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Short Communication

Modeling Alternative Ways to Restrict 'Stray' and Ownerless Dogs Populations and Their Implications for Zoonoses Control

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• Stray dogs
• Control strategies
• Mathematical model
• Capture-recapture

Abstract

Objective: To quantify the impact of dogs' population control strategies and their repercussion on zoonoses.

Methods: Mathematical model based on the generation projection known as Leslie's matrix and takes into account the age-dependent fertility rates and survival probabilities of females.

Results: We applied the model for a real community in the city of Guarulhos, localized in the metropolitan area of São Paulo City, Southeastern Brazil. Considering the total number of wandering dogs estimated by the capture-recapture method of 794 we can estimate, by the ratio male/female of 1.7 that there are about 294 females in the streets of the borough. These females are then able to generate about 271 female offspring.

Conclusions: The capture and culling strategy is more efficient in reducing the females' population in 20 years than the sterilization strategy. In addition, the culling strategy is somewhat more expensive but it is cheaper than an official sterilization program.

INTRODUCTION

In developing countries, the domestic dog is the most important reservoir and vector of human rabies. Rabies is one of deadliest and nastiest diseases and is characterized by afatal encephalitis. To date less than 10 documented cases of human survival from clinical rabies have been reported and only two have not had a history of pre- or postexposure prophylaxis [1]. Although the number of human cases transmitted by dogs decreased by 95% in the decade between 1990 and 2010, the Word Heath Organization believes that in Brazil and other countries in the Americas this number could be much higher [2]. In dogs, there are two forms of rabies: paralytic and furious. In the early symptom (prodomal) stage of rabies infection, the dog will show only mild signs of CNS abnormalities. This stage will last from one to three days. Most dogs will then progress to the furious stage, the paralytic stage, or a combination of the two, while others succumb to the infection without displaying any major symptoms [3]. Traditional rabies control measures in dogs have included mass vaccination, movement restrictions, and control of stray dogs.

The incidence of canine and human rabies in Brazil has decreased over the last three decades as a result of a national rabies-control campaign, including an annual mass vaccination of dogs and cats, increased effectiveness and safety of human post-exposure treatment, educational efforts and the control of street-dogs [4,5].

Other zoonoses (diseases or infections that are naturally transmissible from vertebrate animals to humans, WHO, 2015) [6] also have contributed to the motivation of controlling dogs' populations. For instance, in Brazil, attempts to control zoonotic visceral leishmaniasis (ZVL) has been done by programs based on the mass elimination of seropositive dogs. These programs, however, have failed to reduce the number of leishmaniasis cases [8,9]. The prevalence of canine infection in endemic regions of the country still ranges from 1 to 38%, and reaches up to 67% in certain areas [9-14]. According to Brazilian National Health, data of the past decades show that widespread culling of seropositive dogs does not reduce the number of human cases [15]. This has prompted a reassessment of the dog control policy in Brazil [16]. In addition, some studies suggest that dog elimination control programs are ineffective [9,17,18].

Three practical methods of dog population management are recognized:

Picture shows an example of a dog captured in day 1 and re-captured in day 2.

Picture Example of dog captured in day 1 (a) and re-captured in day 2 (b)

movement restriction, habitat control and reproduction control (WHO,[3] 2004) [19].

Attempts to control dog populations through culling, without alteration of habitat and resource availability, have generally been unsuccessful. Since the 1960s, **A**nimal **B**irth **C**ontrol (ABC) programs coupled with rabies vaccination have been advocated as a method to control urban street male and female dog populations and ultimately human rabies in Asia [20]. The rationale is to reduce the dog population turnover as well as the number of dogs susceptible to rabies and limit aspects of male dog behavior (such as dispersal and fighting) that facilitate the spread of rabies. Culling of dogs during these programmes may be counterproductive as sterilized, vaccinated dogs may be sacrificed.

Based on 1990 WHO guidelines, ABC programmes have been launched in several countries and the results have been encouraging, with a reported reduction in the size of the street dog population and the number of human rabies cases.

How to elect the best control strategy to control dog population and how to optimize the cost-effectiveness of such strategy?

To answer these questions, well-designed dog ecology and demography studies are necessary [21,22,23]. Such studies have proved useful in planning dogs control in Asia, Latin America and North Africa [21,22]. Crucial parameters to be estimated include: the size, turnover, age, survival probabilities and growth of the dog population; the proportion and sources of 'ownerless' dogs; the degree of supervision of owned dogs [24].

This paper is an attempt to help answering the question of which is the most cost-effectiveness control strategy of dog population control, capture and culling or sterilization of females.

