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Dynamics and Control of Stray Dog Populations

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The population dynamics of stray dogs is simulated to assess the effects of sterilization and euthanasia. From simulations representing less than 5 years, sterilization is less efficient than euthanasia to reduce the stray dog population, considering similar rates, but the total number of sterilized dogs is less than the total number of euthanized dogs per km² per year. Over 20 years, both strategies have similar efficiency. Beyond a certain rate of dog abandonment, both strategies are inefficient.

Keywords: control; dynamics; euthanasia; sterilization; stray dog population

1. INTRODUCTION

In many countries, abandoned dogs have become a major public health problem. For the United States, Salman, New, Scarlett, and Kass (1998) mention 10 main reasons for relinquishing dogs: moving, landlord issues, cost of pet maintenance, no time for pet, inadequate facilities, too many pets at home, pet illness, personal problems, biting, and no home for littermates. Sterilization of owned dogs and euthanasia of healthy unadopted dogs in animal shelters are measures to solve the unwanted dog surplus and the subsequent abandonment of dogs to shelters or to streets. Educational campaigns might help avoid abandonment of dogs. The question is whether sterilization, euthanasia, or other methods can be effective to control stray dog populations.

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The survival of dogs depends on food, water, and shelter. Wandeler, Matter, Kappeler, and Budde (1993) have shown that in Tunisia the proportion of ownerless dogs in the proximity of a large dump site was greater than in other studied areas. Population control consists in the reduction of the abandonment of dogs; sterilization programs; euthanasia programs; and waste collection in order to reduce the possibility for dogs to find food, water, and shelter.

To avoid abandonment, the target of sterilization programs is usually owned dogs (Amaku, Dias, and Ferreira, 2009), but some dog caretakers are against the sterilization of their animals. Euthanasia is usually adopted as a control measure for stray dogs and owned dogs relinquished to shelters. Bangkok, Thailand, is an example of a city where a plan to sterilize stray dogs failed to achieve its goals due to a low sterilization rate, as reported by Clifton (2002). In Jaipur, India, the percentage of female dogs sterilized has stabilized at about 70% (Conservation Research, 2007). Dias et al. (2004), Larrieu, Alvarez, Cavagion, and Herrasti (1992), Marx and Furcolow (1969), Nunes, Martinez, Fikaris, and Queiróz (1997), Patronek, Beck, and Glickman (1997), and Virga and Viola (1993) deal mainly with density, dog/human ratio, and age distribution. We employ mathematical models to simulate dog population dynamics with sterilization and euthanasia.

2. MODEL

Control methods (either euthanasia or sterilization) are assumed to be implemented continuously at constant rates; sterilization is lifelong; dog population is subjected to density dependence; and all young are born fertile. According to Carding (1969), a stray dog is a dog whose freedom is not restricted by an owner.

2.1. Population Growth

We follow Barlow, Kean, and Briggs (1997), who simulate the effects of sterilization and culling in wildlife populations. Let us assume that the dog population density $N(t)$ at time t follows a logistic growth:

$$N'(t) = rN(t)\left(1 - \frac{N(t)}{K}\right), \qquad 0 \leq N(t) \leq K, \tag{1}$$

where K is the environmental carrying capacity, $r = a - b$ is the rate of natural increase with a the crude birth rate, and b the crude mortality rate.

2.2. Control by Euthanasia

A constant proportion ε of the population is removed by euthanasia at each time

$$N'(t) = rN(t)\left(1 - \frac{N(t)}{K}\right) - \varepsilon N(t). \tag{2}$$

2.3. Control by Sterilization

Let $Q(t)$ be the proportion of sterilized female dogs, Eq. (1) becomes

$$\begin{aligned} N'(t) &= N(t)\left(a(1 - Q(t)) - b - r\frac{N(t)}{K}\right) \\ &= rN(t)\left(1 - \frac{N(t)}{K}\right) - aN(t)Q(t). \end{aligned} \tag{3}$$

The density $S(t)$ of sterilized females is:

$$Q(t) = \frac{S(t)}{\nu N(t)}, \tag{4}$$

where ν is the proportion of females (the general sex-ratio) and σ the rate of sterilization.

