POPULATION DYNAMICS AND MANAGEMENT OF FREE-ROAMING CATS

A Thesis

by

PAIGE McGEE HILL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Roel R. Lopez
Committee Members,	Frances P. Gelwick
	X. Ben Wu
Head of Department,	Robert Brown

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ABSTRACT

Population Dynamics and Management of Free-roaming Cats.

(May 2006)

Paige McGee Hill, B. S., University of Central Oklahoma

Chair of Advisory Committee: Dr. Roel R. Lopez

With an estimated 400 million domestic cats worldwide, free-roaming cats issues are of global importance due to animal welfare and public health concerns, as well as impacts on native wildlife through predation, competition and disease transmission. Though these impacts have been well documented, no research has evaluated the ecology and population dynamics of unmanaged, free-roaming cat populations using radio-telemetry. My objectives were to (1) compare population demographics (survival, fecundity and annual ranges/movements) among sex and ownership classifications (feral, semi-feral, and owned), (2) evaluate mark-resight and distance sampling for estimating cat abundances in urban areas, and (3) evaluate the effectiveness and costs associated with euthanasia and trap/treat/neuter/release (TTNR) programs for controlling urban cat populations. I radio-collared free-roaming cats (feral, n = 30; semi-feral, n = 14; owned, n = 10) in Caldwell, Texas (October 2004-2005). I found (1) increased levels of ownership or feeding reduce free-roaming cats' ranges and movements while increasing survival and fecundity, (2) distance sampling resulted in precise abundance estimates providing an alternative to estimating urban cat densities, and (3) both euthanasia and TTNR may effectively reduce free-roaming cat numbers if implemented

at high rates (>50% of population treated) the first year. I recommend euthanasia be implemented in ecologically sensitive areas and TTNR in areas lacking public support for lethal control. Population control solutions should include public education to increase awareness of cat issues and impacts, and pre- and post-implementation monitoring plans.

DEDICATION

I dedicate this to my family, all the women who have had a hand in raising me, and the guiding spirit; for their love and support and for nourishing my many journeys.

And to my advisor, Dr. Roel Lopez, for providing a positive, nourishing environment to learn and achieve.

ACKNOWLEDGEMENTS

I would like to thank the members of my committee for their support and direction through my graduate studies: Roel Lopez, Frances Gelwick, and Ben Wu. I also would like to thank my fellow graduate students and the entire staff of the department of Wildlife and Fisheries Sciences (WFSC) at Texas A&M University. A special thank you to the City of Caldwell, Texas for allowing me to conduct my research, animal control officer Linda Anderson for invaluable information and guidance on free-roaming cat issues, the Caldwell Veterinary Clinic for use of their facilities and Dr. Nancy Carter, DVM for her assistance with trapping. I would like to thank David Paul, Andy Garner, Jessica Lucas, David Schmidt and Jason Schmidt for assistance with fieldwork and Bret Collier, Brian Pierce and Todd Swannack for assistance with analyses and modeling. A special thanks to Margaret Slater for providing project oversight and bringing this research opportunity to my attention. Financial support was provided by Texas A&M University, The American Indian Graduate Center, American Indian Science and Engineering Society and The Citizen Potawatomi Nation. The National Council on Pet Population and Policy also provided funding for this research.

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CHAPTER I

INTRODUCTION

The U.S. population of owned cats has recently been estimated around 73 million (Slater 2002) and the number of unowned cats has been estimated between 10-50 million (Mahlow and Slater 1996) for a total cat population >100 million (Clarke and Pacin 2002). With an estimated 400 million domestic cats worldwide (Jarvis 1990), issues associated with free-roaming cats are of global importance. Free-roaming cat populations include owned cats allowed outdoors, recently owned, lost or abandoned cats, and feral cats (Slater 2002). I define semi-feral as unowned cats that are regularly and directly fed by a resident and feral as unowned cats that are not directly fed. Problems that arise from large and ubiquitous free-roaming cat populations in both urban and rural areas are well documented and include animal welfare concerns (starvation, disease, abuse or depredation), public health and nuisance concerns, as well as impacts on native wildlife through predation, competition and disease transmission (see Patronek 1998 and Slater 2002 for summaries). Though the impacts of free-roaming cats have been well documented, no research has evaluated the ecology and population dynamics of unmanaged, free-roaming cat populations using radio-telemetry.

My first objective was to compare population demographics (survival, fecundity and annual ranges/movements) among sex and ownership classifications (feral, semi-feral, and owned). My second objective was to evaluate mark-resight and distance sampling for estimating free-roaming cat abundances in urban areas. My third objective was to evaluate the effectiveness and costs associated with euthanasia,

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trap/treat/neuter/release (TTNR) programs and combinations of the 2 for controlling urban, free-roaming cat populations.

Here, I present an outline of the thesis and my research objectives. The thesis is divided into chapters, each of which represents an independent, stand-alone paper with a distinct research focus. While each chapter has its own unique research objectives, the overall thesis objective is to increase our understanding of the ecology and dynamics of urban, free-roaming cat (*Felis catus*) populations. Thus, some information is repeated among chapters (i.e., problem definition, study area description).

CHAPTER II

POPULATION DYNAMICS OF FREE-ROAMING CATS

SYNOPSIS

Free-roaming cats impact wildlife worldwide through predation, competition and disease transmission. Though the impacts of free-roaming cats (e.g., owned to feral) have been well documented, baseline ecological information (e.g., survival, fecundity, movements) necessary for population control is lacking. I radio-collared free-roaming cats (feral, n = 30; semi-feral, n = 14; owned, n = 10) in Caldwell, Texas (Oct 20042005) to determine survival, fecundity, and annual ranges/movements. I compared population demographics among sex and ownership classification (feral, semi-feral, and owned), and found that survival over the 13 month study period decreased with decreased ownership; 0.61 for feral cats, 0.88 for semi-feral cats, and 1.00 for owned cats. I found evidence that male survival (0.58) was lower than female survival (0.88). Mean kitten survival at 12 weeks for feral cats (1.75 kittens/litters) was 36% lower than semi-feral females (2.75 kittens/litter); all owned females were spayed in my study and did not reproduce. I found male ranges (10.8 ha, SE 2.9) were larger (P = 0.024) than female ranges (4.2 ha, SE 1.3), and feral cat ranges (13.97 ha, SE 3.5) were larger (P = 0.049) than semi-feral (5.2 ha, SE 1.5) and owned cat ranges (1.1 ha, SE 0.2) for minimum convex polygon estimates. Mean movements for feral cats (149.5 m, SE 75.8) were larger than semi-feral cats (71.7 m, SE 44.5) (P = 0.005) and owned cats (25.9 m, SE 10.9) (P < 0.000) but semi-feral cat movements were not larger than owned cats (P = 0.189). I found increased levels of ownership increased survival and fecundity and decreased annual ranges and movements. Such trends have consequences in the dynamics of unmanaged, free-

roaming cat populations and should be considered when evaluating population control strategies.

INTRODUCTION

The U.S. population of owned cats has recently been estimated around 73 million (Slater 2002) and the number of unowned cats has been estimated between 10-50 million (Mahlow and Slater 1996) for a total cat population >100 million (Clarke and Pacin 2002). With an estimated 400 million domestic cats worldwide (Jarvis 1990), issues associated with free-roaming cats are of global importance. Free-roaming cat populations include owned cats allowed outdoors, recently owned, lost or abandoned cats, and feral cats (Slater 2002). Here I define semi-feral as unowned cats that are regularly and directly fed by a resident and feral as unowned cats that are not directly fed.

Problems that arise from large and ubiquitous free-roaming cat populations in both urban and rural areas are well documented and include animal welfare concerns (starvation, disease, abuse or depredation), public health and nuisance concerns, as well as impacts on native wildlife through predation, competition and disease transmission (see Patronek 1998 and Slater 2002 for summaries). In the U.S., proposed population control strategies for free-roaming cat populations include euthanasia, hunting, and TTNR (trap/treat/neuter/release) programs. Ideally, evaluation of population control methods should be conducted *a priori* using appropriate estimates of vital rates for unmanaged cat populations (White 2000). Evaluating the effectiveness of such measures (i.e., method of control, frequency of control, and associated costs) in reducing free-roaming cat numbers and associated impacts can be accomplished using population models (Slater 2002, Anderson et al. 2004). Previous research on free-roaming cat populations has focused on impacts associated with free-roaming cat populations (Hubbs 1951, Jackson 1951, Childs 1986, Langham 1990, Tideman et al. 1994, Hall et al. 2000, Ash 2001, Hutchings 2003) and ecology of a particular type of free-roaming cat (e.g., feral, semi-feral, owned) (Warner 1985, Apps 1986, Genovesi et al. 1995, Hall et al. 2000). Attempts to evaluate and compare population dynamics of free-roaming, untreated cats collectively are important for several reasons. I predict that (1) distinct subpopulations of free-roaming cats may arise from different sources, (2) free-roaming cat subpopulations may be ecologically distinct and produce different impacts, and (3) free-roaming cat subpopulations may respond differently to various control measures. To date, no studies have evaluated the population dynamics of free-roaming, untreated cats using radiotelemetry, particularly for survival and fecundity estimation. Thus, my study objectives were to compare (1) survival, fecundity, annual ranges and movements of free-roaming cats by sex and ownership classifications, and (2) determine if increased levels of ownership will serve to reduce the impacts of free-roaming cats.

STUDY AREA

The City of Caldwell is a small, suburban community of approximately 3,400 residents located in Burleson County, Texas (Figure 2.1). My study was conducted in the center of the city in an area approximately 800 ha. Caldwell has no zoning laws and is highly heterogeneous with single and multi-family dwellings (6–10 houses/ha) intermixed with commercial, industrial and agricultural development (Marzluff et al. 2001). Residents generally tolerate unowned cats. Animals reported to the part-time animal control officer are trapped, held according to state law and euthanized if unclaimed. Socialized cats may be held longer until they are adopted or euthanized.

