ABSTRACT

NUTTER, FELICIA BETH. Evaluation of a Trap-Neuter-Return Management Program for Feral Cat Colonies: Population Dynamics, Home Ranges, and Potentially Zoonotic Diseases. (Under the direction of Michael K. Stoskopf and Jay F. Levine)

With this research project I evaluated the effectiveness of trap-neuter-return management for feral cat colonies, and specifically examined the prevalence of selected infectious diseases, population dynamics, and home ranges for feral cats under different management strategies.

I used an effective trapping method and captured 98% of the target cats with 8.9 trap nights per cat. Breeding female cats produced a mean of 1.4 litters per year, with a mean of 3 kittens per litter. The majority of kittens (75%) died or disappeared by 6 months of age, and trauma was the most common cause of death. Pregnancies occurred throughout the year but peaked between March and May. I showed that feral cats and pet domestic cats had similar baseline health status and fecal prevalences of infections with *Cryptosporidium* spp., *Giardia* spp. and *Toxocara cati.* Feral cats had higher seroprevalences of *Bartonella henselae* and *Toxoplasma gondii*, and these findings are likely related to greater exposure of feral cats to the vectors or hosts of these organisms.

Survival analysis of individual intact and neutered cats in 9 colonies showed that castrated male cats and ovariohysterectomized female cats live significantly longer than their breeding counterparts, or than vasectomized males. Colonies managed by trap-neuter-return were stable in composition and declining in size throughout the seven year follow-up period. On average, breeding control colonies increased in size and had high

turnover of cats, although one colony did experience a population crash followed by a rebound. Immigration into both breeding and sterilized colonies was consistent but occurred at low levels. One sterilized colony went extinct after 31 months of follow-up, and the several other colonies consisted of 5 or fewer cats after 7 years of follow-up. The two most common outcomes for individual cats were disappearance from the colony or death, most often due to trauma. Vasectomized male cats were more likely to be killed by vehicles than intact or castrated males.

The home ranges of the managed feral cats were small, usually less than 1 hectare, regardless of sex or reproductive status. Vasectomized male cats had significantly larger home ranges than intact or castrated male cats, but the sizes of intact and castrated male cat home ranges were similar, as were the home ranges of intact and spayed female cats. Vasectomized males moved significantly greater distances from the feeding sites than intact or castrated males, and spayed females moved farther than intact females though the difference for females may not be biologically important. The larger home range size and greater distance moved from feeding sites for vasectomized male cats are likely related to their search for breeding females, since the females in their home colonies were spayed.

Community-level stakeholder meetings were successful in fostering consensus among participants with different backgrounds, preferences and agendas, and the need for multiple feral cat management options to address a diversity of situations was recognized.

I used the data generated during the monitoring phase of this project to set up and run a population viability analysis model with VORTEX 9.57 software. I simulated the potential fates of intact breeding colonies subjected to various harvest levels and harvest intervals, and of sterilized colonies with different proportions of breeding adults. The models suggested that harvesting breeding colonies every one or two years at very high levels can keep colonies small, but will not lead to long-term reduction in the numbers of cats because colonies can re-establish due to immigration. The models of neutered colonies suggested that sterilization levels of at least 75% to 80% are necessary to cause population decline and eventual colony extinction, assuming that immigrant cats are also sterilized. The mean estimated time to extinction of 12.8 years fits well with ongoing observations of steady decline in the colonies managed by trap-neuter-return.

Overall, the trap-neuter-return strategy is effective and provides a viable option for feral cat management.

Evaluation of a Trap-Neuter-Return Management Program for Feral Cat Colonies: Population Dynamics, Home Ranges, and Potentially Zoonotic Diseases

by

FELICIA B. NUTTER

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APPROVED BY:

Richard. B. Ford	Roger A. Powell
Michael K. Stoskopf Co-Chair of Advisory Committee	Jay F. Levine Co-Chair of Advisory Committee

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ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

DEDICATION

For my mother, Dorothy M. Nutter, who believed me when I announced at age four that I was going to be a veterinarian.

For my father, Fielden B. Nutter, Sr., who made sure that I completed 32 (!) years of school debt-free. That is a rare gift.

For my best friend Julie Osinski, whose house always provided enough cats for everyone at the slumber party, and with whom I shared my very first cat, Larry.

