example 2

Researchers conducted four capture sessions to estimate the free-roaming dog population in a village in Tanzania. During each session, all captured dogs were checked for marks, and unmarked dogs were newly marked before release.

Capture history:

Day	Number Captured (C)	Number Recaptured (R)	Number Marked in the population (M)	New Marked (C-R)
1	20	0	0	20
3	28	9	20	19
5	17	6	39	11
7	22	8	50	14

The Schnabel Estimator for population size Ñ is calculated formulas:

$$\tilde{N} = \frac{\sum(C \times M)}{\sum R}$$

Where:
C = number of animals captured in each sample
R = number of marked animals recaptured
M = number of animals marked and available in the population before each sample

Step 1: Calculate M before each sample

- Before Day 1: M = 0 (no animals marked yet)
- Before Day 3: M = 20 (20 marked on Day 1)
- Before Day 5: M = 20 + 19 = 39 (marks from Day 1 + Day 3)
- Before Day 7: M = 39 + 11 = 50 (marks from Day 1 + Day 3 + Day 5)

Step 2: Plug values into the Schnabel formula

$$\tilde{N} = \frac{(20 \times 0) + (28 \times 20) + (17 \times 39) + (22 \times 50)}{0+9+6+8} = \frac{2323}{23} = 101$$

The estimated free-roaming dog population is approximately 101 dogs.

For comparison, Example 1 used only the first two sampling occasions and the Lincoln-Petersen estimator, resulting in an estimate of 62 dogs. This is then an underestimate compared to the higher and likely more accurate estimate obtained using additional sampling occasions and the Schnabel estimator.

Beck's method: Photographic recapture

Beck adapted the Schnabel extension to estimate free-roaming dog populations using photographic identification, eliminating the need for physical capture or handling. In this approach, both 'capture' and 'recapture' involve photographing free-roaming dogs encountered during surveys, with individuals identified based on natural markings and visible features.

Beck's estimator is expressed as:

$$\tilde{N}_B = \Sigma^t_{j=1} (Mjxj) \ / \ \Sigma^t_{j=1} m_j + 1$$

Where:
t = total number of photographic capture surveys
M_j= number of dogs captured in the j^{th} survey
m_j= number of dogs recaptured in the j^{th} survey
x_j = total number of distinct dogs captured in the j-1 surveys

Errors such as double counting or failure to recognise previously 'marked' dogs in photographs—analogous to mark loss in traditional methods—can be minimised by recording additional identifying information (e.g. age, sex, distinctive natural markings, reference person) alongside photographs.

Beck's method can yield reliable estimates under certain conditions (Fei et al., 2012). A key assumption is that dogs have equal detectability. If this assumption is not true, estimates may be biased, typically underestimating true population size (Belsare and Gompper, 2013). Variation in age, sex, temperament and behaviour influence activity patterns and detectability, and compromise this assumption.

ShinyCMR (https://anyadoc.shinyapps.io/ShinyCMR/) can also be used to estimate free-roaming dog population size from multiple sampling occasions using methods such as the Schnabel estimator or Beck's photographic recapture approach.

Program MARK

Accounting for unequal detectability in CMR models requires specialised software such as Program MARK. These models involve more complex stastistical formulations and are computationally intensive. The first step is to assemble encounter histories for uniquely marked individuals. These are organised in a matrix format, with each row representing an individual and each column representing a sampling occasion. Entries indicate detection (1) or non-detection (0). This structured dataset forms the basis for estimating parameters such as detection probability and population size while allowing individuals to differ in their probability of being caught or detected.

Estimating detection probability using Program CAPTURE

Detection probability can be estimated using Program CAPTURE (online application: https://www.mbr-pwrc.usgs.gov/software/capture/index.shtml), which analyses closed population capture-recapture data while accounting for individual heterogeneity, time variation, and behavioural response.

Steps:

1. Prepare an encounter history file in Excel: For each uniquely identifiable dog, record a binary sequence across sampling occasions (1 = detected; 0 = not detected)

   Below is an example of an encounter history dataset generated from free-roaming dog surveys conducted in a village in Tanzania (refer to Example 2 above). Files can be downloaded from https://github.com/anyadoc/audiseco/blob/main/TZfrd_cmrdata.csv

	A	B	C	D	E
1	A1	1	0	0	0
2	A2	1	1	0	0
3	A3	1	0	0	0
4	A4	1	0	0	0
5	A5	1	1	0	1
6	A6	1	0	0	0
7	A7	1	1	0	0
8	A8	1	1	0	0
9	A9	1	1	0	0
10	A10	1	0	0	0
11	A11	1	0	0	0
12	A12	1	1	0	0

   Each row represents an individual dog, and each column is a sampling occasion.

