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Stray dog population demographics in Jodhpur, India following a population control/rabies vaccination program

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ABSTRACT

Animal Birth Control (ABC) is a program by which stray dogs are sterilized and vaccinated against rabies with the aim of controlling both dog population size and rabies. Population size and demographics of stray dogs were measured before and after implementation of an ABC program in Jodhpur, India. Dog population size declined ($p < 0.05$) in three of five areas surveyed, showed a decreasing trend ($p > 0.05$) in 1 area, and remained stable in 1 area between 2005 and 2007. By 2007, 61.8–86.5% of the free-roaming dog population was surgically sterilized and vaccinated for rabies in the areas surveyed.

In March–May, 2007, adults comprised 80–96% of the free-roaming dog population, while subadults and puppies comprised 0–18 and 0–4%, respectively. The male:female ratio among dogs > 3 months old was 1.4:1. A population demographic model predicted that at the current level of sterilization/rabies vaccination, vaccination coverage would remain above 70%, and the dog population would decrease by 69% reaching stability after 13–18 years. A surgical sterilization coverage under 40% would maintain the dog population at current levels.

1. Introduction

More than 20,000 people die of rabies every year in India, and the majority of victims acquire the disease from the bite of a rabid stray dog (Sudarshan et al., 2007). Animal Birth Control (ABC) is a dog population control strategy by which stray dogs are captured, sterilized, vaccinated against rabies, and released at their point of capture (Reece et al., 2008). ABC has been adopted in many countries including India (Reece et al., 2008; Bogel and Hoyte, 1990). However, little peer-reviewed data exist in the literature assessing the impact of ABC programs on stray dog population size and demographics.

Information on human rabies in the city of Jodhpur, India is scant and incomplete (Dr. Suresh Maheshwari, Professor and Head of the Sampurnanand Medical College in Jodhpur, pers. comm.). The Sampurnanand Medical College in Jodhpur diagnoses an estimated ten human rabies cases annually (Dr. Suresh Maheshwari, pers. comm., February

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24th, 2005). This figure may well underestimate the true incidence of human rabies in Jodhpur as most people who contract the disease in India do not go to hospital for treatment or formal diagnosis, preferring to die at home since there is no treatment (Roy, 1962).

Although the incidence of dog rabies in Jodhpur is unknown it is likely higher than the rabies incidence in humans (Dr. M.S. Rathore, Deputy Director of Government Veterinary Hospital, Jodhpur, pers. comm., 2006). Because there is no requirement or agency for reporting the disease, the majority of dogs with rabies in Jodhpur are not brought to the local government veterinary hospital but are killed by community members without being reported (Dr. M.S. Rathore, pers. comm., February 2006).

The objectives of this study were: (1) to estimate the age and gender demographics of the stray dog population in the city of Jodhpur, India, (2) to estimate the proportion of stray dogs sterilized and vaccinated for rabies through Jodhpur's ABC program, (3) to estimate the current impact of the ABC program on stray dog population size in Jodhpur, and (4) to predict the long-term impact of ABC on dog population demographics in Jodhpur.

2. Materials and methods

The experimental unit was the stray dog, defined as a dog that is allowed to roam on public property in a completely unrestricted or semi-restricted manner, including those dogs which have a reference household or person(s) from whom they obtain food and/or shelter. All dogs used in this study were obtained from the streets of Jodhpur. All dogs in Jodhpur were eligible for this study, with the following exceptions: chained, leashed, confined, and/or collared dogs and puppies (dogs ≤ 3 months old) were not used in this study in deference to community sentiment.

2.1. Study area

This study took place in the city of Jodhpur (26.29°N, 73.03°E; altitude 230 m), in the state of Rajasthan, northwestern India. Pal (2001) divided the year in India into four seasons: summer (March–May), monsoon (June–August), late monsoon (September–November) and winter (December–February).