For Dr. Harold Hammerquist and Dr. George Saperstein, who provided different kinds of encouragement at an early stage.

For all my other friends and family, too numerous to list here without killing more trees than I can justify, for the pieces of you that have become parts of me.

And finally for my husband Dr. Chris Whittier, my dogs Haya and Ruby, and my cats Bishop, Tucker, Sophie (Good and Bad), Stihlman, and the Ponem for tolerating long absences.

"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise." John Tukey

“There are three kinds of lies: lies, damned lies, and statistics.” Benjamin Disraeli

"Alice had no idea what Latitude was, or Longitude either, but thought they were nice grand words to say." Lewis Carrol, *Alice in Wonderland*

“Improvement makes strait roads; but the crooked roads without improvement are roads of genius.” William Blake, *Proverbs of Hell, #66*

“If you can't be a good example, then you'll just have to be a horrible warning.” Catherine Aird

BIOGRAPHY

Felicia Beth Nutter received her B.A. in Biology and Psychology from Yale University in 1989. She attended veterinary school at Tufts University and received her DVM in 1993. Following graduation she completed a Fulbright Fellowship working with baboons and chimpanzees at Gombe National Park, Tanzania. She arrived at the College of Veterinary Medicine at North Carolina State University in 1994 for a one-year internship in Small Animal Medicine and Surgery, but liked it here so much that she stayed for a three-year residency in Zoological Medicine and then a PhD in Comparative Biomedical Sciences.

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This study was funded by the Morris Animal Foundation, the William and Charlotte Parks Foundation, the College of Veterinary Medicine at North Carolina State University, the Randolph County Humane Society (North Carolina), and the North Carolina Zoological Society. Abaxis, in particular Martin Mulroy, provided generous in-kind support of the laboratory work by donating the Diagnostic Profile Plus rotors for the VetScan chemistry system. The Iams Company provided in-kind donations of cat food to standardize colony feeding throughout the four years of follow-up.

I thank Dr. John Canipe, Dr. Leslie Yow, Dr. Dan Dinsmore, and the staff and clients of Asheboro Animal Hospital, Asheboro, NC, for providing the pet cat biological samples for the comparative infectious and zoonotic disease testing.

Operation Catnip gave me access to their historical spay/neuter clinic records, and allowed me to include additional data collection in prospective records. All the volunteers who give freely of their time and energy to run that organization should be proud of their accomplishments. Operation Catnip is a model TNR organization, and the board of directors and program managers are enthusiastic about scientific collaborations, providing resources for veterinarians and veterinary students, as well as for the feral cat caretakers in their community.

I thank Kathy Allen, the Butcher family, Boyd Burgess, Betty Casper, Kay Endres, Patti and Andy Hendrick, Karen Hinson, Ava Holcomb, Scotty and Trissy Hunter, Amy Kearns, Lorraine Meller-Smith, Billie Nance, Tillie Phillips, Vicki Ruhala, Karen and Amanda Russell, and Bobby and Irene Smith for their dedication to monitoring their feral cat colonies. They provided much, much more than the basic observations I requested, and many have promising careers as animal behaviorists. I enjoyed getting to know them all and we spent many hours together, watching cats, talking about cats, sharing stories about life in general, and becoming friends. In particular, I thank those unfortunate caretakers whose feral cat colonies were assigned to the control treatment, which meant that they would breed for at least two additional years. They trusted me when I promised to provide enough cat food for the growing numbers, and struggled with me to trap those last few wily cats so that I could keep my promise to “fix” them all in the end.

This project started while I was in the midst of my Zoological Medicine Residency at North Carolina State University, and while I was frequently on clinical rotation at the North Carolina Zoo. Dr. Mike Loomis and Dr. Barb Wolfe graciously permitted me to use the surgical facilities at the zoo, and allowed me as much flexibility as possible with my schedule so that the feral cat colonies could be enrolled and monitored. The technicians at the NC Zoo were also generous with their time in assisting with the biological sample collection, processing, surgery, and the inevitable clean-up. For their support, for nicknaming me Dr. Neuter, and for coining the term “Nutteroma” to describe the special funk tom cats bring to an enclosed space, I give hearty thanks to Sheila Angel, Janice Coakley, Dave Hill, Cheryl Purnell, Gisela Wiggins, and Paige Wilhoit. Special thanks to Lou and Jennifer Kiessler for providing a home-away-from-home in Randolph County.