2. Enter the encounter history data into the online Program CAPTURE in the specified format. Be sure to copy and paste the header and footer code exactly as shown below, placing your encounter history data in between:

Enter input below:

```
title='free-roaming dog survey '
task read captures occasions=4 x matrix
read input data
A1 1000
A2 1100
A3 1000
A4 1000
A5 1101
A6 1000
A7 1100
A8 1100
A9 1100
A10 1000
A11 1000
A12 1100
A13 1011
A14 1100
A15 1000
A16 1000
A17 1000
A18 1110
A19 1100
A20 1001
B1 0100
B2 0100
B3 0100
B4 0101
B5 0100
B6 0110
B7 0100
B8 0100
B9 0100
B10 0111
B11 0100
B12 0100
B13 0100
B14 0100
B15 0110
B16 0100
B17 0100
B18 0110
B19 0101
C1 0010
C2 0010
C3 0010
C4 0011
C5 0010
C6 0010
C7 0010
C8 0011
C9 0010
C10 0010
C11 0010
D1 0001
D2 0001
D3 0001
D4 0001
D5 0001
D6 0001
D7 0001
D8 0001
D9 0001
D10 0001
D11 0001
D12 0001
D13 0001
D14 0001


task closure test
task model selection
task population estimate appropriate
```

3. Select 'Perform Analysis' to generate results. The estimated probability of capture (p-hat) represents the detection probability.

   For the data provided above, Program CAPTURE estimated the detection probability as 0.2052.

Extrapolation

CMR methods provide precise estimates but are resource intensive are therefore usually applied to relatively small geographic areas. For larger areas, CMR can be conducted in a sample of smaller areas and results extrapolated.

Direct street counts require fewer resources but must be corrected for imperfect detection. CMR can be used in a subset of areas to estimate detection probability, which can then be applied to adjust street count estimates elsewhere.

Where CMR is conducted within administrative areas with known human population data, a HDR can be derived and applied to non-surveyed administrative areas. When selecting areas for CMR, preference should be given to those locations with natural boundaries that support the assumption of a closed population (i.e. minimal immigration and emigration).

Examples from published studies

- Anvik, J. O., Hague, A. E., & Rahaman, A. (1974). A method of estimating urban dog populations and its application to the assessment of canine fecal pollution and endoparasitism in Saskatchewan. Canadian Veterinary Journal, 15(8), 219–223. https://pubmed.ncbi.nlm.nih.gov/4411668

  Estimated the owned dog population in Saskatchewan using a mark–resight method (Lincoln–Petersen estimator), using 1972 dog registration records as the marked population and dogs captured by municipal dog catchers as the resight sample.

- Caminiti, A., Sala, M., Panetta, V., Battisti, S., Meoli, R., Rombola, P., Spallucci, V., Eleni, C., & Scaramozzino, P. (2014). Completeness of the dog registry and estimation of the dog population size in a densely populated area of Rome. *Preventive Veterinary Medicine*, 113, 146–151. https://doi.org/10.1016/j.prevetmed.2013.10.003

  Estimated the owned dog population in Rome using a mark–resight method (Lincoln–Petersen estimator), comparing registered dogs with dogs identified during face-to-face household interviews.

- Beck, A. M. (1973). The Ecology of Stray Dogs: A Study of Free-Ranging Urban Animals. York Press, Baltimore.

- Belsare, A. V., & Gompper, M. E. (2013). Assessing demographic and epidemiologic parameters of rural dog populations in India during mass vaccination campaigns. *Preventive Veterinary Medicine*, 111(1–2), 139–146. https://doi.org/10.1016/j.prevetmed.2013.04.003

  Uses mark–resight methods during vaccination campaigns to estimate demographic and epidemiological parameters of rural dog populations in India.

- Fei, S. Y., Chiang, J. T., Fei, C. Y., Chou, C. H., & Tung, M. C. (2012). Estimating stray dog populations with the regression method versus Beck's method: a comparison. *Environmental and Ecological Statistics*, 1–14. http://dx.doi.org/10.1007/s10651-012-0197-0

  Compares regression-based estimation methods with Beck's photographic mark–resight approach for estimating stray dog populations.

Assessing overlap between owned and free-roaming dog population estimates

When to use

- To establish the proportion of the free-roaming dog population that is owned versus unowned or community owned
- When estimates of both owned dogs (including confinement status) are available from household surveys and estimates of free-roaming dogs are available from direct street counts and/or CMR methods.