Mark-recapture studies were performed in 2005 and 2007 in six different areas within the city of Jodhpur, chosen to reflect different habitat types found in the city (e.g. residential, market, tourist, under construction, etc.). Area 1 was located within the walls of the Old City (oldest part of Jodhpur), contained narrow, winding streets and alleys and comprised Hindu commercial, Muslim commercial and some residential components. ABC was initiated in this area after March 2005. Area 2 was also located within the walls of the Old City. This area is predominantly market and middle-class to lower-class residential. ABC was launched here in December 2004. Area 3 was an upper-class residential area with wide avenues. The ABC program was launched here in March 2005. Area 4 was a middle-class residential area with large green spaces (vacant lots) and extensive areas of construction. When ABC was launched here after October 2005. Area 5 consisted of middle-class residential, some market areas and a few, small parks. This area was covered by the ABC program in February 2005. Area 6 was lower-, middle- and upper-class residential with stray cows, pigs and tethered goats. This was one of the first areas to undergo ABC (April 2004).

2.2. Dog population size and demographics assessment

The 2005 mark-recapture studies were carried out in the late monsoon season (September–November) (except in Area 1 where the 2005 mark-recapture study took place in March) while the 2007 mark-recapture studies were carried out in the summer season (March–April). Each mark-recapture study ran for 5 days because, based on preliminary observations, this was the length of time the marks persisted on the dogs. From day 1 to day 4 the marking team proceeded through the designated area, marking every unmarked dog observed (i.e. no dog was marked more than once). Mark-recapture was conducted between 8:00 a.m. and 10:00 a.m., when stray dogs were most active and visible. Marks were applied from a distance with an Aspee Eden 5-l spray canister. Black dogs were marked with a tumeric solution; all other dogs were marked with beetroot juice. The marking team recorded the total number of dogs they marked, the gender of each dog they marked and whether each dog had a notch in its left ear. All dogs processed through Jodhpur's ABC program received a notch in the left ear at the same time as they were surgically sterilized.

On days 2–5, about 15 min after the marking team had begun marking the dogs and were out of sight of the counting team, the counting team proceeded through the area using the same route, recording the gender, age, notch status and mark status (marked versus not marked) of every dog observed. Dogs were never handled, thus "recapture" refers to visual recapture. In both 2005 and 2007, the marking and counting teams used the same route through a given area when marking and counting dogs, respectively.

Dogs were classified as adults if they had developed teats (females) or descended testes (males). Sexually immature dogs were classified as subadults or puppies using Daniels's (1983) visual criteria of body size and allometry, head size and leg length relative to body size. The number of puppies observed was used solely for population age demographic calculations.

The dog population size was estimated using the Schumacher Method (Schumacher and Eschmeyer, 1943) with 95% confidence limits calculated using the equations of Caughley (1977). Decimal places were rounded up to the nearest whole number. The assumptions of the Schumacher population estimation method were tested using the method outlined by Caughley (1977, p. 140) by plotting on the y-axis the number of marked dogs seen on a given day divided by the total number of dogs seen on a given day, and plotting on the x-axis the cumulative number of dogs marked on that day. If the resulting plot does not form a straight line (assessed by eye) passing through the origin, one or more of the assumptions of the Schumacher Method have been violated. To estimate the prevalence of males in the stray dog population, data from the marking team were pooled across all areas for 2005, and all areas for 2007.

The prevalence of vaccinated dogs was calculated as the number of notched dogs observed by the marking team in each area, divided by the total number of dogs observed by the marking team in that area. Because the marking team did not record age of the dogs marked, nor did they mark puppies, the counting team's data alone were used to estimate the proportion of adults, subadults and puppies in the population. To avoid counting any particular litter of puppies more than once, data from only one randomly selected mark-recapture counting day (using the Random Integer Generator at http://www.random.org/integers/) were used for each of the mark-recapture areas in 2005 and 2007. All dogs observed on the randomly selected days, whether marked or not, were used in our calculations.

2.3. Dog population demographic model

We used the mark-recapture data to develop a demographic model of the stray dog population in VenSim DSS32 Version 5.1A (Ventana Systems, Inc., Harvard, USA) to predict the long-term impact of the current sterilization rates on the dynamics of the dog population over time. The total number of females and males with respect to neuter status and age composition were not estimated therefore the model could not be gender- or age-stratified. The model utilized the following equations:

$$\frac{dD}{dt} = bD - nD - cD(D+N) \quad (1)$$

$$\frac{dN}{dt} = nD - cN(D+N) \quad (2)$$

Jacobian Matrix and Eigen values

$$\begin{bmatrix} b - n - 2cD - cN - E & -cD \\ n - cN & -cD - 2cN - E \end{bmatrix}$$