Assuming that the mortality of sterilized females is equal to the mortality of the whole dog population,

$$S'(t) = \left(-b - r\frac{N(t)}{K}\right)S(t) + \sigma(\nu N(t) - S(t)). \tag{5}$$

Differentiating $Q(t)$ in Eq. (4), and using Eq. (3) and (5), we obtain:

$$Q'(t) = (1 - Q(t))(\sigma - aQ(t)). \tag{6}$$

The equilibrium points N^* and Q^*, for $r > 0$, are:

$$\begin{aligned} (N^*, Q^*) &= (0, 1); \\ (N^*, Q^*) &= \left(0, \frac{\sigma}{a}\right), \quad \text{for } \sigma < a; \\ (N^*, Q^*) &= \left(\frac{K(r - \sigma)}{r}, \frac{\sigma}{a}\right), \text{for } \sigma < r. \end{aligned} \tag{7}$$

The solution for $Q(t)$ of Eq. (6) is:

$$Q(t) = \frac{(aQ(0) - \sigma) + \sigma(1 - Q(0))\exp((a - \sigma)t)}{(aQ(0) - \sigma) + a(1 - Q(0))\exp((a - \sigma)t)}, \tag{8}$$

whose derivative is

$$Q'(t) = \frac{\left(Q(0) - \frac{\sigma}{a}\right)\left(\frac{\sigma}{a} - 1\right)(1 - Q(0))(a - \sigma)\exp((a - \sigma)t)}{\left(\left(Q(0) - \frac{\sigma}{a}\right) + (1 - Q(0))\exp((a - \sigma)t)\right)^2} \tag{9}$$

For $0 \leq Q(0) \leq 1$ and $t \geq 0$:

(i) If $Q(0) = 1$, then $Q'(t) = 0$ and $Q(t) = 1$.

(ii) If $a > \sigma$, $Q(0) > \sigma/a$, and $0 \leq Q(0) < 1$, from Eq. (9), $Q'(t) < 0$. $Q(t)$ is strictly decreasing in the interval $[\sigma/a,\ Q(0)]$, because the equilibrium point is $Q^* = \sigma/a$.

(iii) If $a > \sigma$, $Q(0) < \sigma/a$ and $0 \leq Q(0) < 1$, then $Q'(t) > 0$. $Q(t)$ is strictly increasing in the interval $[Q(0),\ \sigma/a]$, because the equilibrium point is $Q^* = \sigma/a$.

(iv) If $a < \sigma$ and $0 \leq Q(0) < 1$, then $Q'(t) > 0$. $Q(t)$ is strictly increasing in the interval $[Q(0),\ 1]$, because the equilibrium point is $Q^* = 1$.

From (i)–(iv), if $0 \leq Q(0) \leq 1$, then $0 \leq Q(t) \leq 1$, for $t \geq 0$.

2.4. Abandonment of Dogs

Abandonment intervenes through the number h of abandoned dogs per unit of time and unit of area:

$$N'(t) = rN(t)\left(1 - \frac{N(t)}{K}\right) + h - \varepsilon N(t). \tag{10}$$

Eq. (10) has two equilibrium solutions, but only one has a biological meaning:

$$N^* = \frac{1}{2r}\left(K(r - \varepsilon) + \left(K^2(r - \varepsilon)^2 + 4rhK\right)^{1/2}\right). \tag{11}$$

If we consider sterilization and abandonment, the model reads:

$$N'(t) = N(t)\left(a(1 - Q(t)) - b - r\frac{N(t)}{K}\right) + h \tag{12}$$

and

$$Q'(t) = (1 - Q(t))(\sigma - aQ(t)) - h\frac{Q(t)}{N(t)}. \tag{13}$$

2.5. Parameter Estimates

The birth and mortality rates were estimated using the method proposed by Caswell (1972). For free-ranging dogs, Beck (2002) estimated a finite mortality of $\delta = 0.23\,\text{year}^{-1}$. Let $D_0(t)$ be the total number of dogs at the beginning of a time interval $[t,\ t + \Delta t]$, ν the proportion of females, n_p the total number of puppies per litter, and q the number of litters per unit of time. The total number of dogs born in $[t, t + \Delta t]$ is $D_0(t)\nu n_p q \Delta t$. The per head birth rate β is the number of births occurring in the interval $[t,\ t + 1]$, $D_0(t)\nu n_p q$, divided by the population at time t, $D_0(t)$ (Caswell, 1972). Then

$$\beta = \nu n_p q. \tag{14}$$

Beck (2002) found a male/female ratio of 64:36 for stray dogs, which corresponds to $\nu = 0.36$. Assuming that one puppy per female per year ($n_p = 1$, $q = 1\,\text{year}^{-1}$, $\Delta t = 1\,\text{year}$) is born on average, from Eq. (14), $\beta \cong 0.36\,\text{year}^{-1}$.

The instantaneous birth and death rates a and b come from (Caswell, 1972):

$$a = \frac{\beta}{\beta - \delta}\ln(1 + \beta - \delta) \tag{15}$$

and

$$b = \frac{\delta}{\beta - \delta}\ln(1 + \beta - \delta)\ . \tag{16}$$

We estimate them as $a \cong 0.34\,\text{year}^{-1}$ and $b \cong 0.22\,\text{year}^{-1}$.