Description

The free-roaming dog population consists of several sub-populations:

- Unowned dogs
- Community owned dogs (cared for by one or more households but not formally owned)
- Owned dogs that roam unsupervised.

There may also be smaller sub-populations of lost or abandoned owned dogs.

For vaccination campaign planning, it is important to understand what proportion of free-roaming dogs are owned and therefore accessible through their owners, compared with those that are community owned or unowned and may require alternative access strategies for vaccination (e.g. catching and handling or oral vaccination).

Where both household surveys and direct counts and/or CMR methods have been conducted, the resulting estimates can be compared to assess the degree of overlap. This provides an indication of the proportion of the free-roaming dog population that is owned.

How to conduct

The household survey should collect information on confinement practices for each owned dog., This allows the owned dog population estimate to be divided into two subpopulations:

- Owned, fully confined dogs (never roam unsupervised)
- Owned, unconfined dogs (roam unsupervised for at least part of the day)

Owned unconfined dogs can be further classified, for example:

- Semi-confined dogs (roam for at least part of the day or night),
- Never-confined dogs (always free to roam)

Direct count and/or CMR methods should estimate the number of free-roaming dogs within the same geographic areas as the household surveys to enable comparison.

For each area where both estimates are available:

> Number of unowned/community owned dogs = Estimated free-roaming dogs – Estimated owned unconfined dogs

Interpreting discrepancies

In some communities, the estimated number of owned unconfined dogs may exceed the estimated free-roaming dog population. Several explanations are possible:

1. Very small or absent unowned/community owned population

   Estimates of both owned unconfined and free-roaming dogs will have a degree of imprecision (as reflected in their confidence intervals). When there is zero, or very small numbers of, unowned/community owned dogs, there is a reasonable chance that the central point estimate for free-roaming dogs will exceed the central point estimate for owned unconfined dogs. In this situation, the 95% confidence intervals of the two estimates would be expected to overlap.

2. Temporal mismatch

   Free-roaming surveys may be conducted when at times when owned unconfined dogs are less visible. For example, if dogs are allowed to roam primarily in the evening or overnight, but street surveys are conducted at dawn, some owned unconfined dogs may be missed.

3. Underestimation of free-roaming dogs due to methodological issues

   As discussed in the CMR section, estimates based on only two counting occasions may underestimate free-roaming dogs, particularly where there is heterogeneity in detectability (e.g. dogs that are easy to mark on Day 1 are also easier to observe on Day 2).

4. Overestimation of meaningful roaming of owned dogs

   Owners may report that a dog is unconfined, even if the dog rarely enters public spaces. Such dogs may be therefore classified as unconfined in the household survey but not observed during free-roaming surveys.

5. Limited precision with survey methods

   Apparent differences between owned unconfined and free-roaming estimates may not be statistically significant. Confidence intervals should always be examined, and where necessary, statistical testing applied to determine whether these differences reflect expected sampling variation or truly a significant difference.

Examples from published studies

- Moran, D., Alvarez, D., Cadena, L., Cleaton, J., Salyer, S. J., et al. (2022). Heterogeneity in dog population characteristics contributes to chronic under-vaccination against rabies in Guatemala. *PLoS Neglected Tropical Diseases*, 16(7), e0010522. https://doi.org/10.1371/journal.pntd.0010522

  Combines sight–resight surveys using photographic identification with household surveys across urban, semi-urban, and rural communities in Guatemala to estimate human-to-dog ratios and detection probabilities for free-roaming dog populations.

Post-Vaccination Survey

When to use

- To refine initial estimates of dog population size that are suspected to be imprecise
- When vaccination coverage has already been measured to assess campaign effectiveness (i.e. whether target vaccination coverage has been achieved)
- When vaccination coverage has fallen short, to identify underlying reasons and inform remedial actions for future campaigns (see UAR Forum Best Practice: 'Dog vaccination – barriers and solutions').

Description

In this guidance, dog population estimation is used to generate initial estimates that support planning and budgeting for dog vaccination campaigns, particularly in areas lacking formal dog population data. However, these initial estimates may overestimate or underestimate the true dog population.

Despite this uncertainty, dog vaccination campaigns should still proceed using the best available estimates. As post-vaccination data become available, population estimates can be refined to improve planning and resource allocation for subsequent vaccination rounds, including scaling up.

How to conduct

Vaccination, marking and recording

During the vaccination campaign, vaccinated dogs should be marked (e.g. with collars or livestock marking paint that remains visible for several days) and recorded. Marking may be a component in any vaccination campaign, but when a post-vaccination survey is planned, additional recording considerations apply:

- If dogs are vaccinated but not marked, they must still be recorded. The population estimate relies on the number of dogs that are both vaccinated and marked.
- Record whether vaccinated dogs are owned (and therefore accessible through a household survey) or unowned.