where D is the total number of dogs not yet sterilized, N is the number of sterilized dogs, b is the birth rate, n is the overall rate of sterilization and c is the resource competition constant. The term bD represents births; the term nD represents neutering; and the terms $cD(D+N)$ and $cN(D+N)$ represent competition effects: as the total population $D+N$ increases, the terms $cD(D+N)$ and $cN(D+N)$ become larger in magnitude and hence depress population growth more. A Jacobian matrix was used to estimate Eigen values $E1$ and $E2$ which provide stable equilibrium conditions of the dog population (Keeling and Rohani, 2007).

The characteristic polynomial can be written as:

$$(b - n - c(D+N) - E1)(-c(D+N) - E2) \quad (3)$$

$$E1 = b - n - c(D+N) \quad (4)$$

For the model, the total number of dogs in 2005 and 2007 was the combined total of the number of dogs in each area for 2005 and 2007, as estimated by the Schumacher equation. The total number of notched dogs was calculated as the percentage of notched dogs (obtained directly from the marker's data) multiplied by the total number of dogs in 2005 and 2007. We considered the transition between 2005 and 2007 as one time step with 2-year duration, interpolating values for the year 2006 and refitting the model with an annual time step over 3 years. Parameters n and c were fitted for all study areas separately and for all data pooled together.

Per capita birth rates (b) were estimated by multiplying the annual pregnancy rate (0.475) reported for Jaipur, a neighbouring city to Jodhpur (Reece et al., 2008) with the median litter size obtained from the analysis of uterine contents of bitches during sterilization in a separate study in Jodhpur (median = 5) (unpublished data), which provided an annual reproduction rate of females in reproductive age of 2.375. The proportion of reproductive females in the whole population was 0.427 (n = 549) and a median litter size of 5 (minimum 1; maximum 9), which yielded, using a Monte Carlo simulation (@Risk software V.3.5.2, Palisade Corporation, normal approximation of the binomial estimate), an annual per capita birth rate of 1.014 (95% confidence limits: 0.354–1.674). We assumed that mortality rate was dependent on competition over available resources. To avoid over-parameterizing our model, we used a single mortality rate for all dogs (sexually intact and sterilized) in our final model. Mortality rates can be obtained by multiplying the resource competition constant (c) with the population size at a given time.

Parameters were fitted simultaneously using a Powell algorithm.

For the long-term simulations we used the parameter values in Table 1. For the equilibrium analysis we used the first Eigen value $E1 = -0.4773796$ from Eq. (4) which, summed with the sterilization rate, provided a stable dog population (D) for the duration of the simulation (Figs. 1 and 2, line with crosses).

To obtain information of parameter variability for the sensitivity analysis, we used Bayesian estimates of the neutering rate (n) and the resource competition rate (c) using

Table 1
Variation of the birth rate, resource competition constant (death rate) and sterilization rate found in a population demographic model of stray dogs in Jodhpur, India in the wake of an Animal Birth Control program.

Parameter	Mean	SD	Min	Max	Method
Birth rate (b)	1.01412	0.3368	0.2066	1.979067	Monte Carlo
Resource competition constant (c)	0.00099584				Demographic model
Sterilization rate (n)	0.80437				Demographic model
			Lower 95% credibility interval	Upper 95% credibility interval	
Mortality (c*690)	0.7789	0.02038	0.7378	0.8173	Bayesian
c	0.00112	0.000029	0.00106	0.00118	
Sterilization rate (n)	0.7048	0.02255	0.6601	0.7479	Bayesian

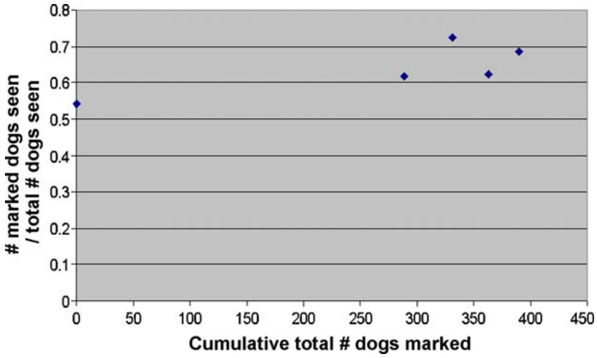

Fig. 1. Graphical test of the assumptions of the Schumacher population estimation method for Area 1 in 2005.