METHODS

Trapping and Marking

Unowned cats were trapped using Tomahawk live traps (Model 608, 91.4 x 25.4 x 30.5 cm Tomahawk Live Trap Company, Tomahawk, Wisconsin) intermittently between October 2004-August of 2005. I attempted to maintain 20 radio-collared cats at any given time throughout the study. Trapped cats were anaesthetized (0.08 mg/kg Domitor + 0.2 Butorphanol given intramuscularly with 0.08 mg/kg Antisedan given intramuscularly for reversal) and fitted with mortality sensitive transmitters (150-152 MHz, 30 g, Advanced Telemetry Systems, Isanti, Minnesota) on break-away collars. Transmitters were <3% of each cat's body weight within the 5% threshold recommended by the American Society of Mammalogists (1998). When captured, cats were weighed, sexed, aged, and checked for neuter scars. Free-roaming, owned cats were enrolled voluntarily by residents of the study area and processed at their residence. Research was approved by the Clinical Research Review Committee at the College of Veterinary Medicine, Texas A&M University (CRRC 04-30, 04-31).

Fig. 2.1. Location of study area for free-roaming cats in Burleson County, Texas, 2005.

Radiotelemetry

Radio-tagged cats were monitored 3-4 times per week from October 2004-2005 via homing and triangulation (White and Garrott 1990). I entered telemetry locations into a Geographic Information System using ArcView GIS, Version 3.2 (ESRI, Redlands, California). Mortality signals were immediately located and cats necropsied if cause of death was unknown.

Data Analysis

Survival.--Free-roaming cats were classified as owned, feral or semi-feral. Unowned cats were classified as semi-feral if I observed them being fed by a resident. Residents that fed cats were contacted to verify that they did not own these animals and fed these cats regularly. I used the staggered entry, Kaplan-Meier survival estimator implemented in program MARK (Pollock et al. 1989, Tsai et al. 1999, White and Burnham 1999) to estimate study period survival by ownership class and sex. Survival estimates were based on the best fitting model, given the data, ranked according to AIC_c (Burnham and Anderson 2002).

Fecundity.--Fecundity was determined by weekly walk-ins on unowned females (feral and semi-feral) to locate litters. I defined fecundity in my study as the number of kittens/litter at time of parturition. I estimated time of parturition for litters not immediately found based on kitten size. Fecundity data were supplemented by observations collected by local residents. Reproductive success was defined as the number of kittens/litter to survive > 12 weeks. Statistical analysis was not conducted due to small sample sizes.

Ranges and Movements.--I calculated annual ranges (95% probability area) and core areas (50% probability area) using a fixed-kernel home-range estimator (Worton 1989, Seaman et al. 1998, Seaman et al. 1999) and 100% minimum convex polygons (MCP) with the animal movement extension in ArcView (Hooge and Eichenlaub 1999). Annual range and core area was calculated for cats with > 25 locations (Seaman et al. 1999). I tested for differences in annual ranges and core area estimates based on ownership status and sex using an analysis of variance (ANOVA). Post hoc comparisons of ownership classifications were conducted using Tukey's HSD (Ott and Longnecker 2001). I tested for an interactive effect of sex and ownership classification on annual ranges estimates. Mean annual movements were calculated for cats with > 25 locations using the animal movement extension in ArcView (Hooge and Eichenlaub 1999). I tested for differences in mean movements based on ownership status and sex using an analysis of variance (ANOVA). Post hoc comparisons of ownership classifications were conducted using Tukey's HSD (Ott and Longnecker 2001).

RESULTS

Survival

Feral cat survival was lower (0.61, SE = 0.12, n = 32) than semi-feral cat survival (0.88, SE = 0.12, n = 11, Figure 2.2), but there was little evidence that these differences were biologically significant. All owned cats (n = 10) survived. The model where survival differed by ownership status best fit the data as indicated by the Akaike weight (w_1= 0.66), however, the next best model suggested some evidence that survival may not differ between ownership status (w_2=0.26). Survival for unowned males was lower (0.58, SE = 0.13, n = 28) than unowned females (0.88, SE 0.12, n = 15) based on the best fitting model (w_1 =0.85). Primary mortality factors for unowned cats were vehicle collisions (n

= 5) followed by gunshot (n = 1), dog attack (n = 1), and euthanasia by animal control (n = 1).

Fecundity

All owned females (*n* = 5) in my study were spayed therefore I did not include them in comparisons of fecundity. Feral cats had a lower mean number of litters/year (1.0) than semi-feral cats (1.5). Mean litter size at parturition for feral females was 3.5 kittens/litter (*n* = 3). Mean number of kittens surviving > 12 weeks was 1.75 (*n* = 2) (Fig. 2.3). Mean litter size at parturition for semi-feral females was 3.6 kittens/litter (*n* = 7). Mean number of kittens surviving > 12 weeks was 2.75 kittens/litter (*n* = 4) (Fig. 2.3). Mean kitten survival for feral females was 36% lower than semi-feral females.

Ranges and Movements

A total of 28 free-roaming cats (*n* = 12 females, *n* = 16 males) met my criteria for calculating ranges and mean movements. In general, I found annual ranges decreased with an increase in ownership for free-roaming cats.

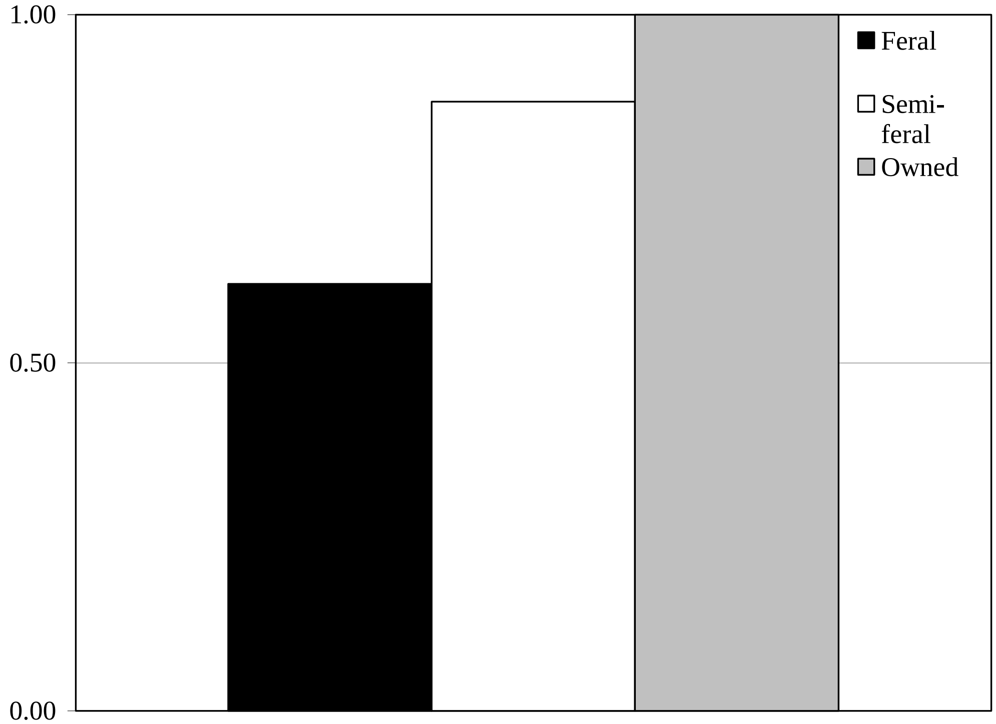

Fig. 2.2. Annual survival for free-roaming cats by ownership classification, Caldwell, Texas, 2005.

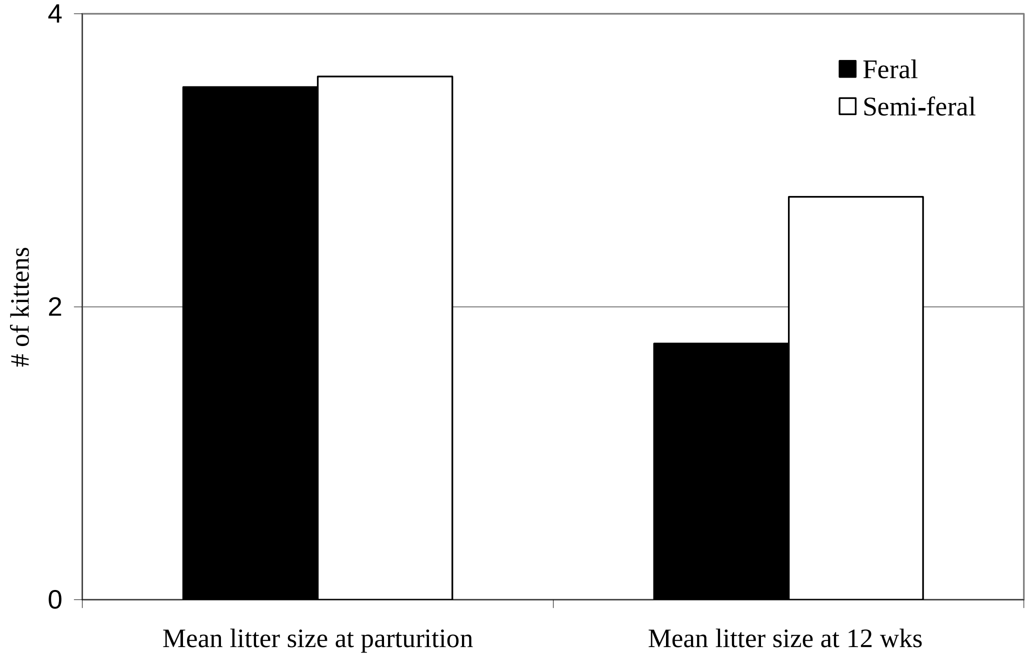

Fig. 2.3. Annual fecundity for free-roaming cats by ownership classification, Caldwell, Texas, 2005.