METHODS

Target Population

The community studied was that of **Jardim Fortaleza**, a small borough of the city of **Guarulhos** (23° S, 46° W), localized in the Metropolitan Area of São Paulo, southeastern Brazil (Figure 1). This borough comprises about 12,000 inhabitants and it was chosen because it is isolated from the rest of the city and it is accessible by a unique paved road. Figure 1[25]. The human to animal's ratio of Guarulhos is about 5.5/1, with a male/female ratio of 1.7/1. This implies in an estimated number of about 2,200 dogs in the borough of Jardim Fortaleza, of which about 810 are females.

Estimating the number of stray dogs

The number of stray dogs was estimated by a variant of the method of capture-recapture [26-30]. In which a given number

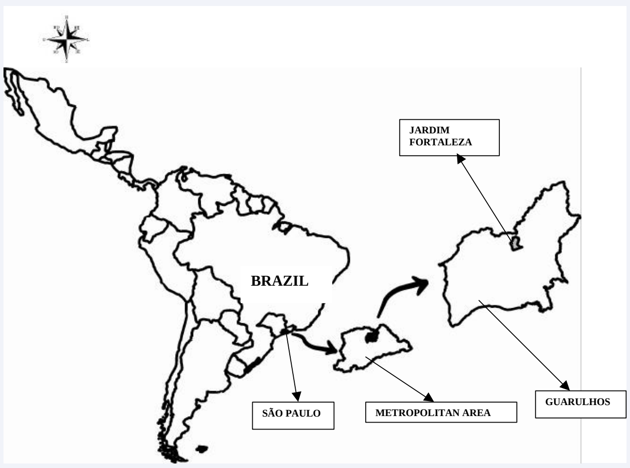

Figure 1 Area of the study, Jardim Fortaleza, in the city of Guarulhos, Metropolitan Area of São Paulo, Brazil.

of animals is digitally photographed in two consecutive days in a given area. The animals photographed in both days are called 'captured' and the animals identified as present in both days are considered 'recaptured'.

Assuming that the captures are independent, the total number of animals estimated by this method is given by

$$\hat{N} = \frac{(A+B)\times(A+C)}{A} \quad (1)$$

Where a means the number of animals captured and marked in day 1 that is also captured in day 2, B means the number of animals captured only in day 2, and C means the number of animals captured only in day 1.

The Leslie's Model of Population Growth

The so-called Leslie's (Leslie, 1945 and 1948) [31,32]. Model is based on a discrete time population growth in which the fertility rate and survival probabilities of females of a given species with discrete generation pattern is estimated. A simple matrix comprising the parameters above then calculates the age-stratified number of animals in each generation. So, calling the number of females aged ***i*** at generation ***t + 1*** as **x_i (t+1)** we have that

$$x_i(t+1) = x(t)p_i + x(t)f_i \quad (2)$$

Where **p_i** is the probability that the females will survive the generation interval between **t** and **t + 1**, and **f_i** is the fertility rate, that is the number of offspring produced by females aged **i** in the generation interval between **t** and **t + 1**. For all ages, the model can be written in its matricial form:

$$\begin{bmatrix} x_1(t+1) \\ x_2(t+1) \\ x_3(t+1) \\ \cdot \\ \cdot \\ \cdot \\ x_n(t+1) \end{bmatrix} = \begin{bmatrix} f_1 & f_2 & f_3 & \cdots & f_n \\ p_1 & 0 & 0 & 0 & 0 \\ 0 & p_2 & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & p_{n-1} & 0 \end{bmatrix} \times \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ \cdot \\ \cdot \\ \cdot \\ x_{n1}(t) \end{bmatrix} \quad (3)$$

Which can be iterated for several years allowing the estimation of projected population sizes. This is done by multiplying the first element of the survival/fertility matrix (f1) by the first element of the matrix representing the number of females in generation t (x1(t)) plus the second element of the survival/fertility matrix (f2) by the second element of the matrix representing the number of females in generation t (x2(t)) and so on. Note that the first line of the the survival/fertility matrix is comprised by the fertility rates, whereas form the second line downwards, only the survival probabilities pi appear. As described below, the estimation of the age-dependent fertility rates, f, and survival probabilities, p, were done experimentally.

Simulating the competing strategies

In this paper we considered two competing strategies for controlling street dog's populations, namely capture and culling and sterilization campaigns.

These strategies can be simulated in the Leslie's model by reducing the survival probabilities or the fertility rate by certain proportions. In this work we simulated an annual reduction of survival or fertility of 10%, 20% and 30%.

