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# A spatial agent-based model of feral cats and analysis of population and nuisance controls

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ABSTRACT

Free-roaming feral cats are common in areas of concentrated human habitation, and can pose considerable threats of nuisance and damage to native ecosystems. Trap-neuter-return (TNR) and trap-vasectomy-hysterectomy-return (TVHR) are two humane methods for the reproductive control of feral cat populations. Both TNR and TVHR render a cat infertile, but cats that have undergone TVHR continue to produce hormones that drive mating behaviors. We built a stochastic agent-based computational model for simulating the survival, reproduction, and movement of individual feral cats and the use of TNR and TVHR to modify cats' reproductive abilities and behaviors. Daily movement of cats between colonies is implemented based on the distance between colonies and landscape properties (e.g. rural, urban). Spatially targeted TNR and TVHR policies are evaluated using two management goals: (1) reduce total population size and (2) reduce nuisance attributed to feral cats. Nuisance includes spraying and noise, both of which are associated with un-neutered males, as well as population abundance. Results indicate that both TNR and TVHR have the potential to greatly reduce population size. Effectiveness of each control depends on the capture rate, number of colonies targeted, size of each colony, and movement of individual cats between colonies. Results show that on average TVHR performs moderately better than TNR at reducing population size, but TNR substantially outperforms TVHR in reducing multiple nuisance measures.



## 1. Introduction

Feral cats are untamed, free-roaming cats that are either born in or abandoned to the wild and lack human socialization (Levy et al., 2003; Slater, 2007). The number of feral cats in the U.S. alone is estimated between 50 and 80 million (Patronek and Rowan, 1995; Levy and Crawford, 2004); this estimate rivals that of the owned cat population (82 million in 2009; Chu et al., 2009). However, 80% of kittens each year are born to feral cats (Levy and Crawford, 2004). Many of these cats live in colonies located near areas of human habitation which can provide a source of food and shelter (Aguilar and Farnworth, 2013; Bengsen et al., 2011; van Heezik et al., 2010). Several surveys in the USA showed that up to 22% of households feed outdoor cats that they do not own (Levy et al., 2003).

The increasing size of the feral cat population is concerning to many parties, including wildlife managers, government agencies, humane societies, and the general public. The main issues surrounding feral cats involve their welfare, nuisance to the public, and potential impact on wildlife and pets. On one hand, many people feel sympathetic towards feral cats and the living conditions (e.g. lack of shelter or food) that can arise in the wild (Levy et al., 2003; Slater, 2007). The life expectancy of feral cats is estimated to be less than five years with high rates of mortality attributed to disease, motor vehicle accidents, and poisoning (Clarke and Pacin, 2002; Nutter et al., 2004). According to a survey of 101 caretakers of free roaming cats in Florida, the major reason for feeding and caring for the cats was sympathy or pity for a hungry, injured, or unhealthy cat (Centonze and Levy, 2002).

On the other hand, feral cats are regarded as one of the world's worst invasive species due to their impact on biological diversity and human activities (Lowe et al., 2000). Domestic cats kill large numbers of wildlife, including a wide range of bird species (Coleman et al., 1997; Coleman and Temple, 1995; Dauphine and Cooper, 2009; Loss et al., 2013). One study concluded that feral cats on islands contributed to at least 14% of modern bird, mammal, and reptile extinctions and to the endangerment of at least 8% of critically endangered birds, mammals, and reptiles (Medina et al., 2011). Other public concerns regarding feral cats include the spread of disease (e.g. rabies, toxoplasmosis) and nuisance behaviors such as spraying (i.e. marking with urine) of territories, fighting,

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and loud and frequent noise (e.g. yowling during mating) (Hughes et al., 2002; Gunther et al., 2015; Robertson, 2008; Ross et al., 2004).

How to best reduce the size of feral cat populations and their impact on humans and wildlife is controversial and the debate is often emotional. Relocation of feral cats to rural farms or sanctuaries is an attractive solution but it is not practical as a sole solution because it is expensive and these facilities cannot accommodate a large number of feral cats (Slater, 2007). Lethal control is advocated as a means of decreasing population size and reducing the length of time a feral cat suffers in poor living conditions (Jessup, 2004). Eradication of feral cat populations through lethal control (e.g. trapping, hunting, poisoning, disease introduction) has been achieved on at least 48 islands. Most of these islands are small (<5 $km^2$) and uninhabited by humans (Nogales et al., 2004). Using lethal control on feral cats in inhabited areas is more strongly contested because a large number of people consider it unethical (Chu and Anderson, Sept; Slater et al., 2008). Additionally, studies suggest that the removal of cats from an open population causes a vacuum effect in which new cats fill the void left by removed cats (Alley Cat Allies, 2011; Robertson, 2008).