Mean annual ranges for feral cats (*n* = 12) were as follows: 50% kernel estimate was 1.5-ha (95% CI, 0.13-2.85 ha), 95% kernel estimate was 11.5-ha (95% CI, 2.3-20.7 ha) and MCP was 13.4-ha (95%CI, 6.2-21.7 ha) (Fig. 2.4). Mean ranges for semi-feral cats (*n* = 9) were as follows: 50% kernels estimate was 0.4-ha (95% CI, 0.2-1.0 ha), 95% kernel estimate was 3.6-ha (95% CI, 0.3-7.5 ha) and MCP was 5.2-ha (95% CI, 1.9-8.6 ha) (Fig. 2.4). Mean ranges for owned cats (*n* = *7*) were as follows: 50% kernel estimate was 0.02-ha (95% CI, 0.01-0.03 ha), 95% kernel estimates was 0.2-ha (95% CI, 0.02-0.2 ha), MCP was 1.1-ha (95% CI, 0.5-1.7 ha) (Fig. 2.4). I found kernel estimates (50% and 95%) did not differ (*P* = 0.256-0.596) by ownership classification; however, 100% MCP estimates did differ (*P* = 0.049) by ownership patterns.

In comparing annual ranges by sex, I found that as expected male ranges were larger than females. Mean ranges for all female cats (n = *12*) were as follows: 50% kernel estimate was 0.2-ha (95% CI, 0.04-0.3 ha), 95% kernel estimate was 1.45-ha (95% CI, 0.3-2.6 ha) and MCP was 4.2-ha (95% CI, 1.2-7.1 ha). Mean ranges for all male cats (*n* = 16) were as follows: 50% kernel estimate was 1.2-ha (95% CI, 0.2-2.3 ha), 95% kernel estimate was 9.6-ha (95% CI, 2.5-16.7 ha) and MCP was 10.8-ha (95% CI, 4.4-17.1 ha). I found kernel estimates (50% and 95%) did not differ (*P* = 0.054-0.218) by sex; however, MCP estimates did differ (*P* = 0.049) by sex.

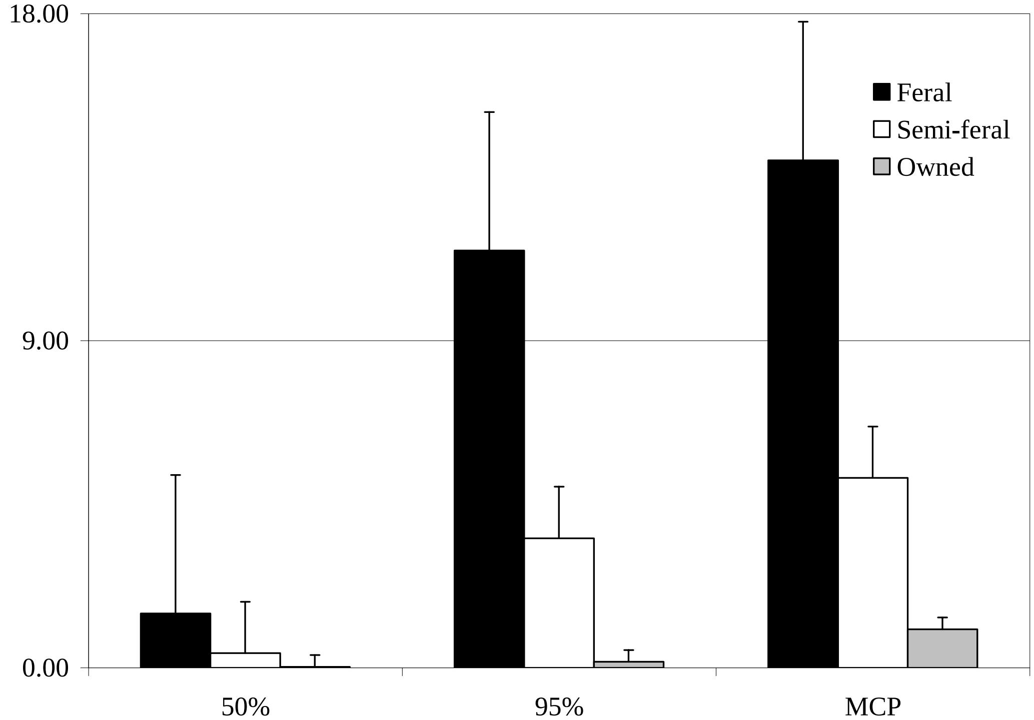

Fig. 2.4. Annual ranges (mean, 1 SE; minimum convex polygon [MCP], 95% kernel) and core areas (mean, 1 SE; 50% kernel) for free-roaming cats by ownership classification, Caldwell, Texas, 2005.

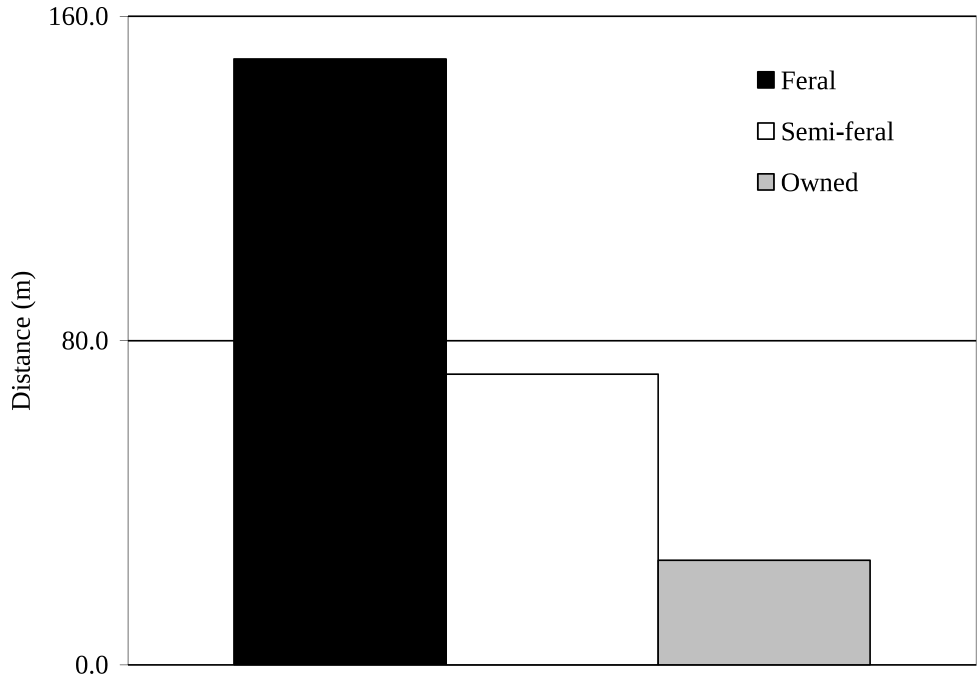

Fig. 2.5. Annual movements for free-roaming cats by ownership classification, Caldwell, Texas, 2005.

In general, feral cat movements were larger (149 m, SE = 76 m, $n = 12$) than movements for semi-feral cats (72 m, SE = 44 m, $n = 9$) ($P = 0.005$), and owned cats (26 m, SE = 11 m, $n = 7$) ($P < 0.000$); but semi-feral cat movements were not larger than owned cats ($P = 0.189$) (Fig. 2.5). I was unable to detect an interactive effect between sex and ownership status ($P = 0.109$) or an effect of sex ($P = 0.067$, males = 124 + 86 m, females = 53 + 27 m) although mean male movements were considerably larger than mean female movements.

DISCUSSION

Survival

We found that ownership classification was an important factor in predicting free-roaming cat survival. We found survival was highest for owned cats followed by semi-feral and feral cats, respectively (Figure 2.2). Additionally, survival for feral and semi-feral males was lower than for unowned females, however, our estimates had limited precision, precluding evaluation of biologically significant differences in survival of semi-feral and feral cats. Previous studies reporting survival estimates of free-roaming cats are limited to non-telemetry studies (e.g., phone surveys, observational data; Jochle and Jochle 1993, Luke 1996, Centzone and Levy 2002), and are not directly comparable For example, many feral and/or semi-feral cats may exploit rich food sources provided for other unowned cats, as well as food left out for outdoor pets and refuse, thus increasing unowned cat survival.

Fecundity

I also found ownership was an important factor in predicting fecundity in free-roaming cats. I found that feral cats produced fewer litters/year than semi-feral cats. Mean litter size at parturition was the same for feral and semi-feral females but kitten survival was reduced for kittens born to feral females (Figure 2.3). Because I was unable to estimate fecundity for owned cats in our study, I was unable to determine how full ownership affects kitten survival. However, I routinely observed owned females in the study area with 3-4 kittens approximately 12 weeks of age (P. Hill, Texas A&M University, unpublished data), which leads me to speculate that owned females that are not spayed experience higher fecundity rates than intact, unowned females. High fecundity has been reported in other studies where unowned cats were supplementally fed either directly by humans or indirectly by abundant refuse. For example, mean litter size estimates of 3.6 kittens/litters and median litter size of 3 kittens/litter were reported for females regularly fed by caretakers in managed colonies (Scott et al. 2002, Nutter et al. 2004). As with survival estimates, reported fecundity estimates, however, were not based on radio-telemetry data and should be viewed with caution.

Ranges and Movements

Ownership also was an important predictor of differences in cat ranges and movements. Ranges and core areas decreased with increased levels of ownership classification for all 3 estimates (Figure 2.4). Mean movements also decreased significantly with increased levels of ownership classification (Figure 2.5). Movements of semi-feral cats were more similar to owned cats than feral cats (Figure 2.5). Previous studies reporting average ranges of feral and semi-feral cats from telemetry data ranged from 32 -187 ha (Warner 1985, Apps 1986, Langham and Porter 1991, Hall et al 2000) and are considerably larger than what we report (5.2–13.4 ha); however, lower ranges in our study may be attributed to the availability of food resources in urban areas.

The abundance and distribution of food resources has been linked to range size and population density in free-roaming cats; areas of abundant and concentrated food resources cats have increased densities and decreased ranges (Liberg and Sandell 1988, Izawa and Doi 1993, Genovesi et al. 1995, Mirmovitch 1995). Wild felids, including feral cats, are generally considered to be solitary; however, feral cats will convert to group living in the presence of large amounts of concentrated and stable food sources (Liberg and Sandell 1988). Ash (2001) reported smaller ranges and distances among group members for cats in areas with a history of highly predictable food resources. Ash's (2001) research was conducted after the initiation of a TTVAR (trap/test/vaccinate/alter/release) program so it is unclear how neutering may have affected range size and group dynamics. However, Calhoon and Haspel (1989) found the distribution of abandoned buildings determined cat densities not supplemental feedings.

