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Free-roaming dog population dynamics in Ranchi, India

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Abstract

Rabies causes approximately 20,000 human deaths in India each year. Nearly all of these occur following dog bites. Large-scale, high-coverage dog rabies vaccination campaigns are the cornerstone of rabies elimination strategies in both human and dog populations, although this is particularly challenging to achieve in India as a large proportion of the dog population are free-roaming and unowned. Further, little is known about free-roaming dog ecology in India which makes defining optimum vaccination strategies difficult. In this study, data collected using a mobile phone application during three annual mass vaccination and neutering (surgical sterilisation of both males and females) campaigns of free-roaming dogs in Ranchi, India (during which a total of 43,847 vaccinations, 26,213 neuter surgeries and 28,172 re-sight observations were made) were interrogated, using two novel approaches to estimate the proportion of neutered dogs that were lost from the city (assumed due to mortality or migration) between campaign years. Analysis revealed high losses of neutered dogs each year, ranging from 25.3% (28.2 – 22.8) to 55.8% (57.0-54.6). We also estimated that the total population declined by 12.58% (9.89 – 15.03) over the three-year period. This demonstrates that there is a high turnover of free-roaming dogs and that despite neutering a large number of dogs in an annual sterilisation campaign, the decline in population size was modest over a three-year time period. These findings have significant implications for the planning of rabies vaccination campaigns and population management programmes as well as highlighting the need for further research into the demographics of free-roaming, unowned dogs in India.

Key words: Neutering; Dog Demography; Population Dynamics; India; Rabies.

Introduction

Indian cities are home to large numbers of free-roaming dogs, the majority of which are unowned (Belsare and Gompper, 2013). These dogs can be a common source of human-animal conflict and are responsible for approximately 75% of human dog bite injuries (Srinivasan et al., 2019; Sudarshan et al., 2007). This presents an enormous risk for rabies transmission, as dogs are the principal reservoir of the rabies virus, and it has been estimated that over 95% of human rabies cases in India are caused by dog bites (Fooks et al., 2014; Sudarshan et al., 2007). Human rabies is almost invariably fatal and approximately one third of the 60,000 people who die from rabies annually are in India (Fooks et al., 2014; Sudarshan et al., 2007).

Mass dog vaccination campaigns are the cornerstone of rabies control, and have successfully reduced the incidence of human rabies in many regions (World Health Organization, 2018). Whilst achieving high vaccination coverage of free-roaming dogs in localised areas has been demonstrated (Gibson et al. ,2015), these campaigns require substantial resources and can be difficult to implement across larger areas (Kakkar et al., 2012). Consequently, vaccination programmes need to be as efficient as possible to minimise inputs and maximise campaign efficiency.

Although vaccination coverage of over 40% should be sufficient to limit the spread of rabies in the dog population, in practice, much higher levels of coverage are recommended for annual mass rabies vaccination campaigns to allow for population turnover (Bilinski et al., 2016; Coleman and Dye, 1996; Davlin and VonVille, 2012; Hampson et al., 2015, 2009; Kitala et al., 2002; Lembo et al., 2010; World Health Organization, 2018). Clearly, understanding population dynamics in these dog populations is therefore crucial to developing effective vaccination programmes. In an effort to reduce both the population size and turnover of free roaming dogs, many rabies vaccination campaigns have utilised neutering (surgical sterilisation of both males and females) in addition to vaccination. However, the ability of neutering programs to achieve these population management goals is unclear (Reece et al., 2013; Reece and Chawla, 2006; Yoak et al., 2014), and specifically in the context of rabies control, the relative value of this approach has been highly controversial (Cleaveland et al., 2014; Collinson et al., 2020; Knobel et al., 2017; Reece et al., 2008; Reece and Chawla, 2006; Rowan et al., 2014; Yoak et al., 2014). Populations have been well-described in sub-Saharan Africa, where many free-roaming dogs are owned. Yet few empirical studies describe populations over multiple years in India, where a larger proportion of free-roaming dogs are unowned and therefore may be more difficult to access (Reece et al., 2008).

There are relatively few empirical studies assessing the ecology of free-roaming dogs in India, and those that do exist often study relatively small populations of dogs (Pal et al., 1998; Pal, 2001; Reece et al., 2008). Greater understanding of dog demography and the dynamics of population turnover, in a variety of locations across India and worldwide, is vital for informing vaccination strategies and assessing the relative value of neutering free-roaming dogs.

This study utilises data captured using the Mission Rabies Smartphone application (MRApp), which has allowed large volumes of geo-referenced data to be gathered (and output in a readily usable format for analysis) during three annual vaccination and neutering campaigns in Ranchi city (Jharkhand, India) that involved the delivery of 43,847 vaccinations, 26,213 neuter surgeries and 28,172 re-sight observations. Through the analysis of this dataset, we describe the demographics of free-roaming dogs in Ranchi over a period of three years by addressing three key research questions. Firstly, how large is the free-roaming dog population and did this change of the course of the three years; secondly, what proportion of dogs are neutered prior to and after the end of each campaign year; and thirdly, therefore what proportion of the neutered dogs were lost from the population (by mortality plus migration) between each campaign. As we seek to explain the observed results, we also utilise the data to assess for sex bias in the neutering campaigns and for temporal variation in the proportion of dogs estimated to be under 12 weeks of age.

Material and methods

Study area

Ranchi (23°22′N, 85°20′E) is the capital city of the North East Indian state of Jharkhand, with an urban human population of 1.07 million people (*Census of India*, 2011). The city is divided into 55 administrative wards (Fig.1).