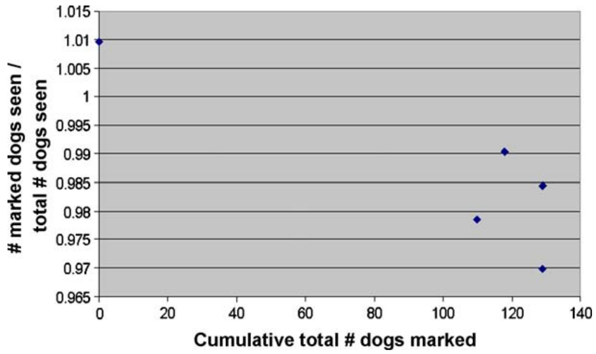

Fig. 2. Graphical test of the assumptions of the Schumacher population estimation method for Area 1 in 2007.

WinBUGS, (Version 1.4.3, Imperial College and MRC, UK) the probability distribution of the observed parameters of all areas assuming a binomial distribution of c and n, and a normal distribution of b.

3. Results

3.1. Stray dog population demographics

According to the graphical test, the assumptions of the Schumacher Estimate were violated in Area 1, as the graphs of the mark-recapture data did not produce a line moving upward toward the right (Figs. 1 and 2) so the data from Area 1 were dropped. The number of stray dogs (>3 months old) and the percentage of dogs notched in each of the remaining 5 areas in 2005 and 2007 are shown in Table 2. Dog population size declined significantly ($p < 0.05$) between 2005 and 2007 in Areas 3, 4 and 6. Area 2 showed a non-significant ($p > 0.05$) decreasing trend. The dog population size did not change significantly in Area 5 between 2005 and 2007.

There was an increase ($p < 0.05$) in the percentage of dogs notched in Areas 2, 3 and 4 between 2005 and 2007. In Area 5 the prevalence of notched dogs did not change. The percentage of dogs notched increased non-significantly in Area 6 between 2005 and 2007.

The prevalence of males in the stray dog population > 3 months old was 56.5% (95%CI = 52.3–60.6%; n = 549) in 2005 and 58.4% (53.7–62.9%; n = 435) in 2007, yielding a male-biased sex ratio of 1.3:1 in 2005 and 1.4:1 in 2007. The prevalence of adults, subadults and puppies in the Jodhpur stray dog population is shown in Table 3.

Table 3
Age structure of populations of free-roaming dogs in five areas within the city of Jodhpur, India.

Area	Age structure 2005[a,b]	Age structure 2007
2	A 96% (90–99%) S 2% (0–7%) P 2% (0–7%)	A 89% (81–94%) S 6% (3–13%) P 5% (2–12%)
3	A 87% (76–93%) S 3% (1–10%) P 10% (5–20%)	A 80% (69–87%) S 18% (11–28%) P 2% (1–10%)
4	A 90% (81–95%) S 1% (0–7%) P 9% (5–18%)	A 93% (81–98%) S 7% (2–19%) P 0% (0–8%)
5	A 95% (87–98%) S 3% (1–9%) P 2% (1–9%)	A 96% (90–99%) S 0% (0–5%) P 4% (1–11%)
6	A 88% (77–94%) S 4% (1–12%) P 8% (4–19%)	A 96% (88–99%) S 4% (2–12%) P 0% (0–5%)

[a] Proportion of the free-roaming dog population which are: A = adult (sexually mature), S = subadult (sexually immature but independent from mother), P = puppy (≤3 months old).
[b] Numbers in brackets are 95% confidence intervals.

3.2. Dog population demographic model

A summary of the parameters estimated by the model is given in Table 4. The dog population remains stable when 31% of the dogs are sterilized (Fig. 3). In contrast, the currently observed sterilization rate reaches a stable proportion of sterilized dogs of 80%. If sterilization were to cease in 2005, the percentage of neutered dogs

Table 2
Stray dog population size estimates[a] and percentage of dogs sterilized (95% confidence intervals in brackets) in six areas in the city of Jodhpur, India.