In comparing semi-feral and feral cat distribution, we observed most semi-feral cats were located in neighborhoods within the center of our study area, while most feral cats were located in natural areas around the edges of the study area with fewer residents. We propose the advantages for semi-feral cats include an increase likelihood of being fed or finding food resources and increased reproductive opportunities. Presumably, food resources provided directly or indirectly by humans are exploitable by all free-roaming cats; it is unclear what mechanisms regulate why some unowned cats exploit food resources in areas inhabited by humans while others do not. However, the ecological consequences of feeding unowned, reproductively viable, free-roaming cats are clear. Abundant food resources should increase survival and fecundity, reduce ranges and movement, thus increasing cat densities and carrying capacity. This is particularly important with pregnant females which local residents routinely feed to ensure survival of kittens (P. Hill, Texas A&M University, unpublished data). We propose that subsidized populations of free-roaming cats may serve as source populations for outlying areas although this needs further investigation.

CHAPTER III

ESTIMATING CAT DENSITIES IN URBAN AREAS

SYNOPSIS

Obtaining reliable population estimates is imperative in managing wildlife populations, particularly when attempting to implement nuisance control measures. Free-roaming cats impact wildlife worldwide through predation, competition and disease transmission. Ideally, measures of controlling free-roaming cat populations should be evaluated *a priori*, which requires obtaining population estimates for use in population control programs (e.g., euthanasia, trap/treat/neuter/release). I compared mark-resight and distance sampling abundance estimates of free-roaming cats in urban areas. I marked a subset of free-roaming cats (n = 54) with radio-collars in Caldwell, Texas to aid in obtaining our estimates. From road surveys (n = 20) conducted in August 2005, I found mark-resight estimates (N = 739, 95% CI 510-1,141) were similar (P > 0.05) to distance sampling estimates (N = 673, 95% CI 357-1,268). Study results suggest that distance sampling provides wildlife managers an alternative in estimating free-roaming cat populations in urban areas and can be implemented to monitor the effectiveness of population control measures with minimal cost and training.

INTRODUCTION

Obtaining reliable population estimates is imperative in managing wildlife populations (Lancia et al. 1994, Krebs 1999), particularly when attempting to implement nuisance control measures. The U.S. population of free-roaming cats has been estimated at over 100 million (Clarke and Pacin 2002), and impact wildlife through predation, competition and disease transmission (see Patronek 1998 and Slater 2002 for summaries).

Proposed measures for control of free-roaming cat populations include euthanasia, hunting and TTNR (trap/treat/neuter/release) programs. Ideally, the evaluation of such control measures (i.e., type, combinations of methods, frequency, and associated costs) should be conducted *a priori* using demographic models of free-roaming cats that incorporate population vital rates and abundances (White 2000). Here I define semi-feral as unowned cats that are regularly and directly fed by a resident and feral as unowned cats that are not directly fed.

Previous studies of free-roaming cats (primarily feral) have included population indices (e.g., Crooks and Soulé 1999, Molsher et al. 1999, Edwards et al. 2000, Edwards et al. 2002, Burrows et al. 2003, Meckstroth and Miles 2005) in rural areas. Methods of estimating free-roaming cat populations in urban areas, are lacking, but may include mark-recapture techniques (Lancia et al. 1994, Krebs 1999) and distance sampling methodologies (Buckland et al. 1993, Focardi et al. 2002). Mark-recapture techniques have been successfully used in estimating mid-sized carnivore abundances using temporary markers (e.g., Nietfeld et al. 1994), natural markers (e.g., Heilbrun et al. 2003, Sequin et al. 2003, Trolle and Kéry 2003), or radio-telemetry (e.g., Riley et al. 1998, Coonan et al. 2005, Hawkins and Racey 2005), and generally provide precise abundance estimates (White and Shenk 2001). However, limitations to mark-recapture estimates include cost, time requirements, and the need for specialized equipment (Lancia et al. 1994). Distance sampling may overcome some of these limitations (Buckland et al. 1993, Forcardi et al. 2002). Distance sampling has been used to estimate the abundances of plants and animals (Lancia et al. 1994, Krebs 1999, Buckland et al. 2001). Recent studies have implemented a distance sampling framework to estimate grey squirrel (*Sciurus* *carolinensis*, Hein 1997) and free-roaming dog (*Canis familiaris*, Childs et al. 1998) abundances in urban areas. Where capture and release of numerous individuals is not feasible (such as estimating urban wildlife populations, including free-roaming cat populations), the use of distance sampling might be applicable. My study objective was to compare the reliability of population estimates of free-roaming cats in urban settings using mark-resight versus distance sampling methodologies, and to evaluate potential benefits of their use in population control programs.

STUDY AREA

I conducted this comparison of free-roaming cat abundances in the city of Caldwell, a small, suburban community of approximately 3,400 residents located in Burleson County, Texas (Figure 2.1). This study was conducted in the center of the city in an 822 ha area. Caldwell has no zoning laws and is highly heterogeneous with single and multi-family dwellings (6–10 houses/ha) intermixed with commercial, industrial and agricultural developments (Marzluff et al. 2001). Residents generally tolerate unowned cats. Animals reported to the part-time animal control officer are trapped, held according to state law, and euthanized if unclaimed. Socialized cats may be held longer until they are adopted or euthanized.

METHODS

Trapping and Marking

Unowned cats were trapped using Tomahawk live traps (Model 608, 91.4 x 25.4 x 30.5 cm Tomahawk Live Trap Company, Tomahawk, Wisconsin) intermittently between October 2004-August of 2005. I attempted to maintain 20 radio-collared cats at any given time throughout the study. Trapped cats were anaesthetized (0.08 mg/kg Domitor

+ 0.2 Butorphanol given intramuscularly with 0.08 mg/kg Antisedan given intramuscularly for reversal) and fitted with mortality sensitive transmitters (150-152 MHz, 30 g, Advanced Telemetry Systems, Isanti, Minnesota) on break-away collars. Transmitters were <3% of each cat's body weight within the 5% threshold recommended by the American Society of Mammalogists (1998). Prior to release, all cats were weighed, sexed, aged, and checked for neuter scars. Free-roaming owned cats were enrolled voluntarily by residents of the study area and processed at their residence using methods identical to those for unowned cats. Research was approved by the Clinical Research Review Committee at the College Of Veterinary Medicine, Texas A&M University (CRRC 04-30, 04-31).

Surveys

I conducted intensive surveys of free-roaming cats (n = 20) in a short time period (August 2005) to ensure our study population was demographically and geographically closed (White and Shenk 2001). I conducted half of the surveys between the hours of 0600-0800 hrs (n = 10) and half between the hours of 1800-2000 hrs (n = 10). The survey route was 14.3 km in length and was completed in approximately 1.5 – 2 hours. To avoid the use of spotlights and disturbing residents, I chose survey times based on when free-roaming cats were most active and easily observed. I conducted surveys from the road with 1 observer. I selected intensive, short time period surveys with 1 observer to evaluate methods most likely to be implemented by city officials (e.g., animal control officer). The use of convenience sampling and the biases inherent in the lack of probabilistic sampling when estimating wildlife populations has been discussed at length (Anderson 2001, Anderson 2003, Ellingson and Lukacs 2003, Hutto and Young 2003).

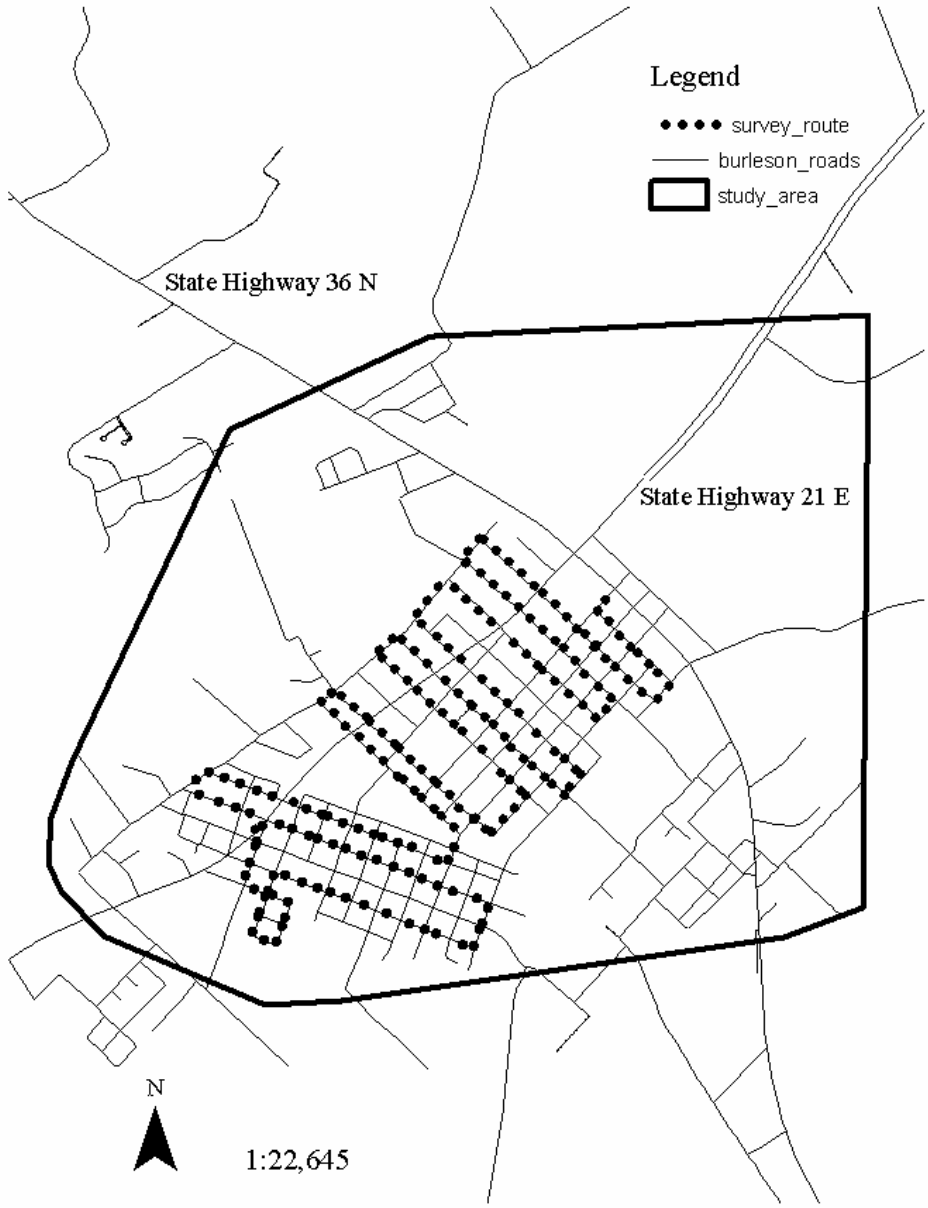

Fig. 3.1. Survey route for mark-resight and distance sampling estimates of free-roaming cat abundance in Caldwell, Texas, August 2005.