For vaccinated owned dogs brought by their owners:

- Record the dog's home location, noting whether it lives inside or outside the intended post-vaccination survey area (as owners may transport dogs to a campaign across area boundaries).
- Record confinement status. Dogs that are always confined will not be part of the free-roaming marked population.

These steps ensure that the number of free-roaming marked dogs within the survey area is known.

Minimum number of dogs to be surveyed

The minimum number of dogs required to obtain a reliable coverage can be calculated using an initial rough estimate of the dog population in the survey area (N).

Minimum number of dogs to be surveyed = $96 / (1 + (96/N))$

This assumes that being 95% confident within +/- 10% of the true coverage is sufficiently reliable.

Survey protocol

Post-vaccination surveys should be conducted ideally within 24-72 hours of vaccination campaign completion.

- At least 24 hours to allow dog behaviour to normalise following vaccination activities.
- Within 72 hours to reduce loss of visible marks (e.g. collars falling off or paint fading)

Transects should be conducted in the early morning or late evening when dogs are most active and visible.

The survey may use:

- Direct street count of free-roaming dogs;
- Household surveys to determine vaccination coverage of owned dogs; or
- A combination of both methods.

Not all streets or households need to be surveyed, but the sample should be representative of the entire survey area and not biased towards areas more likely to have been vaccinated (e.g. streets immediately surrounding static vaccination points).

Each dog observed should be recorded according to its marked status.

Calculating the estimate

Variables measured by the vaccination campaign:

- Number of marked and vaccinated free-roaming dogs released into the survey area
- Number of marked and vaccinated dogs confined within households in the survey area

Variables measured by the post-vaccination sample:

- Number of marked and vaccinated dogs counted (free-roaming and/or confined in households)
- Number of unmarked and assumed unvaccinated dogs counted (free-roaming and/or confined in households)
- Total number of dogs observed

Extrapolation to dog population estimate

The Lincoln-Petersen estimator (see Capture-Mark-Recapture section) is used to refine population estimates. Because this approach involves a single marking event and the 'recapture' stage only involves observation, it is also referred to as a 'Mark-Resight' method:

$$N = \frac{MC}{R}$$

Where:
N = refined free-roaming dog population estimate
M = number of free-roaming dogs marked and vaccinated during the campaign
C = total number of free-roaming dogs observed on the survey
R = number of free-roaming dogs observed during the survey that are marked (and assumed vaccinated).

The same calculation can be applied to household survey data, where M represents the number of owned dogs marked and vaccinated during the campaign.

Rearranging this estimator allows detection probability of free-roaming dogs to be calculated:

$$P = \frac{R}{M}$$

Using the estimate for vaccination planning

As described in the Capture-Mark-Recapture section, the Lincoln-Petersen estimator can underestimate true population size. This is particularly likely when dogs that are easiest to vaccinate and mark are also the most likely to be observed during the recapture survey, while dogs that are difficult to vaccinate are also more likely to be missed by surveyors.

As a result, the estimate derived should be considered a minimum population estimate and the calculated vaccination coverage a maximum vaccination coverage. The true population is likely to be higher, and the true vaccination coverage correspondingly lower. For example, Sambo et al. (2017) found that post-vaccination direct street count transects underestimated coverage by 10% across sites in Tanzania.

When budgeting for the following campaign, it is prudent to assume an increase of 10% in vaccine requirements to achieve the same vaccination coverage. The target number of dogs vaccinated in the next campaign should therefore exceed the number vaccinated previously, and campaigns should continue to scale up until coverage is consistently above 70%.

Post-vaccination evaluations (and therefore opportunities to refine population estimates) should be conducted regularly to assess campaign performance across teams and locations, and to evaluate new campaign approaches. However, due to resource constraints, evaluations do not need to be conducted in every location every year. Once reliable dog population estimates have been established (e.g. after two or three consecutive years vaccination and evaluation), routine post-vaccination evaluations may no longer be necessary, as substantial changes in dog population sizes are not expected.

Robust surveillance of dog rabies cases remains essential. Surveillance supports appropriate health seeking behaviour following suspected exposures and serves as the primary outcome measure of vaccination effectiveness. Detection of dog rabies cases indicates insufficient vaccination coverage and should trigger post-vaccination evaluations in affected areas. Such evaluations may identify increases in dog population size, dog demographic shifts, or underperforming vaccination campaigns contributing to continued rabies transmission.