Vaccination and Neutering Campaigns

A local non-government organisation, HOPE & Animal Trust, has been operating an annual rabies vaccination and neutering campaign for free-roaming dogs in the city since 2008 in collaboration with the local municipal authority. In the years 2015, 2016 and 2017, these services were expanded in collaboration with Mission Rabies. In each of these three campaign years, each ward within Ranchi was covered sequentially, using a vaccinate-assess-move technique described in Gibson et al. (2015). This technique was divided into two phases for each ward: Phase 1, in which dogs were captured and then either vaccinated or vaccinated and neutered; and Phase 2, in which a re-sight survey to assess vaccination coverage was completed. These phases were repeated as necessary until the estimated vaccination coverage was greater than 70%, before moving on to the next ward.

Phase 1: capture, vaccinate, neuter, mark and release

Every street within a ward was walked by a team consisting of one veterinarian, two veterinary assistants and 4 dog-catchers. These walks were conducted between dawn and 11am or between 3pm and dusk in order to avoid the drop in dog activity that has been described in unowned Indian dogs around midday (Kumar Swain and Pati, 2019), whilst avoiding night time due to decreased dog visibility. Capture was attempted for all free-roaming dogs sighted on this walk, using either manual restraint for dogs that voluntarily approached the team, or using a butterfly net for dogs that could not be manually restrained. In cases where a dog struggled within the net, restraint was assisted using a Y-pole and a towel placed over the dog's head. No dog bites were received by handlers during any capturing events. Records were not made for occurrences when dogs were sighted but capture was not possible. Captured dogs that were already neutered (assessed by the presence of an ear notch) were vaccinated intramuscularly or subcutaneously (Nobivac® Rabies, MSD Animal Health), marked on the head with non-toxic paint and released. Entire animals (lacking an ear notch or with visible testicles) estimated to be over 16 weeks of age (estimated by visual appearance) were transported to the HOPE & Animal trust veterinary clinic where they were surgically neutered, the tip of one ear was surgically removed (to enable permanent identification of neuter status), vaccinated and marked as above, and then released back into the area where they were captured. Dogs of all ages were vaccinated in line with recommendations for canine mass vaccination campaigns (World Health Organization, 2018). At the time of capture, an individual data record was made for each dog, utilising the Mission Rabies App (Gibson et al., 2018). This record included the following data, which was used for the subsequent analysis in this study: Global Positioning System (GPS) location, time and date, sex, neuter status, age (<12 weeks or >12 weeks, estimated by visual appearance). Vaccination and neutering were also offered to the owners of any confined dogs encountered, although these animals were excluded from our analysis.

Phase 2: re-sight survey

Once all neutered dogs had been returned to the population (within 2 – 5 days), dog sight surveys were conducted by motorbike, using GPS and internet mapping to follow a pre-determined route in order to cover each street within a ward. Surveys were conducted at the same time of day as in Phase 1 and the same data was collected, additionally recording vaccination status (assessed by the presence of the marker paint). If the percentage of dogs with marker paint sighted in this survey was below 70%, both Phase 1 and Phase 2 were repeated, in order to ensure that this vaccination target was achieved without local geographical heterogeneity, which could compromise rabies elimination efforts (Ferguson et al., 2015). When wards required repetition of Phases 1 and 2, only data captured during the final survey were used for data analysis (in order to prevent counting dogs as 'unmarked' that would then go on to be marked in the repetition of Phase 1). Further details on this 'vaccinate-assess-move' technique, including maps of capture and survey routes, may be found in Gibson et al. (2015).

Data Processing

Data were exported from the Mission rabies App as CSV files. Data processing, presentation and analysis were performed using R (version 3.6.0) in R Studio (version 1.2.1335) (R Core Team, 2017) using the following packages: binom (Dorai-Raj, 2014), cowplot (Wilke, 2018), ggmap (Kahle and Wickham, 2013), maps (Becker et al., 2018a), mapdata (Becker et al., 2018b), maptools (Bivand and Lewin-Koh, 2019), rgdal (Bivand et al., 2019), rsample (Kuhn and Wickham, 2017), and tidyverse (Wickham, 2017).

Estimating Population Size

Using data from Phase 1 and 2 in a capture-mark-resight framework, the population size (N) at the start of each campaign year was estimated using the Chapman estimator (Chapman, 1951):

$$N = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)}$$

Where:

- n_1 was the number of dogs marked as vaccinated in Phase 1
- n_2 was the total number of dogs recorded as seen in the final survey of Phase 2
- m_2 was the number of marked dogs recorded in the final survey of Phase 2

Estimating Neuter Coverage

The neuter coverage prior to each campaign year was estimated using Phase 1 data, whereas post-campaign neuter coverage was estimated using data captured in the final Phase 2 surveys. 95% confidence intervals were constructed for each of these point estimates using the Binomial Exact method.

Estimating the Neutered Population Size

We used the number of dogs neutered during the campaigns to estimate changes in the number of neutered dogs between the end of one campaign and the start of the next. We estimated the neutered population via two methods in order to assess possible differences between catching and sight survey methods (Phase 1 and Phase 2).

Method 1 used neuter coverage estimates from Phase 1 surveys and extrapolated these forwards to estimate post-campaign numbers (adding the number of dogs neutered during the campaign), thus estimating the lowest number of neutered dogs likely to be present. Method 2 used neuter coverage from phase 2 surveys and extrapolated these backwards to estimate pre-campaign numbers (subtracting the number of dogs neutered during the campaign).