Estimating the demographic parameters p_i and f_i

For the estimation of the survival probabilities and fertility rates we interviewed 52 proprietors of female dogs attending the city rabies vaccination campaign about the age and number of offspring in each gestations of each animal. This provided us an estimation of the age-dependent fertility rates and survival probabilities.

RESULTS

Estimating the number of stray dogs

The first collection of data was carried out in 3 hours, during which the whole borough was visited, street-by-street. All the animals wandering were photographed, totalizing 180 animals. In the following day the same team visited the entire borough, following the same pathways as the day before and manage to find 255 animals. The animals identified in both days totalized 51 dogs. The estimation of the total population wandering the borough was then

$$\hat{N} = \frac{(A+B)\times(A+C)}{A} = \frac{255\times180}{51} = 794 \quad (4)$$

Of these 794 animals, about 294 were females.

Estimating the demographic parameters p_i and f_i

Table 1 summarizes the result of the 52 interviews, in which we show the age, number and proportion of the females and the number of offspring in each pregnancy, spanning from 1 to 6

Table 1 where the boldface figures represent the number of offspring born in the year before the interview totalizing 96, of which approximately half or 48 were females. This implies in an average number of 0.92 female offspring per female.

Considering the total number of wandering dogs estimated by the capture-recapture method of 794 we can estimate, by the ratio male/female of 1.7 that there are about 294 females in the streets of the borough. These females are then able to generate about 271 female offspring. Also, by considering the

Table 1: Result of the 52 interviews, in which we show the age, number and proportion of the females and the number of offspring in each pregnancy, spanning from 1 to 6. As mentioned in the main text, the boldface figures represent the number of offspring born in the year before the interview totalizing 96, of which approximately half or 48 were females.

Age	Nº	%	1st	2nd	3rd	4th	5th	6th
1	17	33	79					
2	13	25	113	5				
3	11	21	83	31	6			
4	7	13	41	12	10	6		
5	3	6	3	10	0	0	0	
6	1	2	0	0	3	0	0	0

proportion of females in each age class as in table 1 and the initial number of newborns in this cohort, we can calculate the demographic parameters pi and fi . For instance, from the 79 offspring produced by the 17 females aged 1 year old in table 1, bout 40 was females. Hence 40 divided by 17 gives the fertility rate fa = 2.353, as shown in table 2. Also, from the estimated 271 female offspring of the studied cohort, only 35% survived the first year (96 animals), which gives the survival probability p0 = 0.35. For this calculation we assumed a stationary population. The remaining values of the parameters shown in table 2 were calculated this way. The results are summarized in table 2 and figure 2.

Projecting the Number of Females by the Leslie's Model

With the parameters shown in table 2 we applied the Leslie's matrix model for projecting the impact of the two competing strategies of dog control assuming first, as a baseline, the absence of intervention, that is, the population at steady state.

Figure 3 shows the results of the projection of the Leslie's model for 20 years simulated with the two control strategies with 10%, 20% and 30% of reduction in the survival probabilities and fertility rates.

Note that the capture and culling strategy is more efficient in reducing the females' population in 20 years than the sterilization strategy.

Estimating the costs of the competing strategies

In order to estimate the economic costs involved in each of the competing strategies we computed the total cost of capturing, maintaining the animals in kennels for at least three days. These sums up to US$15.00 per animal. Now, let us illustrate the estimation by considering two strategies that have the same result in terms of reducing the dog population after 20 years, that is, 30% of sterilization every year and 20% of culling every year (see figure 3). The sterilization can be performed either by campaigns, in which voluntaries bring the animals to the surgical theater and take them back to the community, or by official programs in which the animals are captured, operated, kept by an average of 6 days and are inscribed in an adoption program.

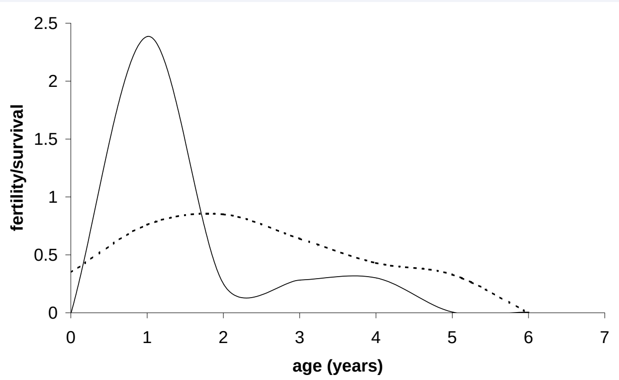

Figure 2 Age-dependent fertility rates (continuous line) and survival probabilities (dotted line).

Table 2: Estimation of the age-dependent fertility rates and survival probabilities from data as in table 2 (see main text for details).

