

Short communication

Using natural marks to estimate free-ranging dog *Canis familiaris* abundance in a MARK-RESIGHT framework in suburban Mumbai, India

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Abstract

Free-ranging dogs (*Canis familiaris*) are a major conservation issue in the tropics and adopt many ecological roles, alternatively functioning as predators, prey, or competitors of wildlife in diverse environments. Dogs are also potential reservoirs of disease that can be transmitted to both wildlife and people. Therefore a range of management interventions have been suggested to control dog populations. In order to monitor interventions to decrease dog populations, estimates of their population size are important and such methods need to be time- and cost-effective. We describe here a potential method that uses natural marks on dogs along with counts of non-marked individuals in a mark-resight framework to estimate the abundance of free-ranging dogs in a suburban area in India. Using the logit-normal mixed effects estimator to incorporate the effects of individual resighting heterogeneity, we found a total (N_j) of 680.64 ± 34.06 (95% CI = 617.22 – 751.35) dogs in the study area, with an overall mean resighting probability of 0.53 ± 0.03 (95% CI = 0.47 – 0.58). This corresponds to a density estimate of 57 dogs km⁻² (CI = 51 – 63). Given that certain assumptions are met, this method may be useful to estimate abundance of dogs where other kinds of marks may be unavailable or impractical. This method may be applied to other species of feral animals as well, where some proportion of a population has distinct natural marks.

Keywords: Natural marks, free-ranging, *Canis familiaris*, abundance, mark-resight

Résumé

Les chiens errants (*Canis familiaris*) sont un problème de conservation majeur dans les zones tropicales et peuvent adopter différents rôles écologiques, jouant tour à tour le rôle de prédateur, proie, ou compétiteur de la faune sauvage au sein de milieux divers. En outre, les chiens sont des réservoirs potentiels de maladies pouvant être transmises aux animaux sauvages comme à l'homme. De ce fait, plusieurs modes d'interventions ont été suggérés afin de contrôler les populations de chiens. Afin de suivre ces interventions, les estimations des leur populations de chiens sont importantes et doivent être effectuées de manière rentable économiquement et en termes de temps. Nous décrivons ici une méthode potentielle basée sur les marques naturelles identifiables de certains chiens et un comptage des individus non marqués en utilisant le cadre du marquage – réobservation. Cela nous permet d'estimer l'abondance des chiens errants au sein de la banlieue d'une métropole indienne. En utilisant le test Logit-Normal à effets mixtes pour intégrer l'effet de l'hétérogénéité des réobservations individuelles, nous avons trouvé un total (N_j) de 680.64 ± 34.06 (95% CI = 617.22 – 751.35) chiens au sein de la zone étudiée, avec une probabilité moyenne de réobservation de 0.53 ± 0.03 (95% CI = 0.47 – 0.58). Cela correspond à une estimation de la densité de 57 chiens/km⁻² (CI = 51 – 63). Si les hypothèses de départ sont vérifiées, cette méthode pourrait être appliquée à d'autres espèces d'animaux féraux montrant une structure de population similaire et chez lesquelles une certaine proportion de la population possède des marques naturelles distinctes.

Mots-clefs: Marques naturelles, chien errant, *Canis familiaris*, abondance, marquage-réobservation

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Introduction

Dogs and man have a complex relationship going back many thousands of years [1]. Dogs, as one of the most widely distributed carnivores, also interact with wildlife in various environments across rural-urban gradients. They often adopt the role of predators [2,3], prey [4-6], competitors [7] and reservoirs or transmitters of disease [8,9]. Additionally, they may also take up the role of “conservation dogs” (*sensu* Reed et al. [10]), and are employed in wildlife research and management [11]. Dogs can broadly be categorized as owned, urban or rural free-ranging, feral or village (as per [12]). Free-ranging dogs often come into contact with wildlife and interact negatively [13,14], sometimes even outcompeting native species [15], as well as posing a high risk of disease spillover to native carnivores, especially to wild canids and felids [5]. Studies from around the globe highlight the influence of free-ranging dogs on native fauna [3,5,16-18].

