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Optimizing free-roaming dog control programs using agent-based models

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ABSTRACT

Urban free-roaming dog populations in the developing world are managed by a patchwork of local veterinary practitioners, government programs, and non-governmental organizations with varied effectiveness. While lethal removal is still commonly practiced, vaccination and fertility control methods are increasingly being adopted. Identifying which method(s) provides the most cost effective management is needed to inform dog population managers who seek to limit conflicts like dog bites, the spread of disease, and predation on wildlife. Here we describe an agent-based model that simulates the population of free-roaming dogs in Jaipur, a northwestern Indian city. We then apply various lethal and fertility control methodologies to identify which most effectively lowered the dog population size. This spatially explicit model includes temporal and demographic details of street dog populations modeled after data from the study city. We tested each pairing of control type (lethal or fertility) with search method (how to target efforts) to see their efficacy at altering the city's dog population size, age structure, sterilization coverage, as well as the number of dogs handled. Models were run for 15 years to assess the long term effects of intervention. We found that the fertility control method that targets areas of the city with the highest percentage of intact bitches outperforms all other fertility control and lethal removal programs at reducing the population size while sterilizing a significantly higher proportion of the population. All lethal program methods skewed population demographics towards significantly younger dogs, thus likely increasing the frequency of conflict with humans. This work demonstrates the benefits of modeling differing management policies in free-roaming dogs.

1. Introduction

Domestic dogs are the most common large carnivore with a global population of 700 million (Hughes and Macdonald, 2005). "Free-roaming" dogs are defined by their unrestricted movement and may be pets, neighborhood dogs, or truly stray, depending on the degree of human assistance (Sudarshan et al., 2001). Free-roaming dog population densities in urban environments vary widely and can range from 88 to 250/km^2 (Matter et al., 2000; Townsend et al., 2013). Dogs can achieve such high densities because of human tolerance and supplementation of their diets with leftovers, refuse, and offal (Butler and du Toit, 2002). However, dense free-roaming dog populations present significant public health risks via bites and the transmission of zoonotic diseases, especially rabies (WHO, 2013).

Controlling dog populations in developing countries is particularly important as these nations are disproportionately affected by free-roaming dogs not only through the spread of zoonoses but also through threats to local wildlife. In India alone, canine rabies kills 20,000 people each year, with patients predominately coming from the lowest socio-economic classes (Sudarshan et al., 2007). These dogs often have low body conditions with high disease burdens (Hughes and Macdonald, 2005; Lacerda et al., 2009; Totton et al., 2011) including leishmaniasis (Ashford et al., 1998), canine distemper, canine parvovirus, and ehrlichiosis (Butler et al., 2004; Yoak et al., 2014). Management of these diseases has significant economic ramifications. For example, dog-transmitted cystic echinococcosis alone costs the nation $212.35 million per year (Singh et al., 2014). Further, dogs in natural areas have been shown to create artificial edge effects in otherwise intact forests

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by disrupting wildlife behavior and land use (Lacerda et al., 2009). Free-roaming dogs regularly come in contact with wildlife, exposing populations of endangered species like tigers to dog-borne diseases (Butler et al., 2004). Measures to reduce local dog density could eliminate, or at least mitigate, the risk to both humans and wildlife (Cleaveland et al., 2000).

Historically, lethal removal has been the preferred method of canine control; however, recent work shows that lethal control is less effective and more expensive over time compared to fertility control programs (WHO, 2013). The culling of free roaming dogs, even at exceptionally high rates, cannot eliminate the disease of most concern, rabies (Hou et al., 2012). Additionally, simulations of lethal removal in modeled wildlife populations show that infection intensity and transmission risk for a generalized pathogen increases due to the removal of naturally immunized individuals (Choisy and Rohani, 2006). This modeling effort can provide some insight into other dog pathogens, but rabies presents a unique challenge.

Fertility control programs are an alternative to lethal control in which free-roaming dogs are caught, neutered, and vaccinated against rabies, then returned back to their point of capture within a few days (Reece and Chawla, 2006). In much of the free-roaming dog literature these programs are referred to as Animal Birth Control or Trap-Neuter-Vaccinate-Release. Fertility control programs are already being implemented in areas of India where lethal control is culturally prohibited in an attempt to curtail dog population sizes and reduce the incidence of rabies (Reece, 2007). Most fertility control programs focus their efforts on female dogs, as any reduction of the intact female population has a much greater effect on reproduction compared to splitting efforts across both sexes (WHO/WSPA, 1990). These programs have produced positive results; in Jaipur, capital of the state of Rajasthan, India, the Help in Suffering program has lowered the local human rabies incidence to zero and reduced the dog population by at least 28% (Reece and Chawla, 2006).