Area	2005 %Notched[b] (95%CI)	2005 Schumacher Estimate	2007 % Notched (95%CI)	2007 Schumacher Estimate
1	0% (0–1.0%)	463 (437–493)	76.7% (68.7–83.2%)	126 (113–143)
2	53.7% (45.3–62.0%)	189 (138–297)	73.5% (64.2–81.1%)	113 (93–145)
3	12.1% (7.3–19.2%)	164 (124–242)	61.8% (50.6–71.9%)	80 (78–83)
4	0% (0–3.7%)	111 (98–128)	65.7% (53.7–75.9%)	68 (67–70)
5	86.8% (79.0–92.0%)	114 (105–126)	86.5% (78.9–91.6%)	111 (105–118)
6	55.9% (45.8–65.6%)	112 (103–123)	67.1% (56.2–76.5%)	81 (74–90)

[a] These estimates are of the number of stray dogs > 3 months old (not including pet dogs). Decimals rounded up to the nearest whole number.
[b] Notched = spayed/neutered and vaccinated for rabies through an Animal Birth Control program.

Table 4
Summary of estimated parameters based on a dog population demographic model of stray dogs in Jodhpur, India undergoing an Animal Birth Control program.

	Area				
	2	3	4	5	6
All dogs	189	164	111	114	112
Dogs (intact)	88	144	111	15	49
Resource competition constant	0.00741275	0.0115608	0.0141232	0.002632	0.0107059
Annual resource competition constant	0.003706375	0.0057804	0.0070616	0.001316235	0.00535295
Number dead dogs	62	137	87	2	29
Neutering rate	1.60721	1.27133	1.35176	1.73034	1.46082
Annual neutering rate	0.803605	0.635665	0.67588	0.86517	0.73041
Number spayed/neutered dogs	71	92	75	13	36

in the population is predicted to drop to 0% by 2009 (Fig. 3).

Long-term simulations revealed that at the current rate of sterilization, the dog population should continue to decrease until it stabilizes at a 69% decrease from the original population size, in about 13–18 years (Fig. 4).

Sensitivity analysis revealed that the most sensitive parameter is the birth rate, followed by the neutering rate and the resource competition constant *c* (which indirectly includes the mortality rate). Variability of the three parameters is given in Table 1.

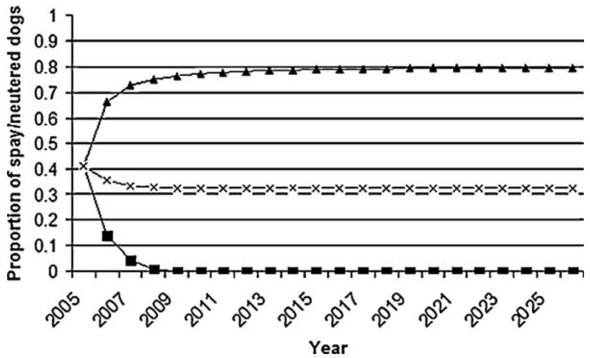

Fig. 3. Dog population demographic model showing proportion of sterilized dogs in the population if sterilization continued at the current rate (triangles), if the population remained stable (crosses) or if sterilization ceased in 2005 (squares).

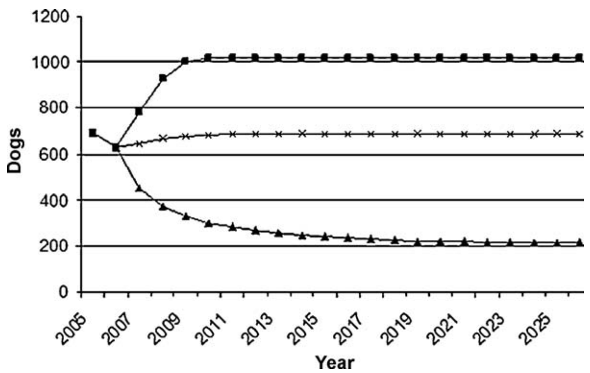

Fig. 4. Change in the total stray dog population size over time in Jodhpur, India, in the wake of an Animal Birth Control program if sterilization continued at the current rate (triangles), if the population remained stable (crosses) or if sterilization ceased in 2005 (squares).