This research was conducted in an urban environment (i.e., free-roaming cats are largely an urban issue), which necessitated sampling via roads in a non-random manner. However, the streets of Caldwell, Texas are of uniform length and width, which closely mimics sampling grids and minimizes biases associated with sampling from roads (Figure 3.1). The observer recorded the number of cats seen (cluster size) and if an animal was marked. Perpendicular distance from the road was measured using a hand held range finder (Bushnell Yardage Pro 500, Bushnell Performance Optics, Overland Park, Kansas, USA). Odometer readings were collected at the start and end of transects to determine transect length. Study area was determined using ArcView 3.2 in a Geographic Information System (ESRI, Redlands, California, USA).

Data Analysis

Mark-resight.--Mark-resight survey data were entered into NOREMARK to obtain abundance estimates for each individual survey period (White 1996). The number of marked individuals available was determined from radio-telemetry data and adjusted for each survey conducted. Abundance estimates were calculated using the joint hypergeometric maximum likelihood estimator (JHE) (White and Garrott 1990, White and Shenk 2001). I chose this estimator because the study population is both geographically and demographically closed. I calculated density by dividing the abundance estimate provided by NOREMARK by the study area.

Distance Sampling.--To estimate abundance and density using distance sampling, I entered survey data into Distance 5.0 Beta 3 (Thomas et al. 2005). Based on the plot of the distribution of observed distances (no shoulder at g(0) and spike in data at 15m), I left truncated the data from 0–15m as recommend by Buckland et al. (2001) (Figure 3.2).

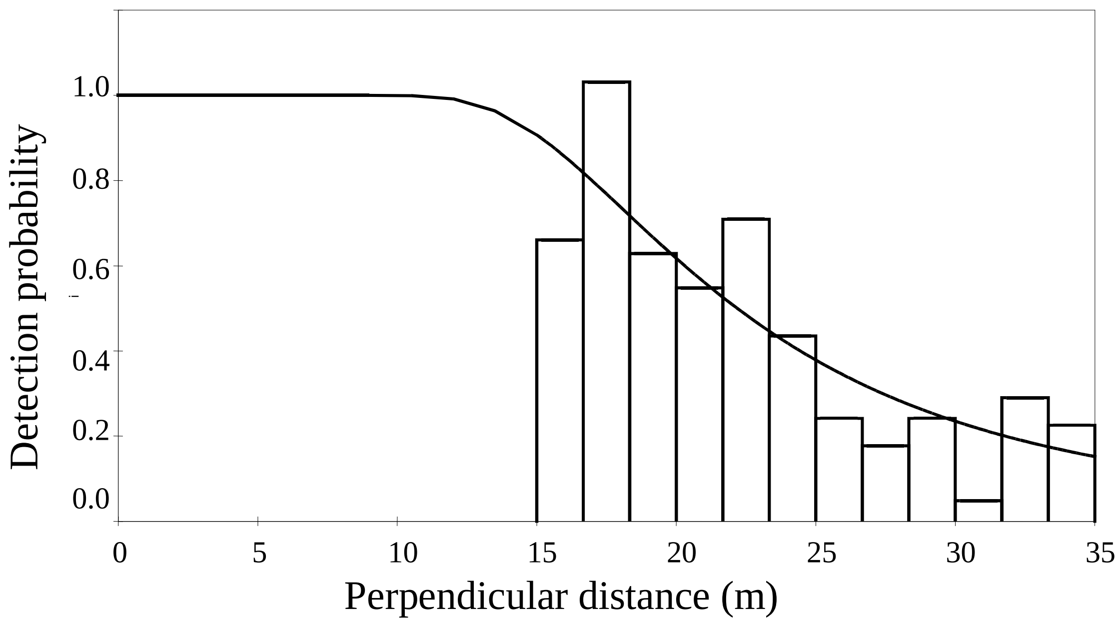

Fig 3.2. Detection probability plot (left truncated from 0 -15 m, right truncated 10%) using a hazard rate function for the distribution of observed perpendicular distances of free-roaming cats in Caldwell, Texas, 2005.

I also truncated the right 10% of observations due to the low frequency of observations at the right end of the distribution (Buckland et al. 2001) (Figure 3.2). I used a hazard rate function using 3 models with < 3 terms allowing Distance to select the best model using Akaike's Information Criterion.

RESULTS

Trapping and Marking

I marked a subset of free-roaming cats (n = 52) with radio-collars from October 2004-August 2005 comprising of 44 unowned (27 M, 17 F) and 8 owned cats (4 M, 4 F). When surveys were conducted a total of 16 unowned (7 M, 9 F) and 7 owned cats (3 M, 4 F) were actively being monitored.

Mark-resight

The number of marked individuals was 23 for the first 13 surveys and 22 for the last 7 surveys due to 1 individual being censored. The average number of marked and unmarked cats seen per transect was 1.1 and 34.8, respectively. Abundance estimates for individual sighting occasions ranged from 191–1,103. Mean abundance for all sighting occassions (n = 20) was N = 739 (95% CI 510 - 1,141). Density was calculated as 0.90 cats/ha.

Distance Sampling

The average number of cats seen/transect (comprised of the entire 14.3 km survey route) was 37.9. Effective strip width (ESW) was 8.73 m, abundance was N = 673 (95% CI 357–1,268) and density was 0.82 cats/ha. Cluster size and encounter rate combined explained 6.4% of the coefficient of variation (CV = 33.1) with the remaining 93.7% explained by the detection probability. In comparing confidence intervals between the 2 methods, cat abundance using distance sampling was not significantly different ($P > 0.05$) from abundance estimates produced using mark-resight methods.

DISCUSSION

As free-roaming cats in the U.S. continue to increase and impact wildlife through predation, competition and disease transmission (Patronek 1998, Clarke and Pacin 2002, Slater 2002), obtaining reliable population estimates is imperative in nuisance control programs. For example, in this study the City of Caldwell was interested in determining the cost of alternative measures of population control (e.g., euthanasia, TTNR), which requires free-roaming cat abundance estimates. I compared estimates of free-roaming cat populations in urban areas using mark-recapture techniques (Lancia et al. 1994, Krebs 1999) and distance sampling methodologies (Buckland et al. 1993, Focardi et al. 2002). I found abundance estimates to be comparable using both methods, though the precision for the distance estimates was slightly less (95% CI 357–1,268) than markresight estimates (95% CI 510–1,141).

Mark-resight estimators allow wildlife biologists to obtain highly precise population estimates and to determine and correct for violations of statistical assumptions (White and Shenk 2001). The cost and time associated with trapping and marking large numbers of animals particularly trap weary species such as free-roaming cats, however, is one drawback of using mark-resight estimators. Furthermore, free-roaming cats are an exotic predator associated with numerous impacts to wildlife; therefore, it may not be feasible or appropriate to release individuals for the sake of obtaining abundance estimates. Thus, distance sampling is a viable alternative in estimating free-roaming cat abundances in urban environments. Our study findings suggest distance sampling precludes the need for trapping and marking animals without compromising precision. Finally, the use of convenience sampling via roads is necessary in urban environments; however, this did not appear to greatly reduce the precision of our estimates although I would not expect this to hold true in all environments. Future research may evaluate the use of distance sampling to estimate free-roaming cat abundances in natural areas, as well as, the effect of season and time of day.

CHAPTER IV

MANAGEMENT STRATEGIES FOR FREE-ROAMING CAT POPULATIONS

SYNOPSIS

With an estimated 400 million domestic cats worldwide, issues associated with free-roaming cats are of global importance due to animal welfare and public health concerns, as well as impacts on native wildlife through predation, competition and disease transmission. Proposed control solutions for managing urban free-roaming cat populations include euthanasia and trap/treat/neuter/release (TTNR) programs. Here I evaluate the effectiveness and costs associated with each of these control methods using a stochastic, demographic population model for free-roaming cats. Model parameters were estimated from a radio-collared subset of an unmanaged, free-roaming cat population in Texas. I evaluated 3 management strategies to control urban cat numbers over a 10 year period: euthanasia, TTNR and a 50:50 combination of both euthanasia and TTNR each at 25%, 50% and 75% implementation rates. I compared final population size, total number of cats treated and treatment cost relative to population reduction for all 3 treatment types and rates. I found the largest population decrease (82%) was achieved with 75% TTNR followed by 75% euthanasia/TTNR combination (70% decrease) and 75% euthanasia (68% decrease). TTNR rates of 75% required treatment of fewest individuals. Euthanasia rates of 75% were most cost effective at $33/1% population decrease. Euthanasia and TTNR were both effective at reducing free-roaming cat populations; TTNR resulted in greater population reductions whereas euthanasia was more cost effective. Although TTNR programs appear to effectively control free-roaming cat populations it is unclear if and how they will address the issues of ecological impacts,

nuisance complaints and potential disease transmission. TTNR campaigns in areas that are ecologically sensitive or in communities that will not tolerate large populations of free-roaming cats should be implemented with caution.