Understanding dog abundance is a fundamental requirement in most dog control and management strategies, whether it involves euthanasia, sterilization programmes or other approaches. A number of methods have been suggested to enumerate dog populations, including the use of block counts [19], mark-recapture using paint solution sprays [20], household surveys [21], collar marking with transect line recaptures [22], and distance sampling [23]. Recently, the mark-resight framework has been applied to estimate dog abundance using ear-notched marks made during Animal Birth Control (ABC) programmes [17]. These methods have been used to understand dog populations covering a range of spatial scales from rural and peri-urban areas, to the level of city blocks and even entire cities. They can be employed in varied circumstances of time, monetary and logistical availability; however many of them require artificial marking. We here describe a potential method, based on the results of a pilot study, which exploits the use of natural marks present on individual dogs to estimate their abundance in a mark-resight framework. This method may be a useful addition to the suite of modeling methods available for counting dogs and can be used at variable scales, especially in the absence of artificial marks.

In many free-ranging dog populations, some dogs may have natural marks by which individuals can be easily identified visually, while others may be mono-coloured or not distinctly marked, which makes it difficult to identify them visually as unique individuals. In such situations, natural marks can be employed to estimate the abundance of a closed free-ranging dog population in a mark-resight framework, given that some assumptions are met. The primary assumption is that the marked population should be representative of the unmarked population in terms of sightability [24]. This is a reasonable assumption with domestic animals that are generally highly visible and not shy or elusive. In normal circumstances,

dog sightability also should not be influenced by the presence or absence of natural marks. This is important since naturally marked individuals can then be assumed to belong to a random subset of the population. Other important assumptions of the mark-resight approach include geographic and demographic closure during primary sampling intervals and no loss or change of marks [25]. Geographic closure may be relaxed in some circumstances; however, the estimate of abundance is then termed a 'super population' [25].

Population estimates are generally more sensitive to heterogeneity, which can result in biased estimates of abundance and over-precision in mark-resight studies [25,26]. Therefore, we used the logit-normal estimator which accounts for individual sighting heterogeneity, since we suspected differential sighting probabilities among dogs. Also, sighting probabilities for marked and unmarked individuals should be independent, and identically distributed [25]. This may be an issue with free-ranging dogs which inherently form loose aggregations; therefore sighting probabilities may not always be independent, leading to underestimation of parameter variance. However, similar mark-resight estimators used with group-living animals indicate that biases associated with parameter estimates are low [27-31]; therefore, we believe that our estimate of population size is still useful. Lastly, it is important to perform the marking or identification of marked individuals immediately before actual sampling, in order to know the exact number of marked individuals present during sampling.

This pilot study of dog ecology was prompted by an ongoing conflict study in the area, where leopards (*Panthera pardus*) leave a neighbouring national park to enter suburban environments in pursuit of dogs, which are a major prey item [4]. This brings leopards into potential conflict situations with humans, which can occasionally have fatal results for people.

Methods

Study area

The study area comprised the Aarey Milk Colony (AMC) situated in suburban Mumbai, in the state of Maharashtra in India (Fig. 1). The AMC, measuring 12.8 km², was established in the year 1949 in order to institute a cleaner and organized way of supplying milk to the citizens of Mumbai city (see: <http://dairy.maharashtra.gov.in>). The AMC consists of more than 30 cattle production units with a total capacity of over 15,000 head of cattle. The eastern portion of AMC is bordered by the Sanjay Gandhi National Park, a forested landscape of nearly 104 km² in area. The northern, western and southern frontiers of the AMC are bordered by the suburbs of Mumbai city, a metropolis of more than 12 million people. Some peripheral portions of the AMC are enclosed by boundary walls of institutions within the AMC or those of housing colonies on the outer side. Nearly 55% of the area of AMC comprises uncultivated land, cultivated grassland, water bodies, gardens, orchards and hillocks with forest cover. The remaining area is allotted to cattle production units and institutions belonging to the Government of India, which largely comprise built-up areas. There are also a number of native tribal villages, residential colonies and slums within its premises.