Estimated number of neutered dogs	Method 1	Method 2
Pre-campaign	N × Phase 1 neuter coverage	(N × Phase 2 neuter coverage) - number of dogs neutered in campaign
Post-campaign	(N × Phase 1 neuter coverage) + number of dogs neutered in campaign	N × Phase 2 neuter coverage

Estimating Losses of Neutered Dogs between Campaign Years

The percentage changes in the number of neutered dogs between the end of one campaign year and the start of the next campaign year were calculated for each method respectively. These estimates assume that there were no other sources of neutered dogs (i.e. no inward migration, no other neutering clinics, and no release of previously confined neutered dogs).

Bootstrap Confidence Intervals

Both Phase 1 and Phase 2 datasets were replicated 1000 times by resampling with replacement. Each of the calculations described above was repeated for each dataset replicate. The median value from these replicates was utilised as the point estimate for the population sizes and percentage changes. The 2.5th and 97.5th percentiles of the replicates were utilised for the corresponding 95% confidence intervals.

Ethical Review

Ethical approval for this research was granted by University of Edinburgh's Veterinary Ethical Review Committee (ref: 64/15). All field components of the study were undertaken as part of rabies control and dog population management programmes through a Memorandum of Understanding between Hope & Animal Trust and the Ranchi Municipal Corporation and were in accordance with the Animal Welfare Board of India regulations on animal birth control.

Results

Population Estimates

Population estimates ranged from 42,038 in 2015 to 36,789 in 2017. There was a progressive decline in the total dog population through the three campaign years, with the total population size in 2017 12.58% (CI: 9.89-15.03) lower than in 2015 (Table 2).

Table 2 Estimated total population of unowned dog population in each campaign year and percentage change in unowned dog population relative to 2015

Campaign Year	Estimated Population of Unowned Dogs (95% CI)	Percentage change relative to 2015 (95% CI)

2015	42,038 (41,129 – 42,997)	
2016	40,693 (40,058 – 41,450)	-3.22 (-0.16 – -5.92)
2017	36,789 (36,121 – 37,380)	-12.58 (-9.89 – -15.03)

Neutering Percentage

Across the three campaign years a total of 26,213 dogs were surgically neutered. As a result, after each campaign more than 70% of the dogs observed in the Phase 2 surveys were neutered (Table 1), with neutering percentages of over 60% observed in the vast majority of individual wards (Figure 3). However, there were large decreases in neuter coverage between the end of one campaign and start of the next (Table 1). These large decreases in neuter coverage were also observed at a ward level (Figure 2).

Table 1 For each campaign year: the percentage of dogs captured during Phase 1 that were already neutered; the number of dogs on which surgical neutering was performed; and the percentage of dogs observed in Phase 2 that were neutered.

Campaign Year	Percentage of Dogs Neutered Pre-Campaign - Phase 1 (95% CI)	Total Number of Dogs Neutered (Female/Male)	Percentage of Dogs Neutered Post-Campaign – Phase 2 (95% CI)
2015	42.0 (41.4 – 42.7)	7522 (3832/3690)	72.9 (72.0 – 73.8)
2016	39.7 (39.1 – 40.2)	9790 (4882/4908)	70.1 (69.2 – 71.0)
2017	31.2 (30.6 – 31.7)	8901 (4394/4507)	82.1 (81.3 – 83.0)

Neutered Dog Losses

Between the end of the 2015 campaign and the start of the 2016 campaign, both methods estimated substantial decreases in the number of neutered dogs (9,094 (CI: 8,453 – 9,729) dogs by method 1; 11,929 (CI: 10,859 – 12,954) dogs by method 2; Figure 3), amounting to a 36.0% (CI: 37.9-33.9) and 38.9% (CI: 41.4 – 36.1) reduction in neutered dogs by methods 1 and 2 respectively (Table 4). This trend was replicated between the end of the 2016 campaign and the start of the 2017 campaign (14,471 (CI: 14030 – 14973) dogs by method 1; 7,243 (CI: 6,410 – 8,157) dogs by method 2; Figure 3), though there was a greater difference between the two methods. Between 2016 and 2017, Method 2 estimated a 25.3% reduction in neutered dogs (CI: 22.8 – 28.2); whereas Method 1 estimated a reduction in neutered dogs of 55.8% (CI: 54.6 – 57.0) during this period (Table 3).

Table 3 Percentage change (95% CI) in the number of neutered unowned dogs between campaigns, estimated by both methods.

	Percentage decrease (95% CI) in the number of neutered dogs between campaigns	
	Method 1	Method 2
2015-2016	36.0 (33.9 – 37.9)	38.9 (36.1 – 41.4)
2016-2017	55.8 (54.6 – 57.0)	25.3 (22.8 – 28.2)

Sex Bias and Age Structure

Similar proportions of male and female dogs underwent neutering surgery in each campaign year (Table 1) and the post-campaign neuter coverage after each of the three campaign years (estimated from the Phase 2 re-sight surveys) were similar for both male and female dogs (Figure 4). This indicates that there was no sex bias in the overall high neutering coverage achieved in all years. In contrast, the pre-campaign neuter coverage was higher for male dogs than female dogs. There was a clear seasonal pattern to the population age structure, with the proportion of dogs under 12 weeks old peaking between November and March in all three years (Figure 5).