As fertility control programs are begun in other Indian cities, there is increasing need for rigorous data collection methods to compare which strategies are most successful in different regions (Totton et al., 2011). Unfortunately, these programs do not often receive substantial funding for monitoring efforts. This under funding is explained, in part, by the lack of enough compelling and pertinent data, caused by the absence of previous monitoring. Real-world evaluation of the differing effects of resource intensive management policies on the same population over long time scales is impractical if not impossible and highlights the value of modeling in dog management.

Agent-based models (ABMs) are becoming increasingly utilized for addressing large scale ecological management questions that are inaccessible to study through traditional observational or experimental research (Bonnell et al., 2010) and canid behavior in particular (Belsare and Gompper, 2015; Pitt et al., 2003). These methods allow repeated trials by explicitly modeling the behavior of agents as well as the interactions between them over time in a two dimensional space (Grimm and Railsback, 2005; Railsback and Grimm, 2011).

Our goal was to build a demographically accurate and spatially explicit agent-based model of a large free-roaming dog population to investigate how to maximize the impact of dog management. Specifically, we produced a model of the dog population (both male and female) in Jaipur, India that matched the demographics of northwest India's street dogs (Hiby et al., 2011), as well as their local seasonal breeding (Chawla and Reece, 2002), and daily movement patterns (unpublished data from J Reece). Our ABM captured the variation in dog movement and survival while accounting for variations in dog density across the city. We sought to identify methods that minimize the costs of dog control for non-governmental organizations while reducing dog population sizes. Using this ABM, we investigated (a) the relative effects of lethal control and fertility control and (b) the effects of various search methods used by programs to target dogs for either lethal or fertility control on resulting dog demographics. In some versions of the model, the treatment effect (euthanasia or sterilization) was applied to both male and female dogs but as these methods always proved inferior at control, their findings can be found in the supplemental materials.

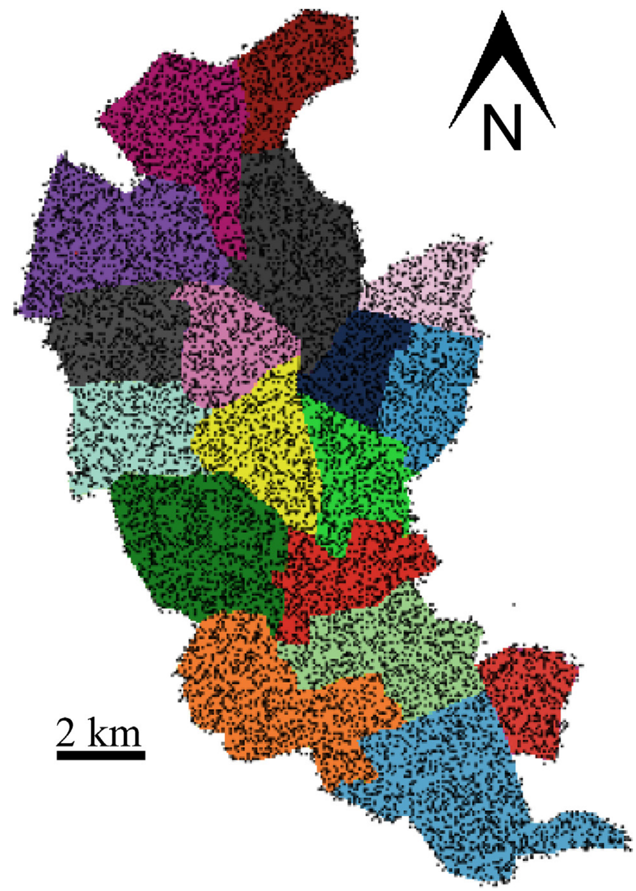

Fig. 1. The model city of Jaipur with its different management zones can be identified by the uniquely colored blocks. Dog agents populate the city and can be seen as the black dots scattered throughout.

2. Methods

We developed a spatially explicit model of the dog population of Jaipur, India that realistically matched canine demographic traits (Section 2.1) and then applied various search methods for both lethal and fertility control methods to compare each combination's effect on population size and demographics. To standardize the presentation of processes and results, we used the updated Overview, Design concepts, and Details (ODD) protocol for describing ABMs (Grimm et al., 2010)

2.1. Model description

This model was created using NetLogo v5.04 (Wilensky, 1999). A map of Jaipur from Google Earth was rasterized using GIMP 2 photo editing software to produce a background landscape. Both programs are open source and are available free for download from http://ccl.northwestern.edu/netlogo/ and http://www.gimp.org/ respectively. Models were run using the Ohio Supercomputer Center's assistance while using the headless Linux version of Netlogo (www.osc.edu).