The vegetation type in AMC is heavily human-modified; however, a few remnant patches of southern moist deciduous forest [32] are also found. Human-modified vegetation includes scrub forest and understory shrubbery composed of Jujube (*Zizyphus* sp.), Lantana (*Lantana* sp.), and plantations of exotic tree species such as Gliricidia (*Gliricidia sepium*) and forest red gum (*Eucalyptus* sp.). A large floating population of recreational visitors to the colony and the resident human population in cattle units, villages, slums, and built-up areas provide many food subsidies for free-ranging dogs (the majority being strays) in the AMC. Given the availability of dogs, proximity to a national park, and availability of

dense cover in the form of scrub vegetation, leopards are often sighted in the premises of the AMC, since free-ranging dogs are a common prey species for the leopard in this region [4].

Dog surveys

We conducted the entire study from 25th February to 1st March, 2012. We initially surveyed all of AMC on a motorbike and identified points where dogs were observed, either in clusters or singly. We tracked the majority of the roads within the AMC using a hand-held GPS (Garmin Inc., USA, GPS 72H) and marked all locations with dog presence. These points were generally close to human habitations, and included garbage and cattle carcass dumps, cattle units, slums, villages, and the premises of institutions within the AMC. A total of 65 such points were identified and overlaid on a map of the AMC to design a survey route. Although we recorded areas where dogs were observed, we ensured that our survey route uniformly covered most areas within the colony where dogs could be found. However, we did not cover a small portion (c. 1.3 km²) in the western edge of the AMC due to its inaccessibility and time constraints (Fig. 1). We ensured that the area covered was large and that the perimeter to area ratio was small, so as to avoid violation of the assumption of geographic closure. Since urban/ village dogs are known to have small home ranges and high territoriality ([16] and references therein) we believe that our study satisfied the assumption of geographic closure for the short period of study.