INTRODUCTION

The U.S. population of owned cats has recently been estimated around 73 million (Slater 2002) and the number of unowned cats has been estimated between 10-50 million (Mahlow and Slater 1996) for a total cat population >100 million (Clarke and Pacin 2002). With an estimated 400 million domestic cats worldwide (Jarvis 1990), issues associated with free-roaming cats are of global importance. Free-roaming cat populations include owned cats allowed outdoors, recently owned, lost or abandoned cats, and feral cats (Slater 2002). Problems that arise from large and ubiquitous free-roaming cat populations in both urban and rural areas are well documented and include animal welfare concerns (starvation, disease, abuse or depredation), public health and nuisance concerns, as well as impacts on native wildlife through predation, competition and disease transmission (see Patronek 1998 and Slater 2002 for summaries). Control of free-roaming cats is an issue of much debate, which pivots upon whether control solutions should use lethal or non-lethal means. In the U.S., the 2 main population control strategies for free-roaming cat populations are euthanasia and TTNR (trap/treat/neuter/release) programs (e.g., Neville and Remfry 1984, Zaunbrecher and Smith 1993, Centzone and Levy 2002, Scott et al. 2002, Levy et al. 2003), while more recently hunting of free-roaming cats has been proposed in Wisconsin (Wisconsin Department of Natural Resources 2005). Proponents for both euthanasia and TTNR control measures argue that their preferred solution is more effective and appropriate than the opposition's, however, studies comparing the effectiveness of euthanasia and TTNR at reducing an unmanaged free-roaming cat population are anecdotal and controversial (Neville and Remfry 1984, Passanisi and Macdonald 1990, Zaunbrecher and Smith 1993, Patronek 1998, Clark and Pacin 2002, Gibson et al. 2002, Hughes et al. 2002, Stoskopf and Nutter 2004). Lethal measures including hunting, trapping and poisoning have been used to successfully eradicate free-roaming cats from 48 islands (Veitch 2001, Bester et al. 2002, Nogales et al. 2004), however, no successful mainland eradication attempts have been reported or evaluated (Short et al. 1997). Furthermore, these studies are for remote populations with little or no human populations making lethal control measures more feasible with less resistance and would not be appropriate for urban populations of free-roaming cats.

Ideally, the evaluation of population control methods for unmanaged cat populations should be conducted *a priori* using appropriate estimates of vital rates (White 2000). Population models are a principal tool used by ecologists and wildlife managers to understand both natural and anthropogenic factors that affect population dynamics (Akcakaya 2000, Caswell 2001). Such models have shown the affect of numerous factors on population levels, including habitat quality, availability and composition (Kauffman et al. 2003), harvest levels (commercial, non-commercial, hunting and accidental) (Hellgren et al. 1995, Guthrie et al. 2000, Alpizar-Jara et al. 2001) and various management scenarios (introductions, control and removal) (Lacy and Clarke 1993, Eastridge and Clark 2001, Gogan et al. 2001, Phillips and White 2003). Wildlife ecologists now use population models as decision making tools to assess the viability of various management scenarios to control or regulate invasive and introduced species

(Gogan et al. 2001), including free-roaming cats (Slater 2002, Anderson et al. 2004). Anderson et al. (2004) modeled the response of free-roaming cat populations to determine the effectiveness of euthanasia versus TTNR but their study was limited to managed or supplementally fed populations. The effectiveness of euthanasia and TTNR on unmanaged, free-roaming cat populations typically found in urban areas, however, is unknown. Thus, my study objectives were (1) to evaluate euthanasia, TTNR and euthanasia/TNNR combinations at different levels of intensity (25%, 50%, 75%) for reducing free-roaming cat populations, and (2) to evaluate the cost effectiveness of euthanasia, TTNR and euthanasia/TTNR combinations for each treatment rate.

STUDY AREA

The City of Caldwell is a small, suburban community of approximately 3,400 residents located in Burleson County, Texas (Figure 2.1). This study was conducted in the center of the city in an area approximately 800 ha. Caldwell has no zoning laws and is highly heterogeneous with single and multi-family dwellings (6–10 houses/ha) intermixed with commercial, industrial and agricultural development (Marzluff et al. 2001). Residents generally tolerate unowned cats. Animals reported to the part-time animal control officer are trapped, held according to state law and euthanized if unclaimed. Socialized cats may be held longer until they are adopted or euthanized.

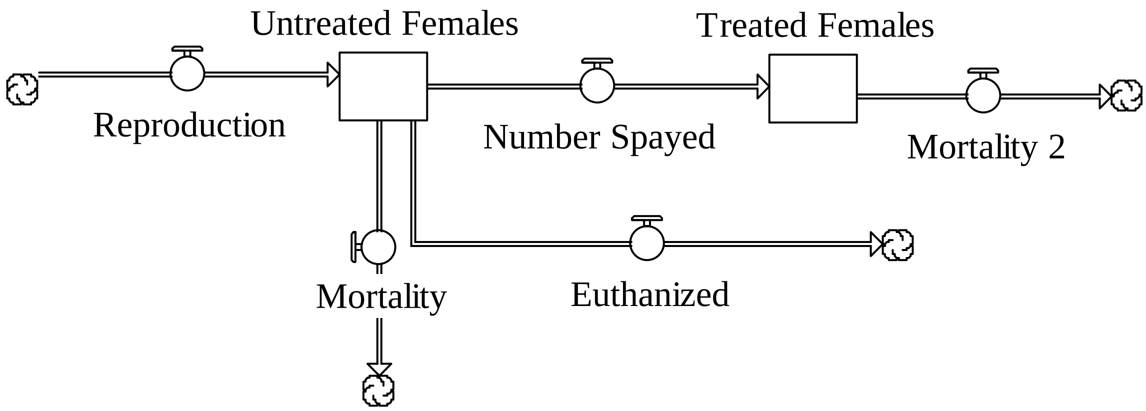

Fig. 4.1. Stochastic population model incorporating fecundity and mortality rates of treated and untreated free-roaming cats in Caldwell, Texas, 2005.

METHODS

Model Overview

A stochastic, stage-structured demographic model was developed to simulate population dynamics of free-roaming cats under various management strategies for Caldwell, Texas (Figure 4.1) (Akcakaya 2000). Model stages represented reproductively active or spayed females. The model was developed using STELLA® Research, Version 7.0.3, computer program (High Performance Systems, Inc., 2002). Model parameter estimates were obtained from a radio-marked population of free-roaming cats in Caldwell, Texas (Chapters II-III).

Model Parameters

Initial Abundances.--Initial abundance estimates were obtained from radio-collared cats using distance sampling and mark-resight (Chapter II). Mean abundance for mark-resight and distance sampling was 744 and 673, respectively. The average initial abundance estimate used in the population model was 354 (assumed a 50:50 sex ratio, thus, 708 divided in half).

Survival.--Survival estimates were obtained from 43 radio-collared cats using a known fate model in Program MARK (Chapter II). Free-roaming cat annual survival for all unowned cats (n = 43) was estimated at 0.686 (1 SE = 0.098). I subtracted survival estimates from 1 to get a mortality rate of 0.314. Demographic variation in survival was based on a random sample from a normal distribution bounded by the estimated survival variance.

Fecundity.--Fecundity estimates were determined by weekly walk-ins of unowned (feral and semi-feral) females (Chapter II). I defined fecundity rates as the number of female offspring/female adult to survive to 12 weeks of age/year. I assumed a 50:50 litter sex ratio and equal survival among male and female offspring. I successfully monitored the litters of 8 females with 3 females having 2 litters/year for an average of 1.3 litters/year/female. Mean fecundity rate for unowned cats was 1.6 female kittens/year/female.

Model Use

The population model simulated the effect of euthanasia, TTNR programs (simulated by spaying females) and a 50:50 combination of the 2 strategies at controlling free-roaming cat population numbers over a 10-year period. Each simulation consisted of 1,000 replications (Harris et al. 1987) with 1-year time increments. I evaluated the following management scenarios and treatment level of intensity:

1. 1. No management: 0% euthanized and 0% TTNR.
2. 2. Euthanasia rates of 25%, 50%, and 75%.
3. 3. TTNR rates of 25%, 50%, and 75%.
4. 4. Euthanasia/TTNR rates of 25%, 50%, and 75% (split treatment intensity in half).

I calculated (1) mean population size and (2) mean number of cats treated for each model scenario over a 10 year period. I ran 1,000 simulations for each model scenario to incorporate stochasticity. I conducted a net cost-benefit analyses (i.e., average cost [$] per 1% population decrease) for each model scenarios. I divided the final population size for each model scenario by the final baseline population size and subtracted from 100 to calculate the total percent population decrease. I estimated treatment costs for euthanasia and TTNR based on the cost of those services as charged by the local veterinary clinic (Caldwell Veterinary Clinic, Caldwell, Texas). I did not include expenses related to trapping, holding and transporting cats since costs would be identical regardless of treatment method employed. I used a Kruskal-Wallis nonparametric analysis of variance (Ott and Longnecker 2001) to test for differences in all comparisons.

RESULTS

Model Use

Mean final population sizes were different (χ^2 = 8894.6, df = 8, P <0.001) for all treatment types (Figure 4.2). Mean ending population sizes were smallest for 75% TTNR rates (= 61, SD 20.6) and largest for the baseline population with no treatment (= 339, SD 43.6). I found little variability among mean ending population sizes for all 3 treatments at 25% implementation rates (Figure 4.3 [a]). I found greater variability among final population size for all 3 treatments at 50% implementation rates (Figure 4.3 [b]) with TTNR being most effective (= 519, SD 29.9). The most variability was found with 75% implementation rates with less variability between euthanasia and euthanasia/TTNR combination than TTNR, with TTNR producing the smallest final population (Figure 4.3 [c]). Euthanasia produced the largest initial decrease in population size for all 3 implementation rates (Figure 4.3 [a, b, c]).