Discussion

This study demonstrates that through neutering large numbers of free-roaming dogs across the city it was possible to consistently achieve neutering coverages of at least 70% year after year. In addition, repeating this high neutering coverage over three consecutive years was associated with a 12.58% (9.89 – 15.03) reduction in the estimated population of free-roaming dogs within the city over the three-year study period. This population decrease was less than that observed in studies with comparable neuter coverage: a 28% population decline was observed in Jaipur by Reece and Chawla (2006) over a five-year period; and a 27.7 – 52.2% decline was observed in some areas in Jodhpur by Totton et al. (2010), over a two-year period. However, Totten et al (2010) also describe two areas with comparable neuter coverage that showed no significant population decline, illustrating the complexity of population dynamics and localised variation in the impacts of neutering campaigns. The substantial decrease in the number of neutered dogs at the start of each campaign season in this study population suggests high mortality or outward migration of neutered dogs and indicates that without continued efforts, the effect of neuter and vaccination campaigns will rapidly decline.

Substantial reductions in the number of neutered dogs between campaign years were estimated using both methodologies (Fig. 3, Table 3). Whilst the two methods give similar estimates for dog losses between 2015 and 2016, the losses between 2016 and 2017 estimated are noticeably greater when estimated by Method 1 than by Method 2. Widyastuti et al. (2015) demonstrated that dogs in Indonesia learned to avoid capture in subsequent campaigns, and this effect may explain the disparity between Method 1 and Method 2 here. Specifically, dogs captured and neutered in 2015 and 2016 may have learned from that experience and been more averse to future capture in subsequent years. Therefore the pre-campaign estimates of neutered dog percentages (Phase 1) may be an under-estimate compared to the capture-independent post-campaign surveys (Phase 2). Given that Method 1 utilises the pre-campaign estimates, whereas Method 2 utilises the post-campaign estimates, we propose that Method 1 is more vulnerable to capture bias, and that this may explain the apparent increased turnover seen in 2016 when assessed by Method 1. Furthermore, the size of this capture bias may vary between the sexes, given the lower proportion of female dogs captured in Phase 1 that were neutered (Fig.4) compared to male dogs captured in Phase 1. Alternatively, this could indicate that mortality is higher in neutered females compared to neutered males; however, this seems unlikely considering the proportions of male and female dogs that were neutered during the campaigns were very similar (Table 1), and the estimated proportions of male and female dogs that were neutered were more similar in the Phase 2 sight surveys than in the Phase 1 capture surveys (Figure 4). This reiterates the value of population estimators that do not rely on capturing in future demographic studies, as has been identified in other studies (Belo et al., 2015; Meunier et al., 2019; Tiwari et al., 2019) and also re-emphasises the potential value of oral-baited rabies vaccine administration for reaching capture-averse free-roaming dogs (Gibson et al., 2019).

Mean losses of neutered dogs between years in our study are around 39%. Given that there are no natural barriers to dog migration at the perimeter of Ranchi city, and there are peri-urban areas surrounding the city, the high losses identified in this study are likely be a combination of both mortality and outward migration. Pal (2001) reported 24% mortality in dogs over 1 year of age, whilst Reece et al. (2008) estimated 30% annual mortality for female neutered dogs over 1 year of age. The annual losses in this study are slightly higher than these previous estimates of mortality in Indian free-roaming dogs, but are comparable given that our estimates also include dogs between 4 and 12 months of age, a demographic shown to have a much higher mortality rate in free-roaming dogs in West Bengal (Pal, 2001).

Establishing the rate at which dogs are lost from the population is crucial to the implementation of successful rabies vaccination campaigns, facilitating calculation of the optimal interval between vaccination campaigns and the level of vaccination required to maintain coverage above the critical 40% threshold (Hampson et al., 2009). Research based in owned, free-roaming dogs in sub-Saharan Africa and Indonesia estimate that vaccination coverage of 60-70% is sufficient when annual crude mortality (including all ages of dog) is 56.8% (Conan et al. (2015). Vaccination coverage of this magnitude has been achieved in Ranchi, as was previously reported by Gibson et al. (2015). However, given our estimated losses only include neutered dogs (and only dogs estimated to be over 16 weeks old were sent to be neutered), crude mortality in the general population (including entire dogs and very young puppies) is likely to be higher, which might result in vaccination coverage falling below the 40% critical threshold before the next annual campaign is conducted. It is therefore vital that further research is conducted into the longevity of free-roaming, unowned dogs in India, e.g. longitudinal studies tracking individual dogs with high granularity, as has been performed for free-roaming, owned dogs in Tanzania (Czupryna et al., 2016), and in South Africa and Indonesia (Morters et al., 2014). In addition, given the potential role of dog migration, there is also a need for further research tracking individual free-roaming dogs in India to examine their geographical ranges, as has been performed in Chile (Pérez et al., 2018) and Australia (Dürr and Ward, 2015; Hudson et al., 2017; Meek, 1999).

The rate of population decline was significantly lower than the rate at which neutered dogs were lost, indicating significant replenishment of entire dogs in the city. Despite high levels of neuter coverage achieved within the city, after each campaign around 15 – 25% of female dogs (estimated over 12 weeks of age) were entire. Considering the high individual fecundity of female dogs reported by Reece et al. (2008), with each female producing an average of 8 pups per year, this is likely to be the major source of population replenishment. In addition, new dogs may have been added via inward migration or the release of confined, owned dogs or their puppies. During the ~11 months between annual campaigns in each ward, substantial numbers of puppies that were not yet born or too young for surgery in the previous campaign have time to reproduce at least once, contributing to the entire population. Considering this, if resources allow, planning neutering interventions at shorter intervals whilst entire dog numbers are still low, may capitalise on previous efforts.