4. Discussion

4.1. Rabies vaccination coverage

Empirical data from a number of studies in the United States indicates that dog rabies will be eliminated if 80% of the dog population ≥ 4 months of age are vaccinated (70% of the total dog population) (Beran, 1991) though the necessary level of coverage is likely to vary with disease transmission dynamics, population demographics, behavioral and spatial characteristics of the dog population (WHO, 2004). Coleman and Dye (1996) created a theoretical model that predicted that vaccinating at least 70% of the dog population was necessary to eliminate or prevent rabies on at least 96.5% of occasions.

Observed data from our Jodhpur study indicate that this threshold of vaccination coverage in the stray dog population is achievable; by 2007, the prevalence of sterilized/vaccinated dogs (>3 months old) in each of our mark-recapture areas was between 61.8 and 86.5%. Total coverage of the dog population was not possible because the dog catchers in Jodhpur's ABC program do not pick up lactating bitches or those in advanced pregnancy (i.e. later than 51 days post-conception) or puppies ≤ 3 months old, since the rabies vaccine is not recommended for use in dogs so young.

Also, our demographic model indicates that at the current level of sterilization, the threshold of 80% of the population should be reached over the long-term, which is sufficient to interrupt rabies transmission in this population. This is assuming that all sterilized dogs are also vaccinated and that immunity following vaccination is lifelong given the short lifespan of stray dogs (as has been assumed by Reece and Chawla, 2006) in Jaipur's ABC program. Stray dogs in India have been reported to live an average of only 2.6 years (Pal, 2001).

However, our model predicts that if the sterilization/vaccination program is stopped in Jodhpur, the percentage of vaccinated dogs in the population will rapidly fall below the threshold and will return to pre-ABC levels within 3–4 years.

4.2. Dog population size

In contrast to the rule of thumb for rabies control, there is no hard-and-fast rule regarding what proportion of the population needs to be sterilized in order to control the dog population itself. It has been reported that Animal Birth Control programs, properly carried out, are expected to decrease the dog population, with stabilization occurring 5–7 years after implementation (Leney and Remfry, 2000). Our population demographic model indicated a longer time-to-stabilization (13–18 years). There is little information in the literature reporting actual dog population size changes in cities undergoing ABC programs. Reece and Chawla (2006) reported a 28% decrease (between 1997 and 2002) in the stray dog population in Jaipur, a city located 343 km from Jodhpur, with an ABC program that was launched in 1994. This is a smaller decrease than we reported. However, because ABC began in Jodhpur in 2004, we expected to see a decrease in the dog population in all areas covered by the program, but not stabilization. We observed a more dramatic decrease in our dog population size ranging from 27.7% (Area 6) to 51.2% (Area 3) between 2005 and 2007. Our population demographic model indicates the most dramatic drop in the dog population occurs in the first 3 years after implementation of the ABC program. The reason for Reece and Chawla's (2006) smaller reported decrease may be because their dog population size estimates began 3 years after implementation of the ABC program in Jaipur had begun.

The reason for the lack of a decrease in our dog population size in Area 5 where > 80% of the free-roaming dog population was already sterilized in 2005, may have been because the effects of ABC on dog numbers in this area may already have become apparent by the time we began our study in 2005, although our demographic model does not predict such a rapid stabilization (see below). Coverage of dogs by the ABC program in areas bordering those in which we conducted mark-recapture studies might also have affected the population dynamics in each of our study areas, since there were no physical barriers to stray dog movement into and out of our study areas.

A possible contributing cause of differences in degree of decrease of the dog population between areas may be that our mark-recapture areas were chosen to reflect different habitat types. They were not chosen with regard to whether or not surrounding areas were undergoing ABC. The dog-catchers selectively implemented ABC in Jodhpur beginning in areas of the city where community acceptance was highest. In some cases, there may well have been "spillover" from an adjacent ABC area into our mark-recapture areas. We were unable to quantify this, because the dog-catchers recorded their progress via street names and unfortunately, since Jodhpur is a military town, we were unable to acquire a detailed street map of the city. This prevented us from calculating the degree of overlap between mark-recapture areas and other ABC-covered areas in the city.