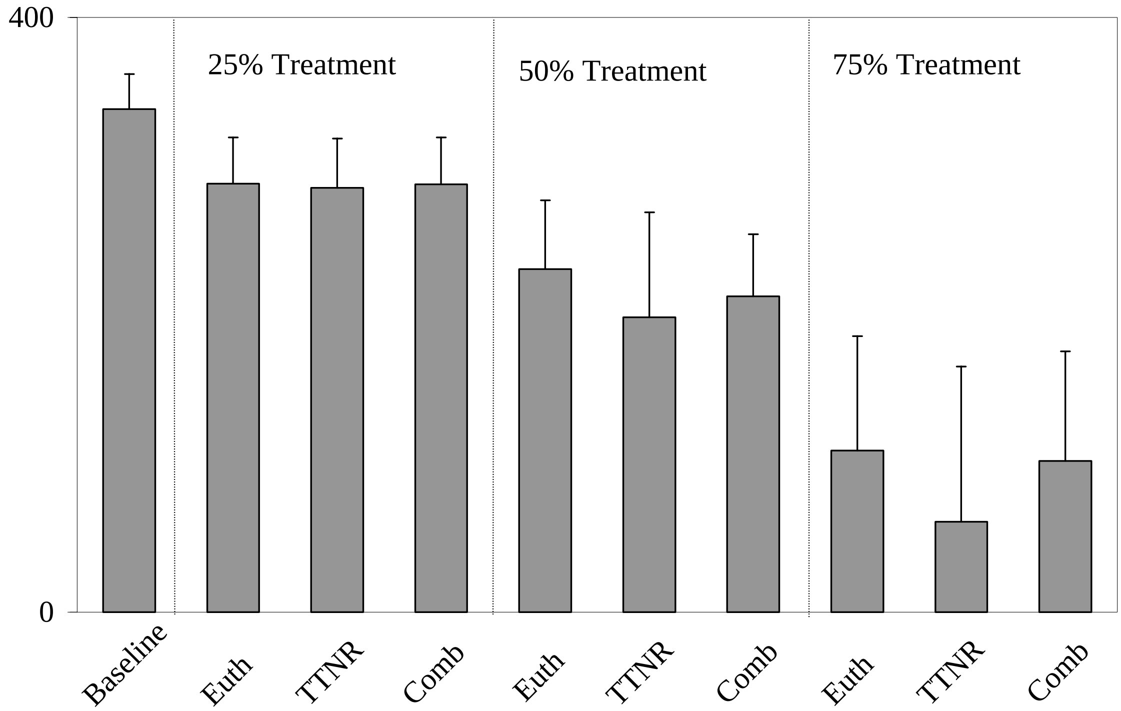

Fig. 4.2. Mean final population size and standard deviations for 1000 model simulations of 0%, 25%, 50% and 75% treatment rates of euthanasia, TTNR and a euthanasia/TTNR combination for free-roaming cats in Caldwell, Texas, 2005.

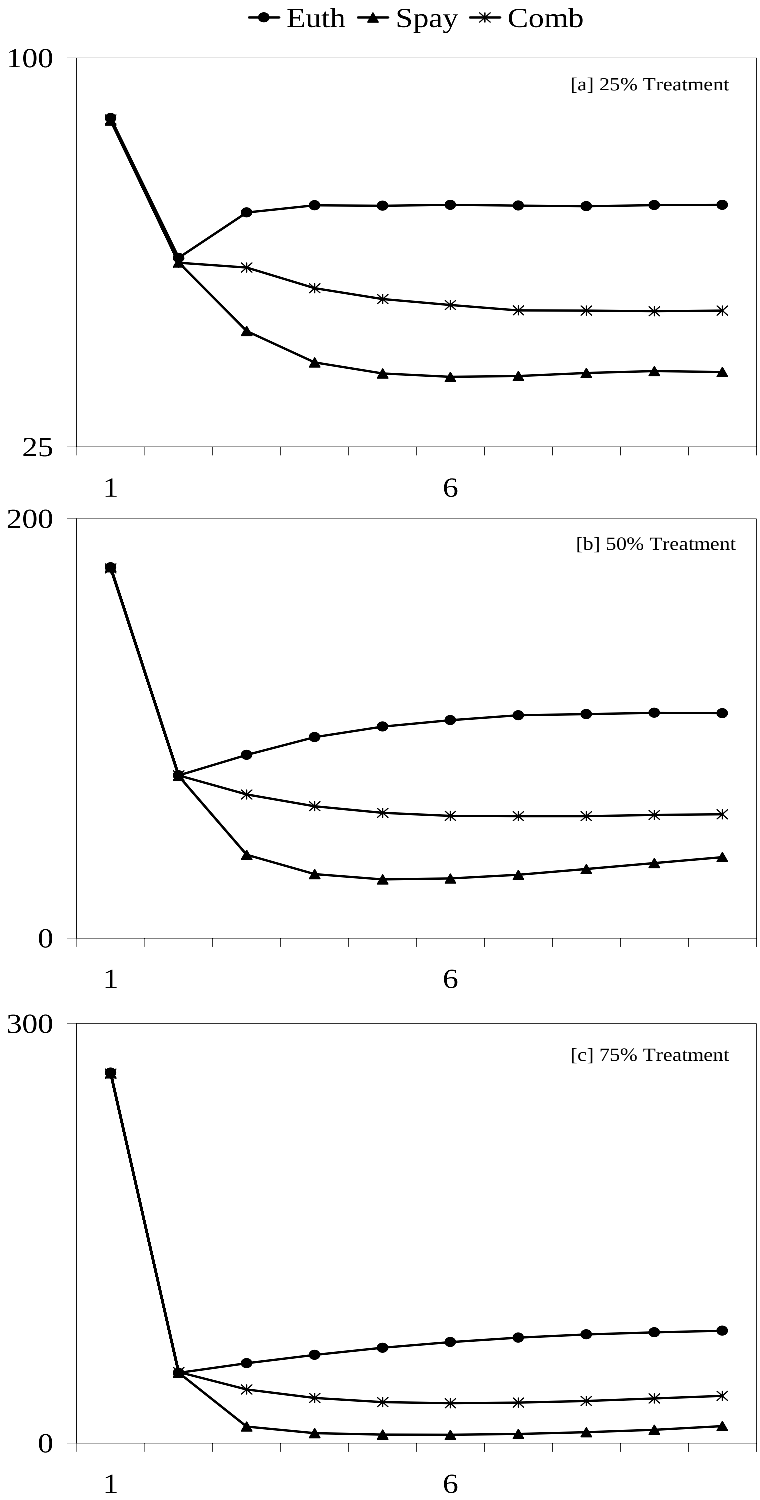

Fig. 4.3. Population trajectories for free-roaming cats by treatment (euthanasia, TTNR, 50:50 euthanasia/TTNR combination) and level of treatment (25% [a], 50% [b], 75%[c]) over 10 years, Caldwell, Texas, 2005.

Mean total number of cats treated was different (χ^2 = 8160.0, df = 8, P <0.001, Figure 4.4) among model scenarios. Implementation of 50% euthanasia rates resulted in the largest number of cats treated (= 1071, SD 71.2) (Figure 4.4). Implementation of 75% TTNR rates resulted in the smallest number of cats treated (= 382, SD 31.2) (Figure 4.4). Implementation of 75% TTNR and euthanasia/TTNR combinations required more cats to be treated initially but resulted in fewer subsequent treatments while still producing the largest population decreases compared to other treatment types and rates (Figure 4.5 [a, b, c], Table 4.1).

I summarized the overall population decrease, total cost and treatment cost/1% population decrease (Table 4.1). I found 25% euthanasia and 25% euthanasia/TTNR combination produced the lowest population decreases of 15%. Treatment costs/individual cat were $23 for euthanasia, $77 for TTNR and $50 for a euthanasia/TTNR combination. Total treatment costs were different (χ^2 = 8172.7, df = 8, P <0.001) among model scenarios. Total cost was least expensive for euthanasia followed by euthanasia/TTNR combination and TTNR for all 3 implementation rates. Euthanasia rates of 25% resulted in the lowest total cost (= $16,692 SD $790) followed by 75% euthanasia rates (= $20,568, SD $590) and 50% euthanasia rates (= $24,777, SD $498). Treatment cost per 1% population decrease was lowest for 75% treatment rates for all 3 treatment types with euthanasia being the overall most cost effective at $33/1% population decrease.

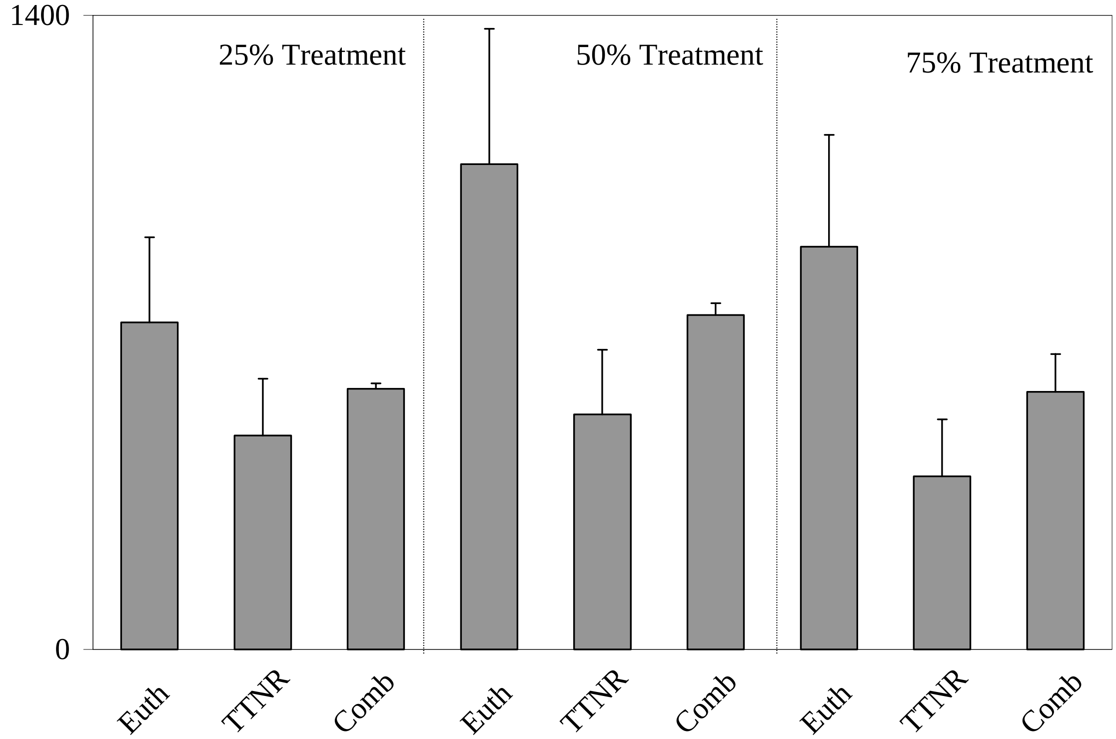

Fig. 4.4. Mean total number of cats treated and standard deviations for 1000 model simulations of 25%, 50% and 75% treatment rates of euthanasia, TTNR and a euthanasia/TTNR combination for free-roaming cats in Caldwell, Texas, 2005.