Two veterinary students were awarded summer research fellowships to work on this project, and only after it was too late did they realize what they had gotten themselves into. Though they ultimately found better ways to spend their summers, I could not have completed the trapping and enrollment of the feral cat colonies without the dedicated assistance of Dr. Gene Maples, who made the long drive to Randolph County at unusual hours and was good natured throughout (though I'm sure he felt otherwise), nor could I have finished the *Bartonella* serology without the preparation and preliminary testing done by Dr. Jim McCarney. Two other veterinary students also shared my work. Dr. Andy Newman decided that fieldwork was ultimately not his calling, but helped with labwork for brownie points, and Dr. Shane Boylan never said no to performing menial tasks of photocopying and data entry in exchange for sushi.

Two lab groups supported the infectious disease analyses. Dr. Ed Breitschwerdt, Julie Bradley, and in particular Dorsey Kordick and Barb Hegarty in the Tick Borne Diseases Diagnostic Laboratory at NCSU made space at their benches, freezers and refrigerators, and worked patiently with me until I was a minimal danger to myself and others and could reliably perform *Bartonella* serology. Dr. J.P. Dubey at the Animal Parasitic Diseases Laboratory of the USDA continued his generous collaboration and performed the serologic testing of feral and domestic cat samples for *Toxoplasma.*

Several NCSU faculty merit status as honorary committee members. Dr. Barrett Slenning enthusiastically participated in the community meetings, and was confident that people disagreeing over feral cat management were a less threatening bunch than those fighting over *Brucellosis* in bison, elk and livestock in the greater Yellowstone ecosystem. He helped me overcome my irrational fear of fuzzy data, and helped make uncertainty my friend. Dr. Maria Correa maintained an open door for me to discuss statistics and epidemiology, but even more importantly has been a good friend and cheerleader. She also facilitated a trip for me to Costa Rica while she was on sabbatical there, and introduced me to wonderful Central American wildlife and wildlife veterinarians, even though she doesn't really like live animals herself. I have had the distinct pleasure of sharing an office "suite" with Dr. Terrence Curtin, the first Dean of the NCSU College of Veterinary Medicine, and Professor Emeritus Dr. Richard Dillman. During my final months of dissertation preparation they took turns checking on me to ensure that I was fed, watered, and occasionally interacting with other members of my species. I thank them for their care and encouragement, and for sharing war stories from their days as graduate students. I regret that I was unable to write the first draft of my dissertation in 36 straight hours, as one of those fine gentlemen managed to do.

Dr. Karen Beck and her husband Brady Beck (who denies all association with feral cats but helped me anyway), my gurus for ArcView when I ran out of bad words to say, helped me navigate the labyrinths of versions and extensions and projections and polylines. Other who were residents and/or graduate students with me at some point during this long process – Dr. Robert Bakal, Dr. Eden Bermingham, Dr. Adam Birkenheuer, Dave Davenport, Dr. Dewayne Fox, Dr. Jody Gookin, Dr. Lori Gustafson, Dr. Craig Harms, Dr. Heather Henson-Ramsay, Dr. Stephanie Kordick, Dr. Scott Larsen, Dr. Ted Mashima, Dr. Kurt Sladky, Dr. Andy Stamper, Dr. Marianne Tocidlowski, and Dr. Scott Willens – provided assistance, support, scientific insight, spirited debate, sound judgement, anger management, and comic relief. Dr. Mike Mitchell was the best Mammalogy teaching assistant, mentor, and good example that anyone could hope for, and I wish I had paid more attention to the question he posed in 1997 (or maybe 1998?) – “are you sure you want to do radiotelemetry?”

I owe a special thanks to my PhD committee co-chairs, Dr. Micheal Stoskopf and Dr. Jay Levine, and members Dr. Richard Ford and Dr. Roger Powell. More traditionally it is the committee members who test the student, but I have tested their limits in a remarkable variety of ways. I thank you all for your patience, persistence, and generosity.

Finally, thanks to my toughest critic and my biggest fan, my husband and fellow wildlife veterinarian/graduate student Dr. Chris Whittier. You have pulled me back from the edge, even as you have pushed me there yourself sometimes. It is a good match.

