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Defining priorities for dog population management through mathematical modeling

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ABSTRACT

We simulated dog population dynamics for a thirty-years period using a logistic growth model. Through sensitivity analyses, we determined the influence of the parameters used in the model. Carrying capacity was the most influential parameter in all simulations. In the owned-dog population, the influence of immigration, abandonment and births was 19%, 16% and 6% of the influence of the carrying capacity, respectively. In the sterilized owned-dog population, the influence of abandonment, female and male sterilization was 37%, 30% and 27% of the influence of the carrying capacity. In the stray population, the influence of abandonment, carrying capacity of the owned-dog population and adoption was 10%, 9% and 6% of the influence of the carrying capacity. In the sterilized stray population, the influence of births, female sterilization and male sterilization was 45%, 15% and 13% of the influence of the carrying capacity. Other parameters had lower influence values. Modification of the carrying capacity requires different interventions for the owned- and stray-dog populations. Dog trade control is a way to reduce immigration. The evaluation of sterilization effects must focus on the variations in the infertile population fraction. Adoption may improve the effects of the reduction in carrying capacity on the stray-dog population.

1. Introduction

Canine population management aims to modify the determinants of population dynamics (reduction of unwanted births and abandonment, increase in prophylactic treatment coverage and immigration control) to promote the health and well-being of both dogs and people (Garcia et al., 2012). However, these determinants interact in a complex way, and modifications of a given determinant may be intensified, reduced or canceled by changes in other determinants. Additionally, a given objective (for example, reduction in the population of stray dogs) is usually favored by the modification of more than one determinant, and resource limitations may prevent interventions with ideal scope and magnitude. Therefore, there is a need to prioritize the modification of the most influential determinants.

Aiming to improve the knowledge of dog population dynamics and to facilitate the evaluation of population management interventions, we developed a logistic growth model based on a coupled system of differential equations. We jointly evaluated the effect of immigration on the population of owned dogs and the effects of abandonment, sterilization and adoption on the dynamics of owned- and stray-dog populations, structured by gender. We considered a net migration equal to zero for stray dogs. Using sensitivity analyses, we determined the influence of the parameters and, consequently, the impact of interventions aimed at these parameters.

2. Material and methods

To model dog population dynamics, we used a coupled system of ordinary differential equations (Fig. 1). In the model, females f and males m could be owned *1* or strays *2*, and they could be sterilized s. An additional compartment q was defined to represent an immigration source of owned animals and a proportion of immigrants z were sterilized. Sterilization rates s [1], abandonment rates a, adoption rates α and death c rates were explicitly modeled. Interaction between sexes were given by a fertility function w. We extended our simulations along a 30 years period to always show transient dynamics and population sizes at equilibrium.

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[1] Although both reproductive status (sterilized or not) and sterilization rates were represented by s, the first was always a prefix and the last was always a subscript.