Beck (2002) estimated a free-ranging dog population density of 232 dogs per square kilometer in Baltimore, Maryland, United States, in 1970–1971, with a 95% confidence interval ranging from 174 and 290 dogs per kilometer square. We assumed a carrying capacity of 250 dogs per kilometer square. The parameters are shown in Table 1.

The differential equations were solved numerically by means of the fourth-order Runge-Kutta method.

TABLE 1 Parameters Used in the Model for the Stray Dog Population

Parameter	Value
Carrying capacity (dogs per km^2)	250
Birth rate, a (year^{-1})	0.34
Mortality rate, b (year^{-1})	0.22
$r = a - b$ (year^{-1})	0.12

3. RESULTS

Figure 1 shows the density of dogs divided by the carrying capacity K, as a function of time, for different sterilization and euthanasia rates, without the effects of abandonment.

Figure 2 represents the total number of sterilized dogs, $\sigma\nu N(t)(1 - Q(t))$, or euthanized, $\varepsilon N(t)$, per km^2 per year for different sterilization and euthanasia rates. We used $\nu = 0.36$ for the proportion of females.

Figures 3a and 3b, respectively, show the results of the simulations for a sterilization program with a rate $\sigma = 0.20\,\text{year}^{-1}$ and for an euthanasia program with a rate $\varepsilon = 0.20\,\text{year}^{-1}$, for different values of h.

In Figure 1, both sterilization and euthanasia applied continuously over time can reduce the dog population density. Over less than 5 years, the reduction produced by sterilization was not as intense as by euthanasia, considering similar rates (Figure 1). The total number of effectively sterilized dogs is less than the total number of euthanized ones per km^2 per year, for equal values of σ and ε (Figure 2). The efficacy of programs based on sterilization of female dogs depends on the proportion of females in the population. Over 20 years or more, the results obtained in both strategies are similar (Figure 1).

Figure 1 also shows that, for a population growth rate of 0.12 per year, both sterilization and euthanasia at rates higher than 0.2 per year can reduce the population in less than 10 years of 50%.

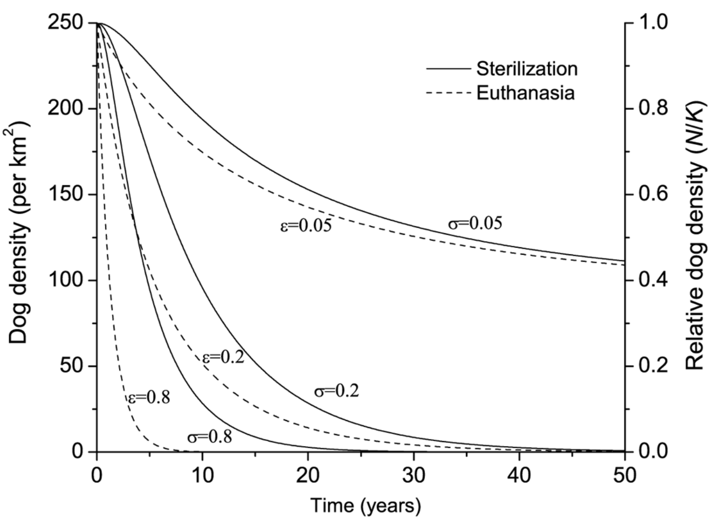

FIGURE 1 Stray dog density (left axis) and relative density (right axis) as a function of time, for different sterilization and euthanasia rates, in year^{-1}.