Age	Nº	%	f_i	p_i
0	271	-	0	0.35
1	96	33	2.353	0.76
2	74	25	0.238	0.85
3	62	21	0.277	0.64
4	40	13	0.295	0.43
5	17	6	0	0.33
6	6	2	0	0.00

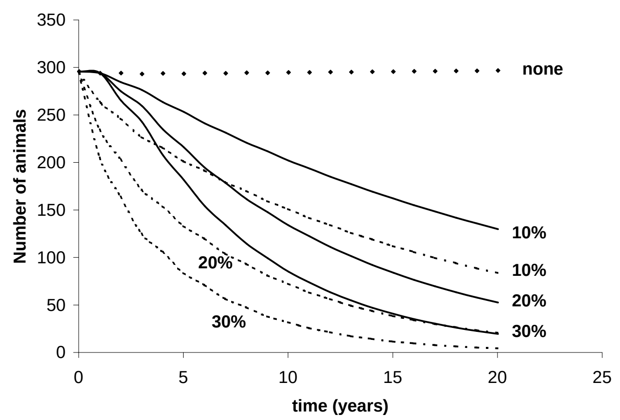

Figure 3 Projection of the impact of the two competing strategies in the size of the female population. Continuous lines represent the sterilization campaigns and dotted lines the capture and culling.

This cost US$15.00 and US$45.00 per animal, respectively. We did not include the eventual cost of the veterinary surgeons because they are voluntary. The culling strategy is comprised by capture, keeping the animals for a period of 3 days and culling. This costs US$23.00 per animal. Figure 4 shows the results of the three competing strategies exemplified above.

We can note from figure 4 that, by including procedures not necessary for the campaign sterilization strategy, this strategy is the cheapest. The culling strategy is somewhat more expensive but it is cheaper than an official sterilization program.

DISCUSSION

Since the dawn of humanity dogs have been considered men's best friends. However, with the advent of urbanization, in particular after the industrial revolution of the XIX century, a set of cultural factors resulted in a more or less important contingent of stray dogs. These ownerless animals wandered loose in the streets and their encounter with humans has resulted in a series of health problems, including several zoonoses and biting accidents. This caused organized societies to implement dog control programs, which traditionally consisted in capture-and-culling methods.

This latter strategy, although effective when adopted in parallel with vaccination programs in controlling rabies in some countries, was of limited use to control other zoonoses.

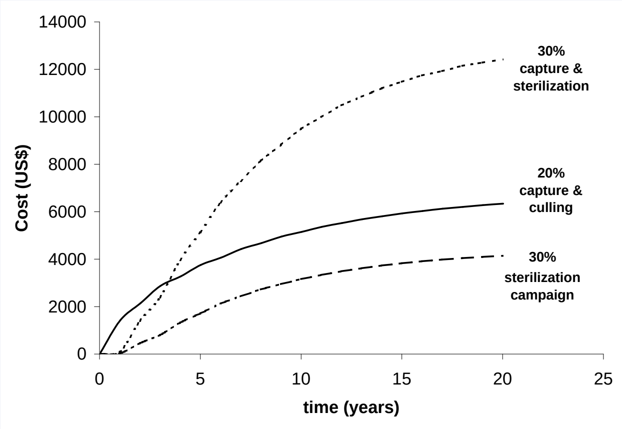

Figure 4 Simulation of the economic costs involved in each strategy.

As mentioned above, previous studies suggest that dog-culling programs alone do not reduce the incidence of leishmaniasis, even with an optimized intervention [7]. Possible reasons for this failure include: currently available serologic methods lack sufficient sensitivity and/or specificity to accurately identify all infected dogs warranting removal in order to prevent *Leishmania* transmission; destroyed dogs are immediately replaced by susceptible puppies, and quite often, by already infected dogs; and other reservoirs may be involved in maintaining canine infection.

In the developing countries with strong cultural ties with their pets, the most important limitation to the success of the capture-and-culling strategy is the fact that culled dos are immediately replaced by susceptible puppies [33]. In addition, that strategy has a high social cost, with the staff of the zoonosis control programs being severely hostilised by the population, who frequently hide the dogs from the captors.

The simple model presented in this work demonstrated that the alternative female sterilization program, with the help of volunteers to capture the stray dogs and bring them to be operated is almost as effective as the culling strategy in reducing the number of dogs in a given region, but is also cheaper by not needing the additional procedures like capturing and keeping the dogs in kennels for a certain time. However, if a voluntary program is unfeasible by any reason, an official sterilization program can be very expensive when compared to the culling strategy [34].

The model here presented was intended to be a guide to public health authorities and it gives support to a more humane way of controlling the size of the street dogs populations than simply destroying the animals.

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