Summary of stages for scaling-up dog vaccinations

1. Estimate initial dog population

   Use available dog estimates or apply one of the methods described in this document. Use this estimate to determine vaccine and consumable requirements (e.g. vaccines, syringes, needles, and other supplies).

2. Initiate dog vaccination campaigns

   Begin dog vaccinations based on the initial dog population estimate.

3. Conduct post-vaccination evaluations

   Perform household and/or direct street count surveys to assess dog vaccination coverage.

4. Refine dog population estimate

   Calculate the refined dog population estimate by dividing the number of vaccinated dogs by the updated vaccination coverage (as described in the post-vaccination survey section).

5. Adjust planning and procurement

   Update vaccination plans and procurement orders based on the refined estimate and conduct the second round of dog vaccinations.

6. Perform Second-Round Evaluations

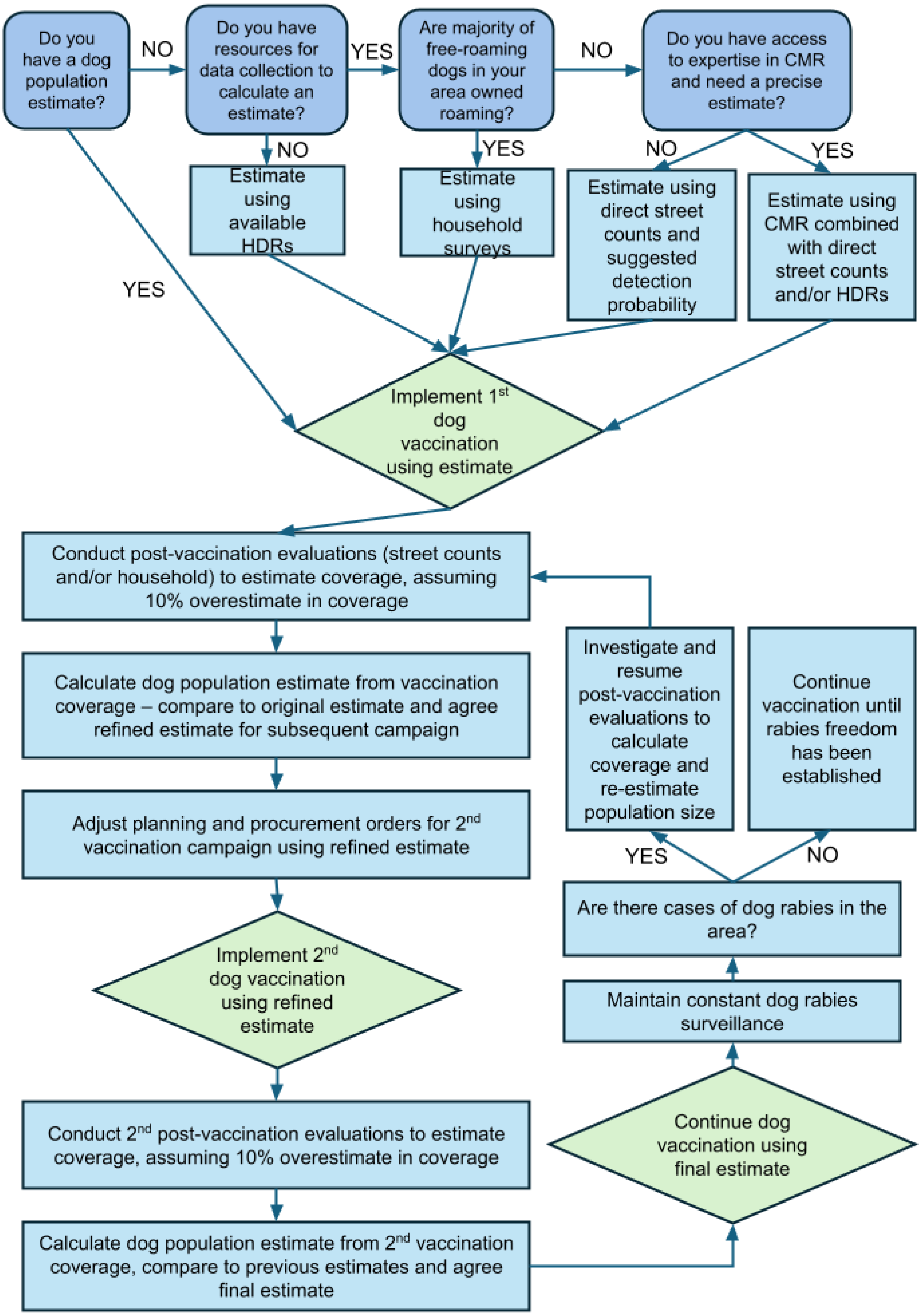
   Conduct post-vaccination evaluations to obtain updated dog vaccination coverage.