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Felicia B. Nutter

Introduction and Literature Review

Domestic cats (*Felis catus*) are currently the most common pet in the United States, with an estimated population in 2005 of 90.5 million owned cats (American Pet Products Manufacturers Association 2005). Their popularity has also unfortunately resulted in a growing number of unwanted or unowned cats, and overpopulation is one of the most important feline welfare issues. Euthanasia is the leading cause of death for companion animals in the United States , and though exact figures are unavailable, it’s estimated that between 4 and 9.5 million cats are euthanized annually in the United States as a result of traditional population control efforts, and that the majority of those animals are stray or feral (American Humane Association 1993; Johnson et al. 1994; Nassar et al. 1992; Olson et al. 1991; Humane Society of the United States 2005). Reliable estimates of feral cat numbers are not available and the task of developing accurate estimates is complicated by various interpretations and applications of the terms feral, stray, unowned, and free-roaming. For the purposes of this document, feral is employed in a broad sense and reflects current popular usage to indicate cats that were formerly domestic, or that had domestic ancestors but that currently live wild, regardless of the sources of their food, water or shelter (Liberg & Sandell 1988; McKnight 1964; Slater 2002).

Feline overpopulation and related feral cat issues are not limited to the United Sates, but are of global importance. Cats have been intentionally or accidentally transported worldwide, to diverse environments ranging from deserts and Sub-Antarctic islands to urban centers, and is probably the most widely-distributed carnivore on the planet (Liberg et al. 2000). The status of cats as popular pet contrasts sharply with their inclusion on the World Conservation Union’s list of 100 of the worst alien invasive species (Lowe et al. 2004), and this dichotomy helps fuel controversy over feral cat management and control options. Feral domestic cats can live individually or form social groups called colonies, which have been compared to prides formed by lions (the only other socially-living felid) (Natoli 1990). Colonies tend to form around food sources, such as human refuse or provisions from volunteer colony caretakers (Liberg 1980; Macdonald et al. 1987; MacDonald et al. 2000). These caretakers frequently develop positive relationships with the feral cats or consider them beneficial because of their perceived value in rodent and pest control. Others consider feral cat colonies public nuisances because of noise, odor from urine spraying, predation on native wildlife and zoonotic health concerns. Different perceptions give rise to different preferences for interventions, and debates can be particularly contentious where feral cats are most visible – when they form colonies around rich, stable food resources (Dards 1981; Gilson et al. 1987; Levy & Crawford 2004; Patronek 1998; Rees 1981; Slater 2002; Tabor 1981). Available feral cat management methods can be broadly categorized as lethal and non-lethal, and are briefly reviewed below.

Lethal Control

Methods used for lethal control of feral cats include trapping, shooting, hunting with dogs, poisoning, and deliberate introduction of diseases such as feline panleukopenia. Traps used include snares, leg hold traps, kill traps, and live traps (with captured cats subsequently euthanized). Hunting may be carried out by wildlife management authorities, pest control companies, or even sport hunters, and rifles, handguns, shotguns, bows and arrows, and clubs have been used as weapons. Poisons employed include cyanide, strychnine, anti-coagulants, chloropicrin, and sodium monofluroracetate. The only disease agent that has been deliberately introduced is feline panleukopenia, though modeling has shown that FIV may theoretically be effective (Biodiveristy Group Environment Australia 1999; Bester et al. 2002; Burrows et al. 2003; Courchamp & Sugihara 1999; Nogales et al. 2004; Short et al. 1997). All lethal control techniques can affect non-target cats (such as free-roaming pets) and other non-target species. Feral cats cannot be differentiated from pet cats by appearance alone and, thus, hunters can accidentally kill pets. Trap selectivity can be improved by using trap-set techniques that favor cats, and poison baits can be designed to be attractive and palatable to cats, but neither method can completely exclude non-target animals or species (Alterio 2000; Biodiversity Group Environment Australia 1999; Molsher 2001; Wickstrom et al. 1999).