Furthermore, we observed seasonal patterns in the population age structure (Figure 5), that correspond to seasonal reproduction reported previously in free-roaming Indian dogs (Chawla and Reece, 2002; Fielding et al., 2021; Pal, 2003, 2001; Reece et al., 2008; Totton et al., 2010). Age estimation was performed by visual assessment, as has been reported in previous canine demographic studies in India (Pal 2001, 2003; Totton et al., 2010). This method cannot give precise age estimates; however estimation was performed by a small team of consistent observers, therefore we do not believe this impacts the validity of this observed temporal variation. Given these seasonal peaks in the proportion of puppies observed, targeting campaigns after these peaks from February to April when puppies are old enough for surgery but have not yet reproduced might also increase the impact of interventions resulting in reduced population turnover and fewer dogs. A more stable population could reduce both the required vaccination coverage and the absolute number of dogs to vaccinate. This could save on resources, although the relative benefit would need to be weighed against the relative costs of neutering versus vaccinating. As part of this assessment, further research investigating whether juvenile mortality also shows seasonal variation would be extremely valuable. This re-emphasises need for further detailed dog demographic studies and modelling targeted at assessing optimum rabies vaccination strategies in India, comparable to those performed for free-roaming, owned dogs in sub-Saharan Africa (Chidumayo, 2018; Conan et al., 2015; Czupryna et al., 2016; Gsell et al., 2012; Hampson et al., 2009; Kitala et al., 2002).

Conclusions

Over the course of three years, 26,213 free-roaming unowned dogs were surgically neutered, with post-campaign surveys indicating that more than 70% of free-roaming dogs were neutered by the end of each campaign year. Over the three campaign years studied here, the total dog population was estimated to decrease by 12.58%; however, our analysis also demonstrated that high numbers of neutered, vaccinated dogs were lost between campaign years. In addition, the results reveal potential biases in capture-based techniques and demonstrate seasonal reproductive patterns. These findings highlight knowledge gaps regarding the demographics of free-roaming dogs in India and the need for further research in order to optimise both dog population management strategies, and mass rabies vaccination campaigns.

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Conflicts of Interest

None to declare.

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Figures and Legends

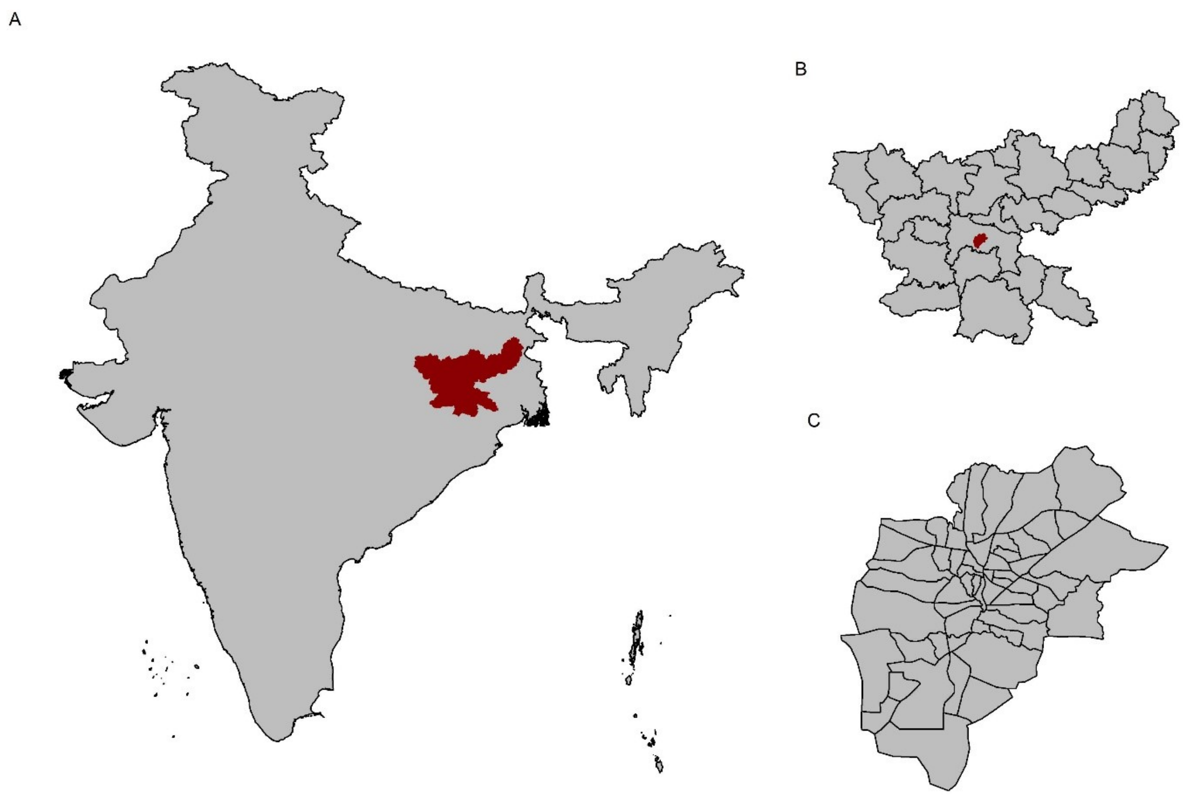

Figure 1 A: Jarkhand state within India B: Ranchi city within Jarkhand C: Administrative ward boundaries within Ranchi city