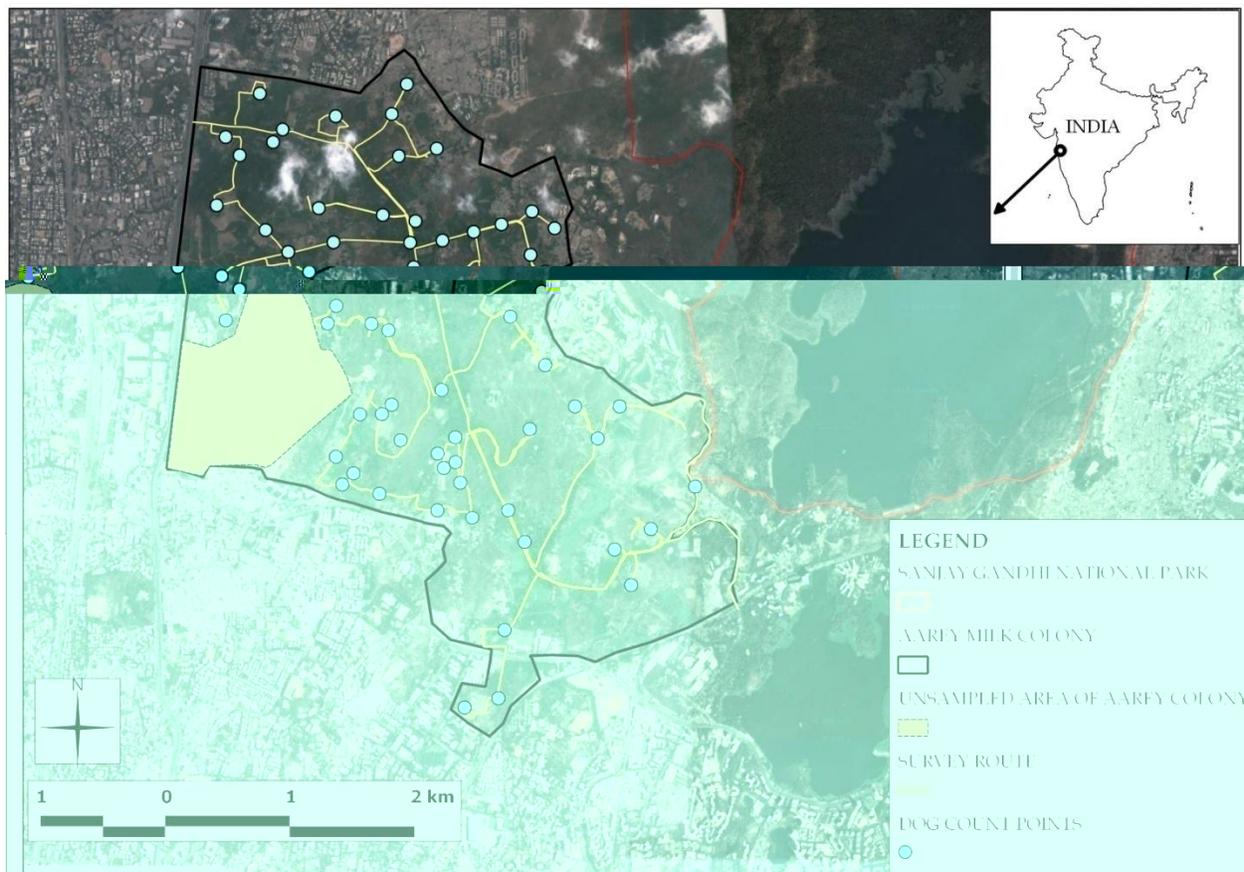


Fig. 1. The map of the study area indicates the survey route and dog count points used to estimate dog abundance in a mark-resight framework in Aarey Milk Colony, India.

We first followed this survey route to identify and photograph free-ranging adult dogs with easily distinguishable natural marks. The majority of dogs were strays, while some dogs may be categorized as semi-owned, since they were associated with specific cattle units or households; all the dogs were unrestricted by humans in their movements. Dogs were identified as marked by observing natural marks on their flanks, head, and tail. We ensured that during our initial survey we identified as many naturally marked dogs as we could detect. Such naturally marked dogs were identified as marked individuals in the population. This was done two days prior to actual sampling to adhere to the assumption of closure, since mortality rates of free-ranging dogs are assumed to be moderate to high [17,33]. Mono-coloured adult dogs or dogs without conspicuous natural marks were regarded as unmarked individuals in the population. We also observed that free-ranging dogs were most visible during morning and evening hours in our study area. Thus, surveys (initial and actual) were planned keeping in mind activity and visibility levels of dogs, in order to increase the sightability of individuals.

We conducted the primary sampling surveys during daylight hours over three days, where each day comprised one secondary sampling interval. The primary sampling interval (28th February to 1st March 2012) was kept short to adhere to the assumptions of geographic and demographic closure. On each secondary sampling interval, the entire survey route was covered using a motorbike and high quality photographs of dogs with natural marks were taken using a digital SLR camera (Canon India Pvt. Ltd., India, Canon 1000D, Canon 18-55 mm lens) (Fig. 2). The photographs of dogs included as many distinct natural marks as possible on each individual to minimize the possibility of misidentification. At each point, as well as along the survey route, all marked dogs seen were photographed and the numbers of unmarked dogs were recorded. We thoroughly surveyed the area around each point to detect as many dogs as possible, ensuring that we did not traverse the surveyed area twice to avoid double counts. The survey route was covered in a unidirectional way such that sampling was without replacement, i.e., each individual was sighted only once during each secondary sampling interval [34]. If some roads had to be repeatedly traversed on the same sampling interval to reach other points, we did not count or photograph dogs during this repeat traverse to avoid double counts of unmarked dogs.

The logit-normal mark resight estimator may be employed when the number of marked individuals in the population is known exactly and sampling is without replacement [34]. The model provides an estimate of abundance (N_j) for primary interval j , mean resighting probability (p_{ij}) for each secondary sampling interval i of primary interval j based on the kind of model used, and individual heterogeneity parameter (σ_j), when individual identification is possible [25]. When heterogeneity is estimated, the model also provides an estimate of overall mean resighting probability (μ_{ij}), which otherwise is equal to p_{ij} . For our study, we photographed all individuals with distinct natural marks, as it was essential to identify whether the individual was from the known marked population, or an entirely new individual with distinct natural marks, in order to avoid biasing the overall mean resighting probability (μ_{ij}). Such naturally marked individuals, which were not identified during our initial surveys, were included in the unmarked population. Although our goal was to estimate the abundance (N_j) of dogs, this method can be used to estimate other demographic parameters of dog populations as well. This is possible when data are collected over multiple primary intervals, and new marks may be introduced at any time between sampling intervals (refer to [25,35] for details).