Lethal control methods, usually aimed at extermination, can be successful if repopulation of the target area by immigration cannot occur, as with feral cats on islands (Biodiversity Group Environment Australia 1999; Nogales et al. 2004). Even in these situations, great effort over a protracted time is required to accomplish extinction (Bester et al. 2002; van Rensburg & Bester 1988; Winter 2004). For example, in 1975 an estimated 2500 feral cats resided on Marion Island, a 290 km^2 sub-Antarctic island off the southeast coast of South Africa. Sixteen years later, after an intensive campaign involving a combination of trapping, hunting (with both guns and dogs), poisoning with sodium monofluoroacetate, and introduction of feline panleukopenia virus, feral cats were finally eradicated. In total, when the years of preliminary planning are included, the extermination effort took nineteen years and the cost has not been reported (Bester et al. 2002; van Aarde 1980; van Rensburg & Bester 1988; van Rensburg et al. 1987). A recent review reported that the majority of successful feral cat eradications (36 of 48, 75%) have been achieved on islands less than 5 km^2 in size, with feral cat populations estimated at an average of 40 per site (estimates available for 32 of 36 sites reported, and range from 1 cat to “possibly hundreds”). Most successful island eradication programs (18 of 31, 58%) have used a combination of lethal methods (Nogales et al. 2004). Information on the methods applied were not reported for three islands, and feral cats on two islands disappeared for unknown reasons (Nogales et al. 2004).

Though they can cause rapid depopulation, lethal control methods have rarely proven effective in the long-term at mainland sites and extermination on mainland areas is unrealistic. The presence of human populations insures that an irresponsible proportion of pet cat owners will supply cats to reoccupy colony sites. It can be difficult to reach all resident cats with any control method or combination of methods, leaving breeding cats to repopulate the area along with immigrant cats. As long as food is available, either as uncontrolled rubbish or through intentional provisioning, cats will fill a void (Biodiversity Group Environment Australia 1999; Neville 1983; Passanisi & Macdonald 1990; Remfry 1996; Tabor 1983; Veitch 2001; Zaunbrecher & Smith 1993).

Protection of valuable resources like threatened and endangered wildlife in mainland habitats can be accomplished by targeted lethal interventions, alone or in combination with feral cat exclusion measures such as predator fences. These endeavors are expensive, with an estimate of $18,000-$50,000 Australian dollars (in 1994) per kilometer reported for construction and maintenance of fox exclusion fences in Australia (Biodiversity Group Environment Australia 1999). This is equivalent to $16,553-$45,924 US dollars in 2005, after adjusting based on historical exchange rates for 1994 Australian and US dollars (xe.com 2005) and the Consumer Price Index between 1994 and 2005 US dollars (Williamson 2004).

Requirements for successful eradication programs for any species include the availability of sufficient resources to fund the eradication effort to its conclusion, prevention of reinvasion, and clear lines of authority to empower a single responsible authority (individual or organization) to take all necessary actions. (Myers et al. 2000) Feral cat eradications on islands have succeeded because these conditions can be met, usually because of conservation concerns for insular or endemic species on the islands. Lethal population control methods in mainland areas are short-term fixes, not long-term solutions, due to violations of these requirements (Biodiversity Group Environment Australia 1999; Slater 2002). They are also less popular with the general public than non-lethal options because of concerns for cat welfare (Ash 2001; Ash & Adams 2003; Levy & Crawford 2004; Slater 2002).

Non-lethal Control

A growing number of organizations and individuals prefer that non-lethal methods be used to control feral cat populations (Centonze & Levy 2002; Hughes et al. 2002; Levy & Crawford 2004; Patronek 1998; Slater 2002). A variety of non-lethal methods have been used, with varying success, as alternatives to lethal control.

<u>Trap and removal:</u> Trapping and removal of feral cats is a natural alternative to trapping and euthanasia as a control method. Sociable kittens or adult cats may be offered for adoption, with unadoptable animals transferred to a sanctuary or another sites willing to accept them, such as farms or barns. Feral cats are usually sterilized surgically

after trapping and before adoption or transfer to another site (Levy & Crawford 2004; Slater 2002). Evidence on the effectiveness and challenges of trapping and removal programs is largely anecdotal.