7. Finalise dog population estimate

   Divide the number of vaccinated dogs in the second round by the updated vaccination coverage to establish a final population estimate and confirm procurement and planning assumptions.

8. Maintain dog rabies surveillance

   Continue robust surveillance of dog rabies cases. Detection of cases indicates insufficient vaccination coverage and should trigger renewed post-vaccination evaluations in the affected area.


Do you have a dog population estimate?
NO
Do you have resources for data collection to calculate an estimate?
YES
Are majority of free-roaming dogs in your area owned roaming?
NO
Do you have access to expertise in CMR and need a precise estimate?
NO
Estimate using available HDRs
YES
Estimate using household surveys
NO
Estimate using direct street counts and suggested detection probability
YES
Estimate using CMR combined with direct street counts and/or HDRs
YES
Implement 1st dog vaccination using estimate
Conduct post-vaccination evaluations (street counts and/or household) to estimate coverage, assuming 10% overestimate in coverage
Calculate dog population estimate from vaccination coverage – compare to original estimate and agree refined estimate for subsequent campaign
Adjust planning and procurement orders for 2nd vaccination campaign using refined estimate
Implement 2nd dog vaccination using refined estimate
Conduct 2nd post-vaccination evaluations to estimate coverage, assuming 10% overestimate in coverage
Calculate dog population estimate from 2nd vaccination coverage, compare to previous estimates and agree final estimate
Continue dog vaccination using final estimate
Maintain constant dog rabies surveillance
Are there cases of dog rabies in the area?
YES
Investigate and resume post-vaccination evaluations to calculate coverage and re-estimate population size
NO
Continue vaccination until rabies freedom has been established

Examples from published studies

- Sambo, M., Johnson, P. C. D., Hotopp, K., Changalucha, J., Cleaveland, S., Kazwala, R., Lembo, T., Lugelo, A., Lushasi, K., Maziku, M., Mbunda, E., Mtema, Z., Sikana, L., Townsend, S., & Hampson, K. (2017). Comparing methods of assessing dog rabies vaccination coverage in rural and urban communities in Tanzania. *Frontiers in Veterinary Science*. https://doi.org/10.3389/fvets.2017.00033

  Compares methods for estimating dog rabies vaccination coverage and finds that post-vaccination street transects provide the most cost-efficient approach, although they may overestimate vaccination coverage by approximately 10%.

- Sambo, M., Hampson, K., Changalucha, J., Cleaveland, S., Lembo, T., Lushasi, K., Mbunda, E., Mtema, Z., Sikana, L., & Johnson, P. C. D. (2018). Estimating the size of dog populations in Tanzania to inform rabies control. *Veterinary Sciences*, 5, 77. https://doi.org/10.3390/vetsci5030077

  Compares dog population estimation methods following vaccination campaigns in Tanzania and demonstrates that post-vaccination transects can provide more accurate population estimates than household or school-based surveys.

- Matter, H. C., Wandeler, A. I., Neuenschwander, B. E., Harischandra, L. P., & Meslin, F. X. (2000). Study of the dog population and the rabies control activities in the Mirigama area of Sri Lanka. *Acta Tropica*, 75(1), 95–108. https://doi.org/10.1016/s0001-706x(99)00085-6

  Estimated the owned dog population in the Mirigama area of Sri Lanka using a mark–resight method (Petersen–Bailey estimator), combining vaccination records with household survey observations of marked dogs.

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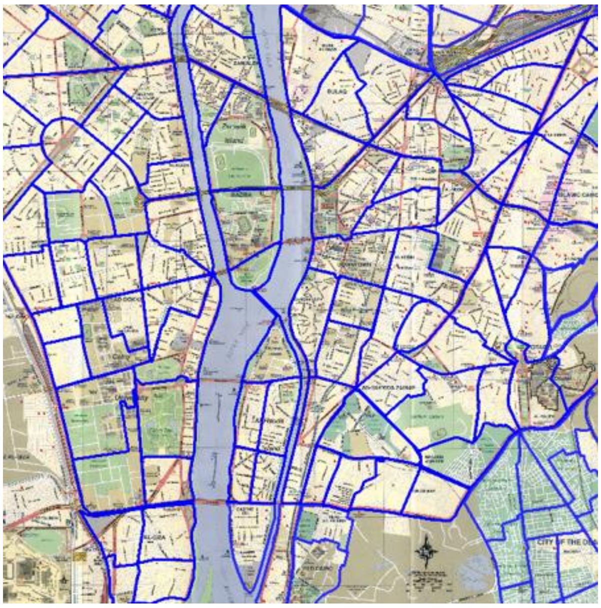
6.0. Annexes