Data input and Analysis

We performed the analysis in Program MARK ([36], Version 6.2) using the mixed logit-normal mark-resight estimator, where the number of marked individuals in the population should be known exactly

[34]. This is similar to Bowden's estimator in the NOREMARK program [24]. As marks were individually identifiable, we used individual heterogeneity models with the data, since we expected individual dogs to have differential sighting probabilities. We used the time-constant models, with or without individual heterogeneity parameters. Since some convergence issues occurred for values of σ (individual heterogeneity parameter) for the time-constant model with heterogeneity, we manually supplied initial values covering the probable range of parameters in the three models. We also used other options to overcome convergence issues for values of σ , such as the 'Alt.Opt.method' and 'Do not standardize design matrix' in another two models. In all we used seven time-constant models, the first six of which represented the time-constant model with individual heterogeneity, with various options as described above. The last model represented the time-constant model without the individual heterogeneity parameter (where σ was fixed to zero). Model comparison was performed in an information-theoretic framework using Akaike's information criteria corrected for small sample size (AICc).



Fig. 2. The image indicates photographs obtained for a distinct naturally marked dog over two secondary sampling intervals in Aarey Milk Colony, India.

Results

We identified a total of 101 naturally marked individuals in the population before actual sampling, and these were resighted over three secondary sampling intervals during the primary interval. Fifty-seven dogs were resighted once, 29 dogs were resighted twice and only 15 dogs were resighted all three times across the three sampling intervals. A total of 270, 294 and 356 unmarked dogs were counted over the three secondary sampling intervals.

We used a total of seven models, of which the first six represented the time-constant individual heterogeneity model and one model represented the time-constant model where (individual heterogeneity parameter) σ was fixed to zero. All seven models were ranked evenly, since σ could not be estimated correctly in any of the first six models and experienced convergence problems. All real parameter estimates of N_j (Abundance) and p_{ij} (mean resighting probability) were exactly identical and there was no difference in the AICc scores for any model.

A total abundance (N_j) of 680.64 ± 34.06 (95% CI = 617.22 – 751.35) dogs were estimated to be present in the AMC. Mean resighting probability (p_{ij}) and overall mean resighting probability (μ_{ij}) was estimated to be 0.53 ± 0.03 (95% CI = 0.47 – 0.58).

Discussion

We demonstrate a simple approach for estimating dog numbers using natural marks with the flexible logit-normal mark-resight model [34]. The method has several advantages, especially in reducing cost for marking individuals, which has usually been recognized as the most expensive component of mark-resight studies [37]. Using natural marks avoids the need of artificially marking dogs or handling them for the purpose of marking. This reduces the risk of stray dog bites or disease exposure to researchers, as well as possible biases due to dog shyness as a result of handling or marking. When used over longer sampling intervals, this method may be useful to estimate abundance at smaller spatial scales, such as the level of blocks, wards, or villages, and may also be useful at the scale of larger cities, where randomly selected spatial sub-units (such as blocks) can be sampled. However, given the need to identify a fair proportion (at least 15%) of the population as ‘marked’ before sampling, the method may have potential limitations in covering relatively large populations occurring at larger spatial scales. Although we could not assess potential biases in this pilot study, we refer the reader to McClintock et al. [34] to understand the range of scenarios under which the logit-normal estimator may be efficient. We recognize that our model parameter variances may be underestimated since we could not account for possible overdispersion, due to slight non-independence among marked individuals. However, we would like to point out that similar mark-resight estimators used with group-living animals indicate that biases associated with parameter estimates are low [27-31], therefore our method and estimate of population size are useful.