In addition to ABC programs, habitat modification (decreasing the amount of food available in the habitat) should help maintain the population at the new reduced levels brought about by ABC programs (Beran and Frith, 1988). However, the most important determinant of dog population size is the attitude of humans (Matter and Daniels, 2000). Due to cultural tolerance, it is unlikely that stray dogs will ever be completely eliminated from India.

4.3. Gender and age ratios

We found a significant male-biased gender ratio among the population of adults and subadults in Jodhpur. In West Bengal, India, a male:female ratio of 1.37:1 was reported for free-ranging dogs (Pal, 2001). However, the ratio of males:females was approximately 1:1 in Jaipur after an ABC program had been implemented (Reece and Chawla, 2006). The male sex ratio bias has been attributed to the selection of males as pets, perhaps because of the perception that males make better guard dogs than females and to avoid the nuisance of owning a bitch in estrus or having to deal with unwanted puppies (Daniels and Bekoff, 1989; Daniels, 1983). Estrus females tend to cause neighbourhood complaints because they attract groups of intact male dogs. The male-biased sex ratio was not significantly different between 2005 and 2007 in our study. It could be that the full impact of ABC on dog gender ratio in this population has yet to be observed.

In theory, ABC programs should increase the adult fraction of the population by increasing longevity and decreasing reproduction. In one study of urban dogs (30% of which were allowed to roam free) in Ecuador, 18% of the dog population was 3–11 months old (Beran and Frith, 1988). Given that stray bitches in India have been reported to have their first estrus at 7–13 months of age (Ghosh et al., 1984) the 3–11 month old dogs are roughly equivalent to the subadult fraction of our population. In the same study, 14% of urban dogs were < 3 months of age (puppies) and 67.6% were 1 year of age or older (adults) (Beran and Frith, 1988). As in our study, adults comprised the majority of the population. We did not see a clear pattern regarding whether there was a higher prevalence of puppies than subadults.

4.4. Study limitations/future outlook

Potential bias arises in our dog population size estimates because the marking team did not mark collared free-roaming dogs, in deference to community attitudes. These dogs were not represented in our population estimate. However, collared free-roaming dogs were rare in the dog population; no collared dogs were observed in 2007, and only 4 were observed in 2005 so this bias is probably minimal.

Ideally, the 2005 and 2007 mark-recapture surveys in our study should have been carried out at the same time of year, however, our 2005 mark-recapture studies were carried out in the late monsoon season (September–November) while our 2007 mark-recapture studies were carried out in the summer season (March–April). This may be important if whelping is seasonal, because the population would be expected to fluctuate as new dogs are born and enter the population. A study of stray dogs in Jaipur, a city 331 km from Jodhpur, found a mean whelping date of November 23rd (Reece et al., 2008). If whelping is seasonal in Jodhpur, as is likely since estrus and pregnancy are seasonal in the Jodhpur stray dog population (Totton et al., 2010), our mark-recapture studies in March–April should have, shown an increase in the dog population in the form of new subadults entering the population at this time of year. The consistency of the observed population decline in areas from 2005 to 2007 is suggestive of a real decline as opposed to normal fluctuation in population size. Admittedly, the higher ambient temperature typical of the summer season in Jodhpur may have caused more dogs to seek shelter from the sun during the counting period compared to the late monsoon season when temperatures were more moderate. However, both the counting team and the marking team took care to search for dogs under parked vehicles and porches and community members were often helpful in pointing out dogs that were hiding from the counting team. We therefore feel confident that though a slight difference may have existed in our ability to detect dogs in the summer season that this difference would not have been great.

Our demographic model is parsimonious, but was fitted to a very limited number of time points. For the estimation of the variability of resource competition constant c we used a Bayesian binomial model using observed mortality data. Average values of c were close between the demographic and Bayesian estimate (Table 1). Longer time series and possibly gender- and age-differentiated numbers of sterilized and total numbers of dogs would allow us to fit a gender- and age-structured model possibly as a stochastic process. It is important to continue annual monitoring of the stray dog population size in Jodhpur over time as this will help refine model estimates.

5. Conclusion

Because the Jodhpur ABC program was launched in 2004, its full impact on the dog population is likely still to be realized. The results of this study showed a promising decline in the dog population after implementation of an ABC program. In addition, the observed data indicate that the target 70% vaccination coverage required for the elimination of rabies from this population is achievable.

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