Annex A: Checkerboard Sampling

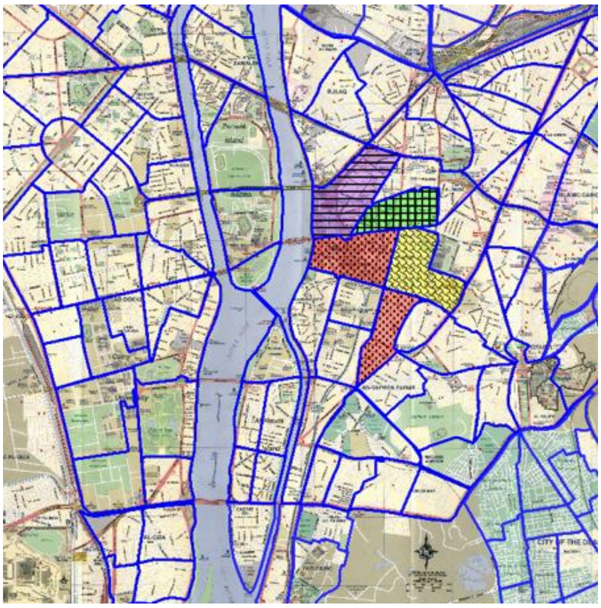
The checkerboard method results in a random and evenly spaced sample of areas. The following is reproduced from WSPA's (2008) ['Surveying roaming dog populations: Guidelines on methodology']().

1. Identify administrative units that are of a feasible size for sampling, and access boundaries for these units.
    a. This is an example of contiguous areas within a city; in this case these areas are blocks drawn to create areas of approximately equal size. Using administrative units is preferred when they also provide information on the human population.



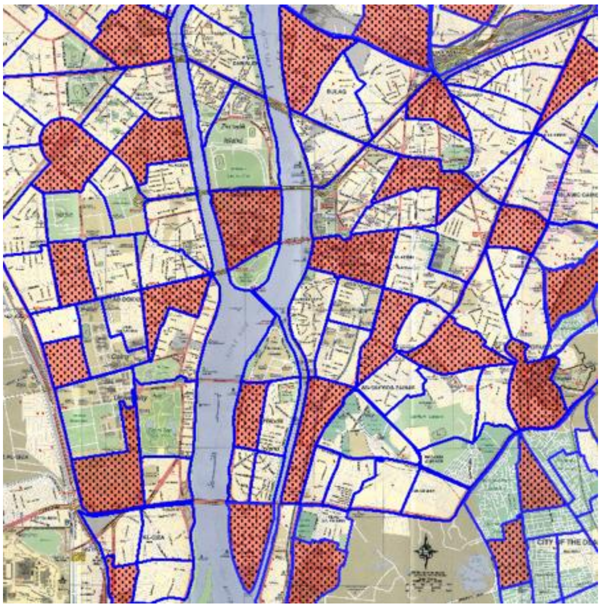
2. Use four colours to colour all the areas. A phenomenon in mapmaking called the 'Four Colour Theorem' states that any map can be coloured with no more than four colours so that no two adjacent areas share the same colour. For example:

a. Starting to colour the blocks in four colours: Beginning at the centre and spiralling outwards, never assigning the same colour to neighbouring blocks.

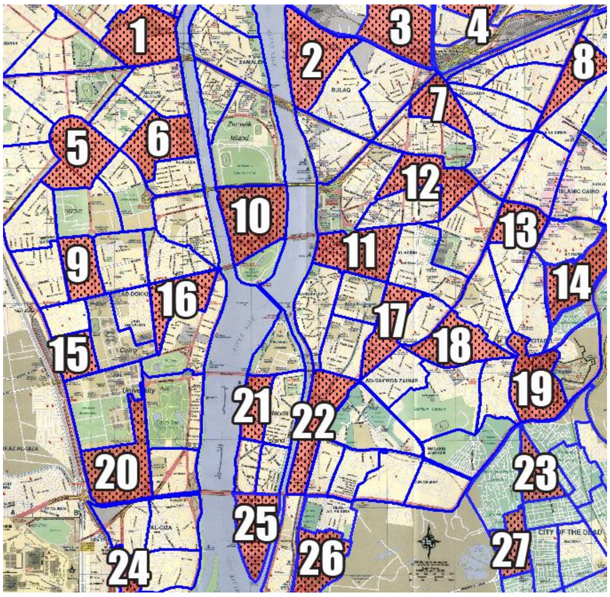


b. All blocks assigned one of four colours, with no neighbouring blocks of the same colour and an equal number of blocks of each colour.