Implications for conservation

Since free-ranging dogs are a major conservation issue in the tropics, a brief overview of some other methods available to enumerate dog populations would be useful. Hiby et al. [17] demonstrated a convenient mark-resight approach to estimate dog abundance for entire cities using ear-notched marks made during animal birth control (ABC) initiatives. Totton et al. [20] used paint sprays to mark individuals for estimation of dog population in a mark-recapture framework at the scale of areas used for ABC initiatives. Childs et al. [23] demonstrated the use of distance sampling for estimation of dog densities, when assumptions of mark-recapture methods were not met. Distance sampling can enable larger area coverage due to logistic convenience, but may not be useful when parameters such as individual

heterogeneity or survival are of interest. Kitala et al. [21] and Matter et al. [22] used questionnaire and household surveys to estimate numbers of owned dogs. Household surveys are applicable when other approaches may be unsuitable to enumerate such 'confined' dog populations.

Our method may be appropriate when point estimates of free-ranging dog populations are required, but no readily available marks exist and limitations preclude other forms of artificial marking. The establishment of photographic databases of individual animals and computer-aided photo-recognition software could facilitate upscaling to larger survey areas. At similar scales, our method should be applicable in counting other species of urban or feral animals such as cats (*Felis catus*) and pigs (*Sus scrofa*), where some proportion of individuals in a population have distinct natural marks. Because such feral species are often subject to control programmes, understanding the abundance of feral populations of animals before an intervention and successively over the years will help evaluate the success of such initiatives. Our method accounts for imperfect detectability and individual sighting heterogeneity; not accounting for it may result in biased and over-precise estimates of abundance [34]. Assessing bias and precision of this method at relatively larger population sizes and proportions of naturally-marked individuals in the population requires further exploration.

The dog to man ratio estimated in India is about 1:36, and stray dogs are responsible for most bites causing human rabies [38]. Human rabies causes more deaths in India than in any other country [39]. Dog management is poor and the majority of dogs, even those with a formal owner, are partially or totally unrestricted in their movements [40]. In our study area (c.12 km²) in suburban Mumbai, we estimated a total of 681 (95% CI = 617 - 751) free-ranging dogs, which would yield densities of approximately 57 (51 - 63) dogs km⁻². All dogs were mixed-bred mongrels, and the majority of them were strays. No dogs had any collar to indicate ownership, and even those dogs that seemed semi-owned were unrestricted by humans in their movements. The results of our pilot study demonstrate a reasonably large population of free-ranging dogs in the AMC of suburban Mumbai, acting as potential prey for leopards as well as posing a disease risk to humans. Currently in our study area, systematic Animal Birth Control initiatives, as well as vaccination drives, are recommended, in order to control the dog population and minimize disease risk to humans. However, there is no established site-specific monitoring of the effect of control programs on dog populations over time. Our study provides a practical and time-effective method to assess changes in dog populations in such areas where control programmes are in progress.