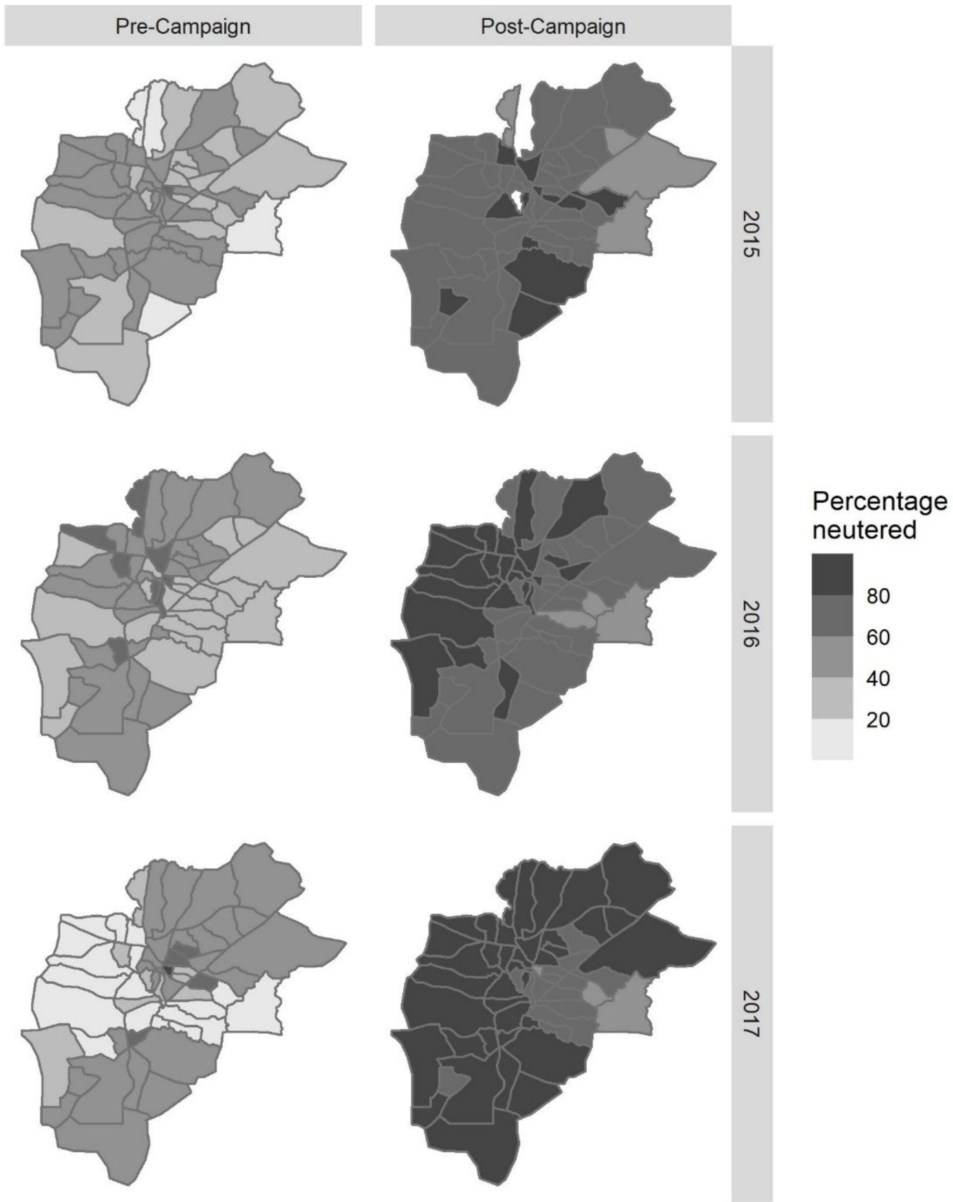

Figure 2 Choropleth maps of the percentage of dogs captured during Phase 1 (Pre-Campaign) and sighted in the Phase 2 re-sight surveys (Post-Campaign)) that were neutered.