3. Randomly pick one of these four colours. This will provide a random sample spread out across the city. Each area's probability of being selected for the sample will be the number of selected areas divided by the total number of areas. This will be approximately 1/4, and exactly 1/4 if the total number of areas is divisible by 4. If this sample is too large to count, continue to the next step.
    a. All red blocks selected, each block had a ¼ (27 red blocks divided by the total of 108 blocks) chance of being selected.



4. To reduce the total number of areas in the sample, use a skip pattern to select a proportion of the areas for the final sample, starting with a randomly selected area. For example, selecting every other area (resulting in a ⅛ sample) or skipping every 3rd area (resulting in a ⅙ sample). Numbering the areas can make applying a skip pattern easier.
    a. Number each of the selected blocks working as much as possible across and down the map, as if reading words from a page. Once numbered, applying a skip pattern to the block is easier, for example selecting only odd or even numbers for a ½ skip pattern.



Annex B: Sample questions for Household Questionnaire on dog vaccination and management

The following questionnaire includes necessary questions in **blue font** and optional in **pink font**.

1. Date and interviewer name.
2. Consent statement.
    a. *Include study purpose, who is conducting the study and the interview, how information will be stored, used, and by whom. That participation is voluntary, unpaid and can be withdrawn. That an adult can be a respondent, or a child with adult supervision.*
    b. *If consent is refused, still record the household location to enable a non-response rate to be calculated.*
3. Household information.
    a. GPS location
    b. Province > District > Subdistrict > Village/Block/Ward
    c. How many people live in the household?
    d. Respondent information:
        i. *Further household/respondent information should be limited to what is essential for establishing how representative the final household sample is for the area of interest. For example, dwelling type (as reported in human census), religion of head of household, income.*
        ii. *Exclude name, if possible, to limit how much personal information is held.*
4. Dog ownership.
    a. Do you or anyone in your household own dogs? Y/N
        i. If no, skip to section 5.
        ii. If yes, continue.
    b. How many dogs do you/your household own?
    c. For each dog owned (one child form per dog):
        i. Are they vaccinated? Y/N
            1. If no, why not? *Give list of options: Don't know about vaccination, too expensive, not necessary to vaccinate, dog too young, vaccination is dangerous, vaccination causes an unwanted change in dog behaviour, vaccination point too far away*.
            2. If yes, when? By whom? Are they marked as vaccinated?
        ii. What age?

iii. What sex?

iv. Is this dog allowed to roam unsupervised during any part of the day or night? Y/N
   1. If yes, are they
      a. always free to roam and never confined to the household (house and yard)
      b. Confined for <2 hours
      c. Confined for 2-12 hours
      d. Confined for >12 hours
v. Are they sterilised?
vi. Where is the dog now? In the house / in the yard / on a walk under supervision / outside the boundary of the premises (free roaming)
vii. What is the purpose of this dog?
viii. What breed?
ix. How were they acquired?
x. Have you had any litters of puppies born in your household in the last 12 months? Y/N
   1. How many litters?
   2. How many puppies in these litters?
   3. How many puppies did you keep? Sell/give away? Abandon? Died?

5. Dog bite history.

   a. Has anyone in your household been bitten by a dog in the last 12 months, this includes anyone who resided in your household in the last year but has died? Y/N

      i. If no, skip to section 6

      ii. If yes, continue

   b. For each bite (one child form per bite):

      i. Who was bitten? M infant, F infant, M child, F child, M adult, F adult.

      ii. Who were they bitten by? Own dog, dog owned by someone else, a known unowned dog, an unknown dog (we do not know if it was owned or not)

      iii. What did the person who was bitten do about the bite? Nothing, wash with water, wash with soap and water, went to pharmacy, went to doctor, went to hospital, went to local healer, other.

6. Stray dogs.

   a. Has anyone in your household offered care to a stray dog that you do not own in the last week? Y/N

   b. Has anyone in your household been troubled or concerned about stray dogs in the last month? Y/N

      i. If yes, what kind of trouble/concern? *Provide a list of common problems caused by strays and concerns for their welfare and allow multichoice*.

   c. In your neighbourhood, what has happened to the number of dogs over the last 12 months? Increased, stayed the same, decreased.

d. How do you think stray dogs should be managed? Left alone, sterilised and returned to their street, vaccinated and returned to their street, sterilised and vaccinated and returned to their street, taken away to live in a shelter, rehomed as pets, killed, other.

Thank the respondent for taking the time to answer these questions. If possible, provide contact details for follow-up.