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References

- [1] Clutton-Brock, J. 1995. Origins of the dog: domestication and early history. In: *The dog: its ecology, behaviour and evolution*. Serpell, J. (Eds.), pp. 7-20. Cambridge University Press, Cambridge.
- [2] Kruuk, H. and Snell, H. 1981. Prey selection by feral dogs from a population of marine iguanas (*Amblyrhynchus cristatus*). *Journal of Applied Ecology* 18:197-204.
- [3] Campos, C.B., Esteves, C.F., Ferraz, K.M.P.M.B., Jr, P.G.C. and Verdade, L.M. 2007. Diet of free-ranging cats and dogs in a suburban and rural environment, south-eastern Brazil. *Journal of Zoology* 273:14-20.
- [4] Edgaonkar, A. and Chellam, R. 2002. Food habit of the leopard, *Panthera pardus* in the Sanjay Gandhi national park, Maharashtra, India. *Mammalia* 66:353-360.
- [5] Butler, J., du Toit, J.T. and Bingham, J. 2004. Free-ranging domestic dogs (*Canis familiaris*) as predators and prey in rural Zimbabwe: threats of competition and disease to large wild carnivores. *Biological Conservation* 115:369-378.
- [6] Athreya, V. 2006. Is relocation a viable management option for unwanted animals? – The case of the leopard in India. *Conservation and Society* 4:419-423.
- [7] Lacerda, A.C.R., Thomas, W.M. and Marinho-Filho, J. 2009. Domestic dogs as an edge effect in the Brasília National Park, Brazil: interactions with native mammals. *Animal Conservation* 12:477-487.
- [8] Cleaveland, S., Appel, M.G.J., Chalmers, W.S.K., Chillingworth, C., Kaare, M. and Dye, C. 2000. Serological and demographic evidence for domestic dogs as a source of canine distemper virus infection for Serengeti wildlife. *Veterinary Microbiology* 72:217-227.
- [9] Fiorello, C.V., Deem, S.L., Gompper, M.E. and Dubovi, E.J. 2004. Seroprevalence of pathogens in domestic carnivores on the border of Madidi National Park, Bolivia. *Animal Conservation* 7:45-54.
- [10] Reed, S.E., Bidlack, A.L., Hurt, A. and Getz, W.M. 2011. Detection distance and environmental factors in conservation detection dog surveys. *Journal of Wildlife Management* 75:243-251.
- [11] Dahlgren, D.K., Elmore, R.D., Smith, D.A., Hurt, A., Arnett, E.B. and Connelly, J.W. 2012. Use of dogs in wildlife research and management. In: *Wildlife techniques manual: research (Volume I)*. Silvy, N.J. (Eds.), pp. 140-153. The John Hopkins University Press, Baltimore, USA.
- [12] Vanak, A.T. and Gompper, M.E. 2009. Dogs *Canis familiaris* as carnivores: their role and function in intraguild competition. *Mammal Review* 39:265-283.
- [13] Iverson, J.B. 1978. The impact of feral cats and dogs on populations of the West Indian rock iguana, *Cyclura carinata*. *Biological Conservation* 14:63-73.
- [14] Alexander, A.K. and Appel, M.J.G. 1994. African wild dogs (*Lycaon pictus*) endangered by a canine distemper epizootic among domestic dogs near the Masai Mara National reserve, Kenya. *Journal of Wildlife Diseases* 30:481-485.
- [15] Butler, J. and du Toit, J.T. 2002. Diet of free-ranging domestic dogs (*Canis familiaris*) in rural Zimbabwe: implications for wild scavengers on the periphery of wildlife reserves. *Animal Conservation* 5:29-37.
- [16] Boitani, L., Francisci, F., Ciucci, P. and Andreoli, G. 1995. Population biology and ecology of feral dogs in central Italy. In: *The dog: its ecology, behaviour and evolution*. Serpell, J. (Eds), pp. 217-244. Cambridge University Press, Cambridge.
- [17] Hiby, L.R., Reece, J.F., Wright, R., Jaisinghani, R., Singh, B. and Hiby, E.F. 2011. A mark-resight survey method to estimate the roaming dog population in three cities in Rajasthan, India. *BMC Veterinary Research* 7:46.
- [18] Ovsyanikov, N.G. and Poyarkov, A.D. 1996. Wolves and feral dogs in the ecosystems of Russian nature reserves. *Journal of Wildlife Research* 1:240-244.
- [19] WSPA: Surveying roaming dog populations: guidelines on methodology. <http://www.icam-coalition.org>.