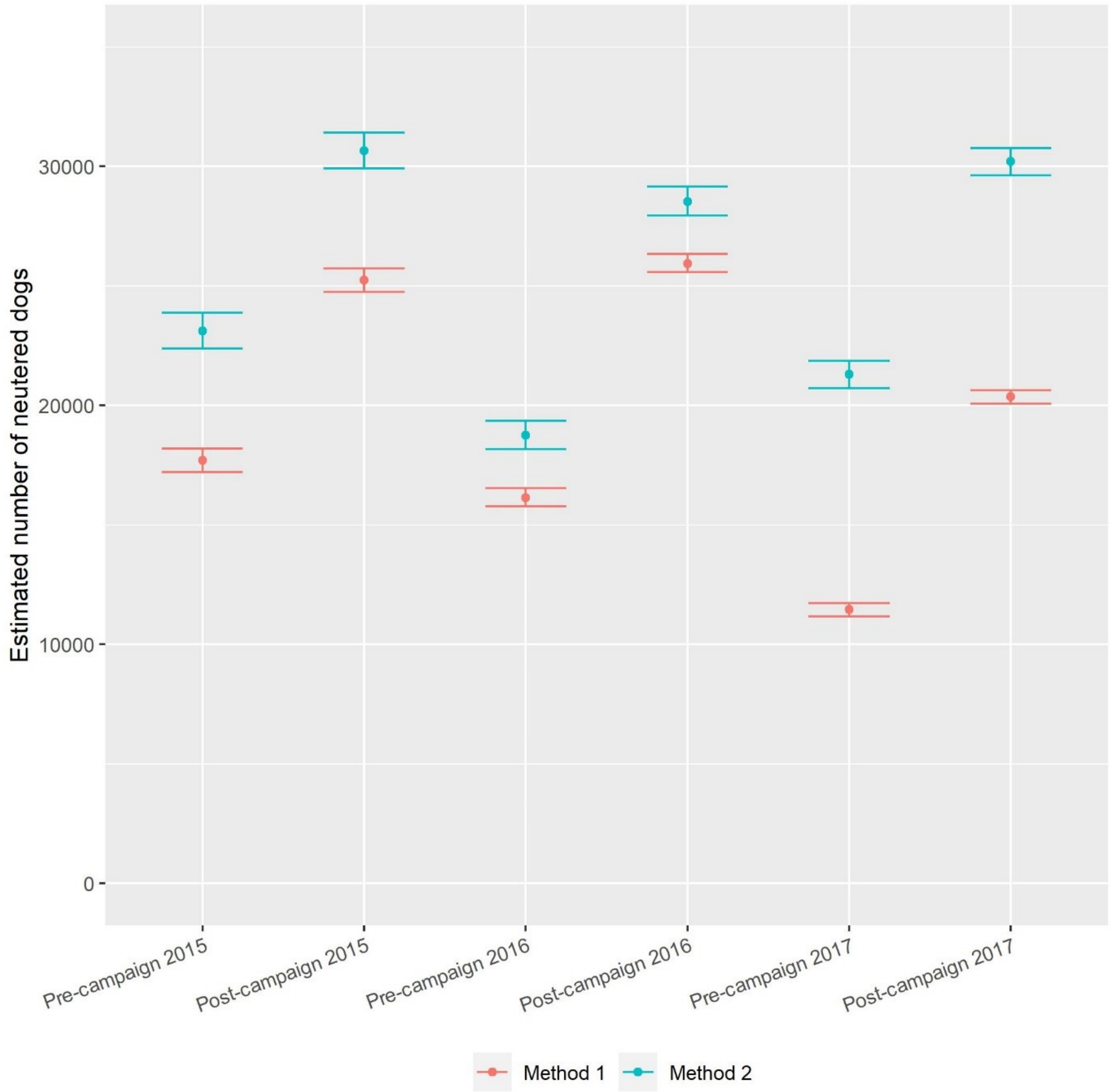

Figure 3 Number of neutered free-roaming dogs (and 95% CIs), before and after each campaign, asses by Method 1 and Method 2.