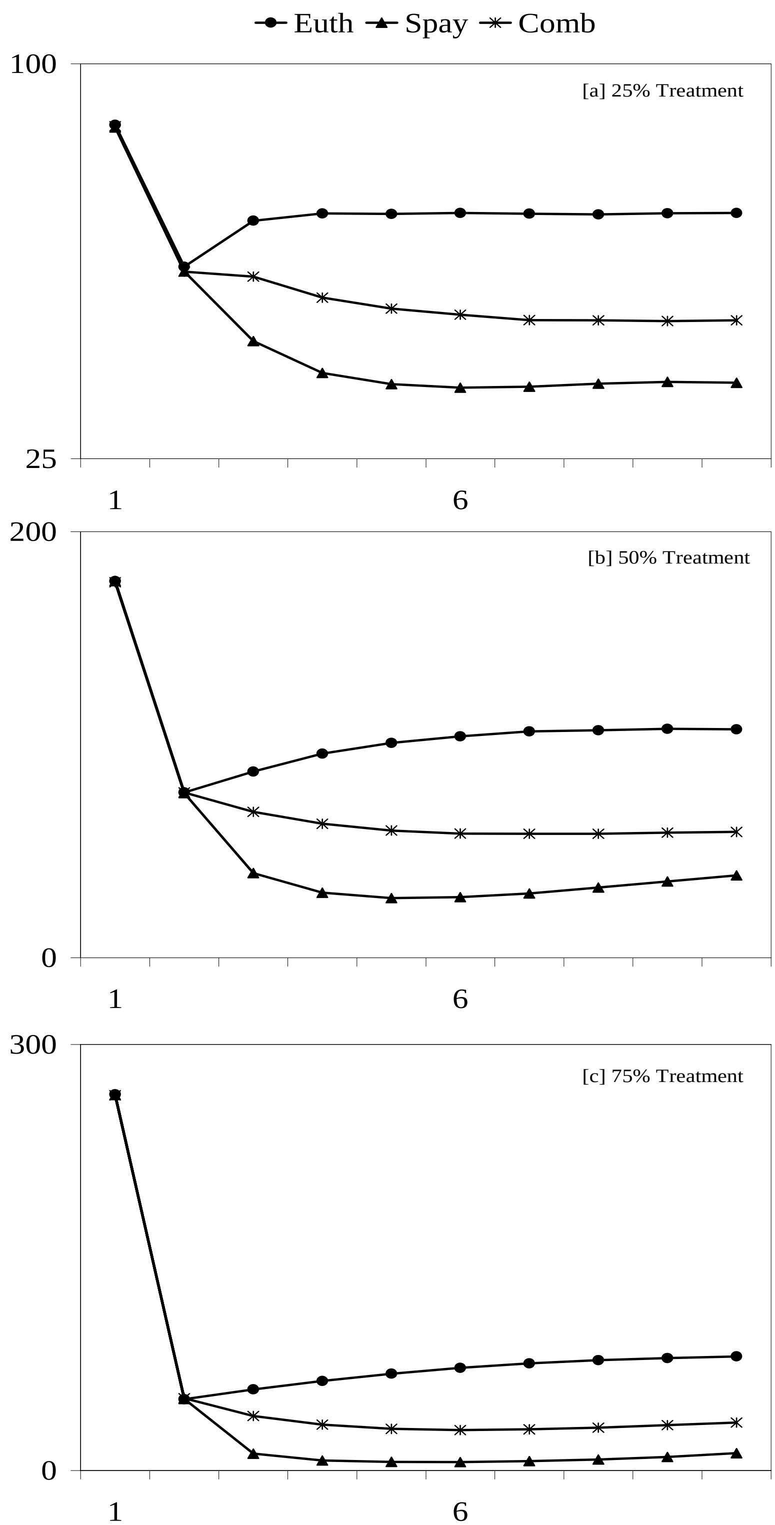

Fig. 4.5. Mean total number of free-roaming cats treated by treatment (euthanasia, TTNR, 50:50 euthanasia/TTNR combination) and level of treatment (25% [a], 50% [b], 75%[c]) over 10 years, Caldwell, Texas, 2005.

Table 4.1. Cost benefit analysis for 25, 50 and 75% treatment rates of euthanasia, spay and a euthanasia/spay combination over 10 years for free-roaming cats in Caldwell, Texas, 2005.

Treatment	Population Decrease (%)	Total Cost ($)	Treatment Cost/Cat ($)	Treatment Cost/1% Population Decrease
25% Euth	15	16,692 (SD 790)	23	154
25% Spay	16	36,478 (SD 2,159)	77	483
25% Combo	15	28,749 (SD 2,412)	50	333
50% Euth	32	24,777 (SD 498)	23	72
50% Spay	41	40,081 (SD 1,648)	77	188
50% Combo	37	36,913 (SD 3,680)	50	135
75% Euth	68	20,568 (SD 590)	23	**34**
75% Spay	**82**	29,518 (SD 1,327)	77	94
75% Combo	70	28,431 (SD 4,110)	50	71

DISCUSSION

I found 75% TTNR implementation resulted in the largest population decrease at 82% followed by 70% population decrease with a 75% euthanasia/TTNR combination and 68% population decrease with a 75% euthanasia rate. High treatment rates (5075%) produced an overall greater population reduction than low treatment rates (25%) for all 3 treatment types and required treatment of fewer total individuals than lower treatment rates. Treatment costs were lowest for 75% treatment rates for all 3 treatment types with euthanasia being the overall most cost effective ($33/1% population decrease). Euthanasia and TTNR were both effective at reducing free-roaming cat populations, however, TTNR produced greater population reductions while euthanasia was more cost effective.

These results indicate both euthanasia and TTNR may effectively reduce free-roaming cat numbers if implemented at high rates. If implemented by local officials, euthanasia would be more cost effective; however, many volunteer organizations provide financial, technical and volunteer support for TTNR campaigns, which may reduce costs making TTNR a feasible option. I stress that TTNR campaigns may not be appropriate in ecologically sensitive areas or in communities with high rates of nuisance complaints for free-roaming cats. Both euthanasia and TTNR programs should include pre- and post-implementation monitoring using accepted scientific procedures.

CHAPTER V

CONCLUSIONS AND IMPLICATIONS

Free-roaming cats impact wildlife worldwide through predation, competition and disease transmission (see Patronek 1998 and Slater 2002 for summaries); however, baseline ecological information (e.g., survival, fecundity, movements) necessary for population control is lacking. In radio-collaring 54 free-roaming cats in Caldwell, Texas, I obtained baseline demographic information (Chapter II). I found that survival, fecundity, annual ranges and movements were good indicators of ecological differences between subpopulations of free-roaming cats. These parameter estimates should be considered when evaluating various control strategies for free-roaming cats, as each subpopulation is likely to respond differently. For example, TTNR has been proposed as a non-lethal control strategy for unowned cats (Patronek 1998, Slater 2002). These results indicate that increased levels of ownership or feeding reduce free-roaming cats' ranges and movement while increasing survival and fecundity. Increasing the level of ownership localizes/concentrates the impacts of free-roaming cats. Therefore, areas where there are concentrations of native prey or threatened/endangered species may not be appropriate for TTNR campaigns (Stoskopf et al. 2004). Additionally, while TTNR programs may reduce free-roaming cat numbers and localize/concentrate their effects it is not clear if this will reduce or eliminate nuisance behaviors, disease transmission or predation of wildlife.

Next, I conclude distance sampling is a comparable alternative to mark-resight for estimating of the number of free-roaming cats in Caldwell, Texas (Chapter III). Distance sampling can easily be conducted with minimal training and does not require the time and cost of traditional mark-resight estimates. Data can easily by entered and evaluated in Program Distance (Thomas et al. 2005), which is available online at no cost. I recommend free-roaming cat management programs incorporate distance sampling to estimate cat abundances and that pre- and post- estimates are used to evaluate population control programs.

Finally, my results indicate both euthanasia and TTNR may effectively reduce free-roaming cat numbers if implemented at high rates (Chapter IV). If implemented by local officials, euthanasia would be more cost effective; however, many volunteer organizations provide financial, technical and volunteer support for TTNR campaigns, which may reduce their costs making them a feasible option. I stress that TTNR campaigns may not be appropriate in ecologically sensitive areas or in communities with high rates of nuisance complaints for free-roaming cats. Both euthanasia and TTNR programs should include pre- and post-implementation monitoring using accepted scientific procedures.

Free-roaming cat control may be achieved through either euthanasia or TTNR, however, these solutions must be thoroughly implemented within the first year to effectively reduce populations. Those responsible for population management should consider the ecological sensitivity of free-roaming cats, community sentiment towards control solutions as well as financial constraints on solution implementation. I found population control can be achieved using combinations of euthanasia and TTNR, which may allow officials flexibility in how and where they implement either solution. I suggest euthanasia should be implemented in ecologically sensitive areas and TTNR in areas lacking public support for lethal control. I caution that public preference for free-roaming cat management may not be ecologically appropriate (Ash and Adams 2003); however, population control solutions should also include public education to increase awareness of free-roaming cat issues and impacts. Low cost spay/neuter programs for owned cats would compliment free-roaming cat control by reducing the probability that owned cats will serve as source populations thus negating control attempts.

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