Trap-neuter-return (TNR) is an increasingly popular approach that aims to humanely reduce population size by spaying or neutering feral cats and returning them to their original habitat (Slater, 2007). An additional benefit of TNR is that spayed or neutered cats are less likely to exhibit nuisance behaviors such as aggression, yowling, and roaming (Finkler et al., 2011; Hart and Barrett, Assoc; Neville and Remfry, 1984; Scott et al., 2002). Some TNR programs include veterinary care, colony registration, monitoring, and adoption of cats (Levy et al., 2003). Before sterilized cats are returned to their colony, the tip of their ear is removed. Ear-tipping allows a caretaker to easily and harmlessly identify fertile cats that enter the colony, and sterile cats can be quickly identified so they are not mistakenly re-trapped. Results from targeted TNR programs, including two that were implemented on U.S. university campuses (Levy et al., 2003; Slater, 2003), indicate this approach is effective at reducing or at least stabilizing local populations when the vast majority of cats are targeted (Centonze and Levy, 2002; Hughes et al., 2002; Zaunbrecher and Smith, 1993).

This study focuses on use of TNR and a less commonly used method, trap-vasectomy-hysterectomy-return (TVHR), to manage populations of feral cats. Implementation of TVHR is similar to that of TNR except cats are sterilized through hysterectomy or vasectomy (Mendes-de-Almeida et al., 2011; Kendall, 1979). TVHR results in cats that are infertile but continue to produce hormones (e.g. testosterone) that drive mating behaviors. Mating activities performed by infertile cats can provide an additional source of population control. For instance, a sexually intact female that mates with a vasectomized male can exhibit symptoms of a false pregnancy (i.e. pseudo-pregnancy) which reduces the chances of her mating with an intact male (Paape et al., 1975; Foster and Hisaw, 1935; Kendall, 1979). Further, when cats are hysterectomized/vasectomized, the social structure of the colony is retained, resulting in an ability to resist intruders hoping to share resources (Mendes-de-Almeida et al., 2011). On the other hand, a downside of choosing TVHR over TNR is that the nuisance behaviors associated with mating still continue after the cat has been sterilized (Kendall, 1979).

Mathematical and computational models have been used increasingly to evaluate the effectiveness of various approaches in reducing the number of feral cats. Lohr et al. (2013) used a computational systems approach to track the abundance of feral cats in a single colony in Oahu, Hawaii over a period of 30 years and evaluate the costs and benefits of TNR and an euthanasia program. Benefits measured in this study were limited to the reduction in predation pressure on Wedge-tailed Shearwaters, a native species. Results showed that euthanasia is the cheapest population reduction method and, in most cases, the benefits of euthanasia exceeded the costs. For TNR, the benefits did not exceed the costs unless the shearwaters were valued at $1500.00 each. In a study by Anderson et al. (2004) a matrix population model was developed with a range of fecundity and survival values, and elasticity analysis was used to demonstrate population growth following different management actions. In particular, effective population control was achieved by use of annual euthanasia of 50% of the population or annual neutering of ≥75% of the fertile population.

It is not uncommon for population models to assume spatial homogeneity for simplicity; however, studies have shown that the geography of feral cat colonies is important in the design of a successful control program. Results from a statistical analysis by Foley et al. (2005) on data collected from two separate county-wide implementations of TNR showed the control methods failed to produce a consistent reduction in the per capita growth in the proportion of female cats that were pregnant. The authors suggest that using programs focused on large geographic areas, such as those defined by a county, are less successful than geographically targeted programs in which individual cats can be managed. Recently, a spatial model of feral cats was developed by Miller et al. (2014) and includes interaction between a treated colony and neighboring untreated colonies. Here, treatment refers to removal, permanent sterilization, or temporary sterilization of cats. Using the model, the authors showed that even low levels of interaction with untreated colonies significantly reduce the effectiveness of any management intervention.

The aim of this research is to investigate the ability of spatially-targeted TNR and TVHR programs to reduce the size and nuisance of a feral cat population. As far as we know, this is the first study to quantify the impact of reproductive control on the nuisance associated with a feral cat population. We present a computational agent-based model (ABM) for the simulation of individual feral cats and evaluation of population dynamics during spatially-targeted TNR and TVHR programs. ABMs are used increasingly to recreate biological systems (Railsback and Grimm, 2012; Wilensky and Rand, 2015). In 2013, McCarthy et al. (2013) constructed an ABM for a single feral cat colony and used the ABM to evaluate the ability of three control methods (lethal, TNR, TVHR) to reduce the colony's size. Results showed that TVHR outperformed TNR (and lethal control) at all annual capture probabilities between 10% and 90%. Our study aims to expand upon their findings by investigating the effectiveness of spatially-targeted feral cat control in the presence of interacting colonies for a range of landscape scenarios (e.g. urban, rural). Further, our model includes abandonment of new feral cats into the population to simulate realistic scenarios.

## 2. Model description

A description of the model is presented in this section in accordance with the Overview, Design concepts, and Details (ODD) protocol (Railsback and Grimm, 2012).

### 2.1. Purpose

The purpose of this model is to assess the ability of targeted reproductive control strategies to manage one or more interacting feral cat colonies over a period of several years. Control strategies differ by type of control (TNR or TVHR), timing, number of cats targeted, and location of colonies targeted. Strategies are evaluated for different spatial landscapes (e.g. rural, urban) using two different management goals: reduce total population size and reduce public nuisance attributed to feral cats.