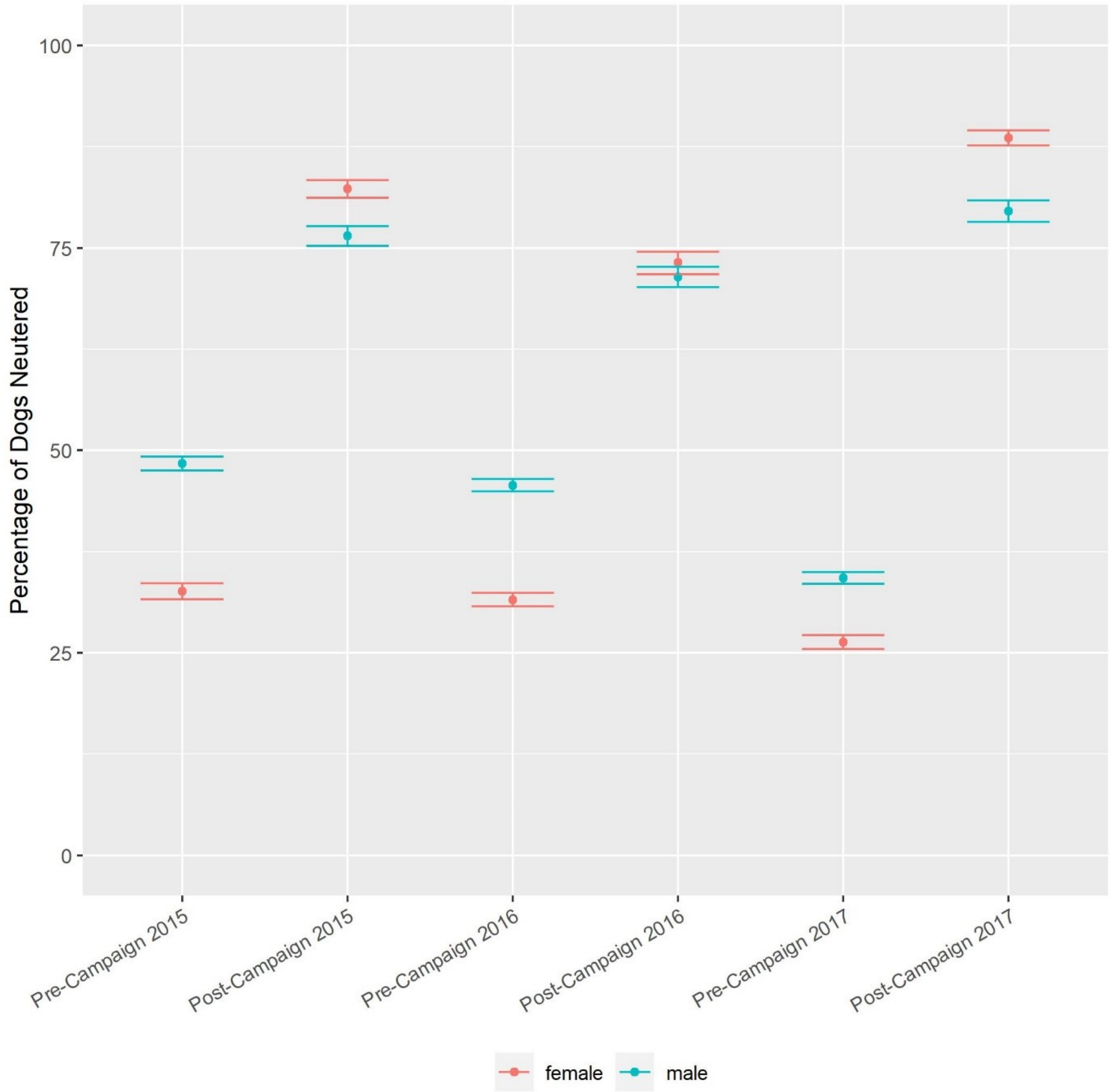

Figure 4 Percentages (and 95% CIs) of free-roaming dogs (estimated >12 weeks of age) that were neutered, Pre- and Post-Campaign, stratified by sex.

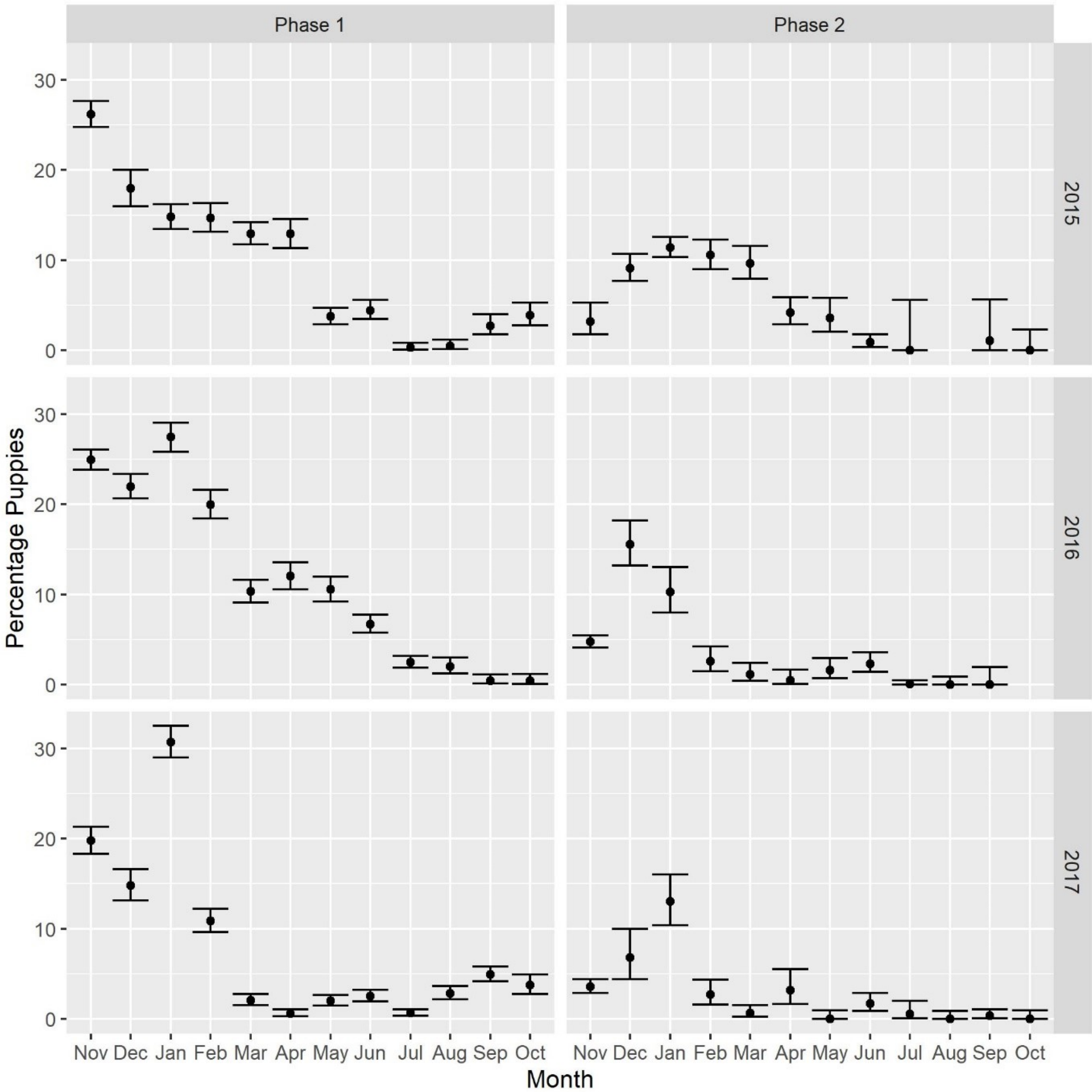

Figure 5 Percentages (and 95% CIs) of dogs that were puppies (<12 weeks) during the months of each campaign