- [20] Totton, S.C., Wandeler, A.I., Zinsstag, J., Bauch, C.T., Ribble, C.S., Rosatte, R.C. and Mcewen, S.A. 2010. Stray dog demographics in Jodhpur, India following a population control / rabies vaccination program. *Preventive Veterinary Medicine* 97:51-57.
- [21] Kitala, P., Mcdermott, J., Kyule, M., Gathuma, J., Perry, B. and Wandeler, A. 2001. Dog ecology and demography information to support the planning of rabies control in Machakos District, Kenya. *Acta Tropica* 78:217- 230.
- [22] Matter, H.C., Wandeler, A.I., Neuenschwander, B.E., Harischandra, L.P.A. and Meslin, X.F. 2000. Study of the dog population and the rabies control activities in the Mirigama area of Sri Lanka. *Acta Tropica* 75:95 - 108.
- [23] Childs, J.E., Robinson, L.E., Sadek, R., Madden, A., Miranda, M.E. and Miranda, N.L. 1998. Density estimates of rural dog populations and an assessment of marking methods during a rabies vaccination campaign in the Philippines. *Preventive Veterinary Medicine* 33:207-218.
- [24] White, G.C. 1996. NOREMARK: population estimation from mark-resighting surveys. *Wildlife Society Bulletin* 24:50-52.
- [25] McClintock, B.T. and White, G.C. 2012. From NOREMARK to MARK: software for estimating demographic parameters using mark-resight methodology. *Journal für Ornithologie* 152:S641-S650.
- [26] McClintock, B.T.M., White, G.C. & Burnham, K.P. 2006. A robust design mark-resight abundance estimator allowing heterogeneity in resighting probabilities. *Journal of Agricultural, Biological and Environmental Statistics* 11:231-248.
- [27] Neal, A.K., White, G.C., Gill, R.B., Reed, D.F. and Olterman, J.H. 1993. Evaluation of mark-resight model assumptions for estimating Mountain sheep numbers. *The Journal of Wildlife Management* 57:436-450.
- [28] Bowden, D.C. and Kufeld, R.C. 1995. Generalized Mark-Sight Population Size Estimation Applied to Colorado Moose. *The Journal of Wildlife Management* 59:840-851.
- [29] Sweitzer, R.A., Vuren, D.V., Gardner, I.A., Boyce, W.M. and Waithman, J.D. 2000. Estimating sizes of wild pig populations in the north and central coast regions of California. *The Journal of Wildlife Management* 64:531-543.
- [30] Morley, R.C. and Aarde, R.J. van. 2007. Estimating abundance for a savanna elephant population using mark-resight methods: a case study for the Tembe Elephant Park, South Africa. *Journal of Zoology* 271:418-427.
- [31] Curtis, P.D., Boldgiv, B., Mattison, P.M. and Boulanger, J.R. 2009. Estimating deer abundance in suburban areas with infrared-triggered cameras. *Human-Wildlife Conflicts* 3:116-128.
- [32] Champion, H.G. and Seth, S.K. 1968. *A revised survey of the forest types of India*. Nueva, Delhi.
- [33] Reece, J.F., Chawla, S.K., Hiby, E.F. and Hiby, L.R. 2008. Fecundity and longevity of roaming dogs in Jaipur, India. *BMC Veterinary Research* 4:6.
- [34] McClintock, B.T., White, G.C., Burnham, K.P. and Pryde, M.A. 2009. A Generalized Mixed Effects Model of Abundance for Mark-Resight Data When Sampling is Without Replacement. In: *Modeling Demographic Processes in Marked Populations*. Thomson, D.L., Cooch, E.G. and Conroy, M.J. (Eds.), pp. 271-289. Springer, USA.
- [35] McClintock, B.T. and White, G.C. 2009. A less field-intensive robust design for estimating demographic parameters with mark-resight data. *Ecology* 90:313-320.
- [36] White, G.C. & Burnham, K.P. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46:120-138.
- [37] Minta, S. and Mangel, M. 1989. A simple population estimate based on simulation for capture-recapture and capture-resight data. *Ecology* 70:1738-1751.
- [38] Sudarshan, M. 2004. *Assessing burden of Rabies in India*. WHO sponsored National Multi-centric rabies survey 2003. Association for Prevention and Control of Rabies in India, Bangalore, India.

- [39] Suraweera, W., Morris, S.K., Kumar, R., Warrell, D.A., Warrell, M.J., Jha, P. and Collaborators, for the M.D. study. 2012. Deaths from symptomatically identifiable Furious Rabies in India: A nationally representative mortality survey. *PLoS Neglected Tropical Diseases* 6:e1847.
- [40] Menezes, R. 2008. Rabies in India. *Canadian Medical Association Journal* 178:564-566