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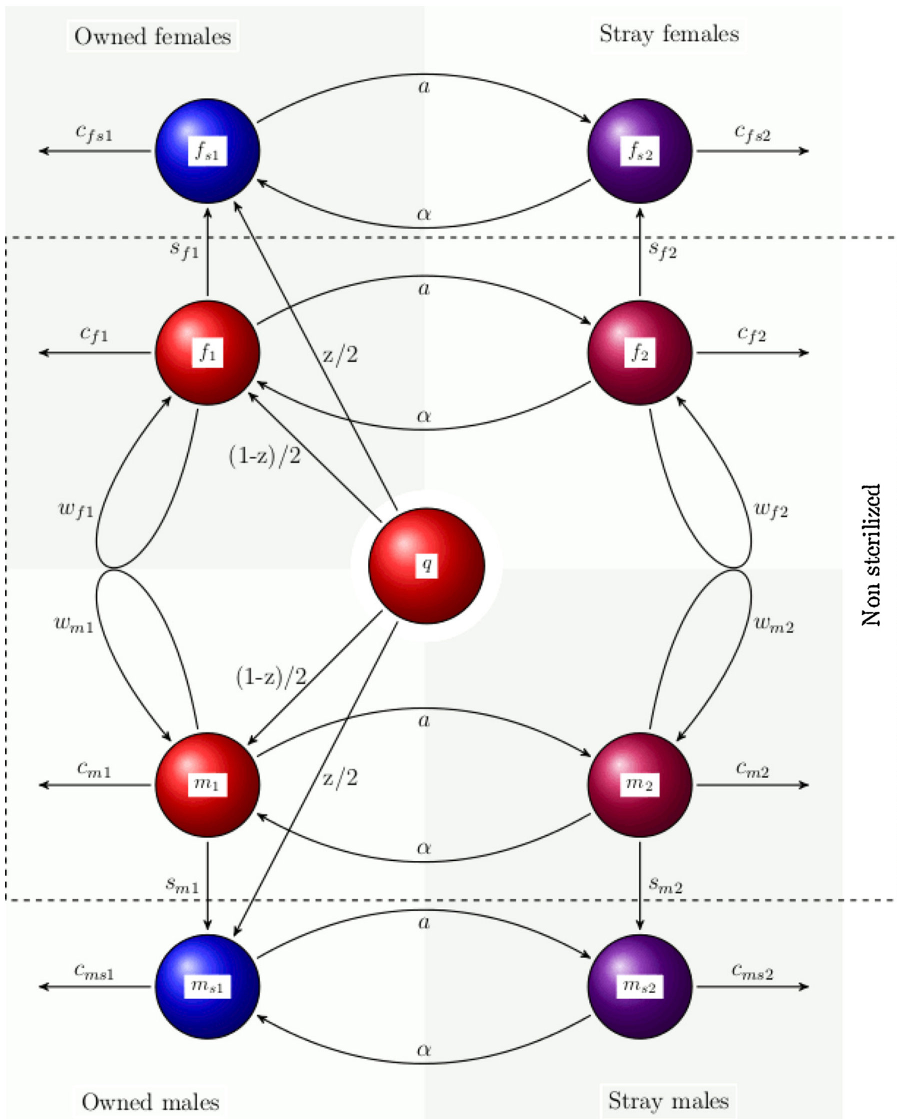

Fig. 1. Compartmental model of dog population dynamics. q: immigrants; f: intact females; m: intact males; f_s: sterilized females; m_s: sterilized males; *1*: owned; *2*: stray; z: proportion of sterilized immigrants; w: birth function; c: mortality function; a: abandonment rate; α: adoption rate; s sterilization rate.

We assumed that all rates were constant, population growth was density-dependent (in the owned-dog population, the fertility function was density-dependent; in the stray-dog population, the mortality function was density-dependent), sterilization was lifelong and migrants came from external areas and trade.

2.1. System of equations

Following the notation introduced in Fig. 1,

$$n_1 = f_1 + f_{s1} + m_1 + m_{s1}, \tag{1}$$

$$n_2 = f_2 + f_{s2} + m_2 + m_{s2} \quad \text{and} \tag{2}$$

$$n = n_1 + n_2, \tag{3}$$

are the total number of owned dogs, the total number of stray dogs, and the total number of dogs, respectively. Neighborhood and abandoned dogs are considered as strays (Slater, 2001).

2.1.1. Owned females

Consider h the mean size of the harem (mating system described by the number of females per male), b_1 the number of births and d_{f_1} and $d_{f_{s_1}}$ the mortality rates of females and sterilized females, respectively. The fertility function was calculated based on the equation used by Caswell (2001) and presented in Eq. (4). This function was modified by introducing the density-dependence so that a new fertility function was obtained, w_{f_1}, determined by Eq. (5).

$$y_{f_1} = \frac{b_1}{2f_1} = \frac{x_1 m_1}{m_1 + f_1 h_1^{-1}} \tag{4}$$

$$w_{f_1} = y_{f_1} - (y_{f_1} - d_{f_1})\frac{n_1}{k_1} \tag{5}$$

where x_1 is the number of births per harem, calculated from the second equality of Eq. (4).

The mortality function is equal to the mortality rate

$$c_{f_1} = d_{f_1}. \tag{6}$$

The immigration rate is equivalent to a fraction v of the carrying capacity of the owned-dog population, and a fraction z of immigrants is sterilized. Assuming that the male/female ratio of