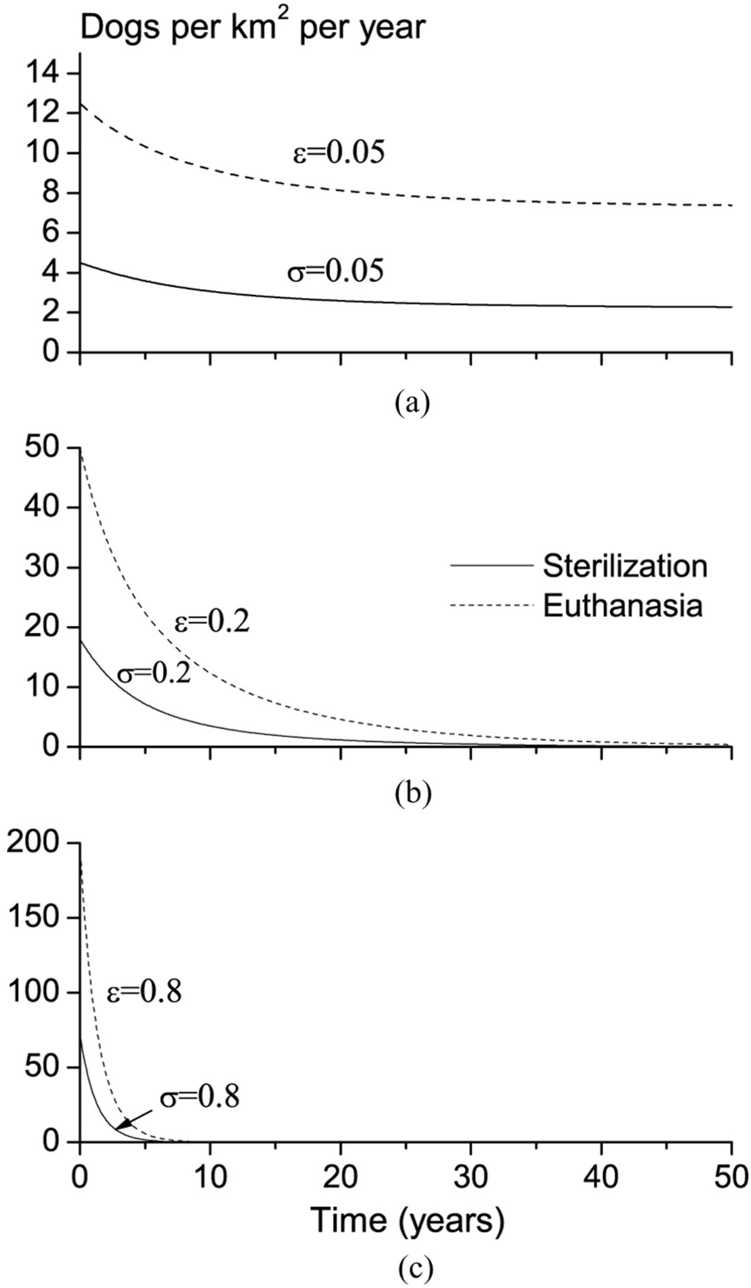

FIGURE 2 Density of sterilized (solid line) or euthanized (dashed line) dogs for $\nu = 0.36$ and sterilization and euthanasia rates, in year^{-1}.

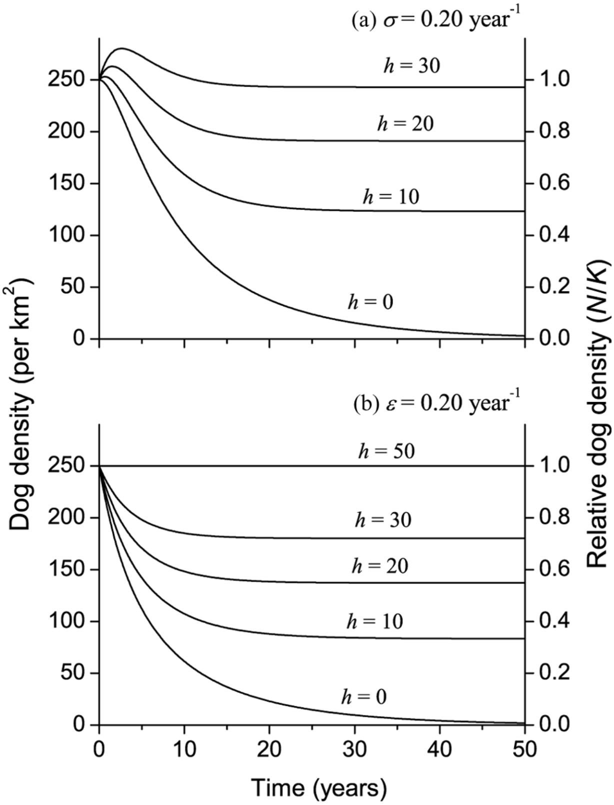

FIGURE 3 Stray dog density (left axis) and relative density (right axis), for different abandonment rates h (in year^{-1}) and for two control programs: (a) sterilization at rate $\sigma = 0.20\,\text{year}^{-1}$ and (b) euthanasia at rate $\varepsilon = 0.20\,\text{year}^{-1}$.

For a sterilization rate $\sigma = 0.20\,\text{year}^{-1}$ (Figure 3a), a rate of abandonment of $h = 30$ dogs $\cdot$ year^{-1} $\cdot$ km^{-2} ($h/K = 0.12\,\text{year}^{-1}$) maintains the dog population at the carrying capacity. For a euthanasia rate $\varepsilon = 0.20\,\text{year}^{-1}$ (Figure 3b), a rate of abandonment of $h = 50$ dogs $\cdot$ year^{-1} $\cdot$ km^{-2} ($h/K = 0.2\,\text{year}^{-1}$) maintains the dog population at the carrying capacity. In both cases, the control strategies fail to contain abandonment.

4. CONCLUSION

Our model showed the effect of sterilization and euthanasia on street dog population density. Both these control strategies depend heavily on abandonment, which turns out to be the major target of any reduction program. Our results can serve as a guideline for such a program, notably in São Paulo where it is needed.

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