The experience of the Chico Cat Coalition provides an example of both the successes and pitfalls of this option. The Coalition formed in 1996 as a grass-roots effort to offer a non-lethal solution for fewer than 20 cats resident in Bidwell Park (Chico, California). By 2003, 633 cats had been trapped, with the majority (77%) adopted and the remainder transferred to a sanctuary exclusively for Bidwell Park cats. Though fewer than 20 cats were initially present, publicity about the program led to unexpectedly high numbers of cats being abandoned at the park (Levy & Crawford 2004). Such a high adoption rate is improbable for truly feral cats, and it seems likely that many of the cats dumped at Bidwell Park were unwanted pets. Although the program is considered a success because cats have been successfully removed and new cats are quickly detected and removed, it also illustrates the unfortunate reality of cat abandonment and the role it can play in the development of feral cat populations. Additional challenges for trap and removal programs are the limitations on available space - whether permanent homes, sites for relocation, or sanctuaries. These issues make trap and removal programs impractical as sole alternatives to lethal feral cat control and unrealistic on a large scale. There are already insufficient homes for the available pet cats, without adding potentially adoptable feral cats to the equation (Levy & Crawford 2004; Slater 2002).

Fertility Control: Fertility control has been investigated for the management of species from screw worms and fruit flies to brushtail possums, geese, rabbits, feral horses, white-tailed deer, wolves, and foxes (Converse & Kennelly 1994; Garrott 1995; Kirkpatrick et al. 1990; Myers et al. 2000; Ramsey 2005; Saunders et al. 2002; Spence et al. 1999; Twigg et al. 2000). It has also been used to mitigate negative impacts of predators on prey , such as coyotes predation on domestic lambs (Bromley & Gese 2001b). Preventing births is considered more humane and financially responsible than spending time and money to manage a larger problem at a later date (Oogjes 1997). Some methods of fertility control also hold the promise of being scaleable to large populations occupying large areas.

Preventing reproduction within feral cat colonies is being explored as an alternative to euthanasia that, theoretically, allows populations to be eliminated by natural attrition. Administration of the synthetic progestin oral contraceptives megesterol acetate and medroxyprogesterone acetate to female feral cats was investigated in Denmark and the United Kingdom in the 1970s. These steroids prevent ovulation by inhibiting the feedback mechanisms of the hypothalamic-pituitary-gonadal axis. These programs reduced the numbers of litters born, but were abandoned because of the numerous difficulties encountered, including empirical dosing based on estimated body weights, problems accurately identifying individuals and insuring the labor-intensive weekly follow-up dosing, and pyometra in erratically treated animals (Kristensen 1980; McDonald 1980; Remfry 1978). Progestins can also be administered as long-acting injections or impregnated silastic implants, but the necessity of capturing animals for initial and follow-up treatments negates any benefit over surgical sterilization.

Cabergoline, a prolactin inhibitor, is luteolytic and acts as an abortifaciant when administered during the second half of gestation. It also causes regression of the mammary glands within 36-48 hours of administration, so that milk production stops. It is technically a lethal method of population control, but is included here under fertility control. Term pregnancy in a cat is typically 58-65 days (Seguin 1998) and daily oral administration of cabergoline in food has produced abortion in feral queens when given for at least 4 days between 36 and 41 days gestation, or early parturition when given thereafter. Kittens that were born died quickly because they could not nurse. Treatment before 30 days gestation was ineffective. After single or multiple abortions, queens were subsequently able to carry term pregnancies with no apparent problems. Effective control using cabergoline would require constant exposure of the entire population throughout the breeding season (in regular food or bait), and concerns about the money and personnel required, welfare issues related to starving kittens, and effects on non-target species renders this approach generally impractical (Jochle & Jochle 1993). Its utility is still being explored in Australia and New Zealand, where it does not appear to affect marsupials and could be used to cause abortion in a variety of introduced mammalian predators, including feral cats (Hearn et al. 1998; Marks et al. 2001).

Chemical sterilants for male cats, specifically sclerosing agents for injection into the testes and/or epididymides, have been investigated. Intraepididymal injections of 4.5% chlorhexidine in water were not completely effective at causing permanent sterility, though intratesticular or intraepididymal injections of neutralized zinc arginine were effective. A commercial zinc arginine formulation, Neutersol®, has been approved by the FDA for use in puppies 3-10 months old, but is not yet available for cats

(Bloomberg 1996; Olson & Johnston 1993; Wang 2002). Though less invasive than standard surgical castration or vasectomy, use of these chemical sterilants in male feral cats would still require trapping and heavy sedation or anesthesia, and may not be more time or cost effective than traditional surgery.

Development of a vaccine for contraception could provide a valuable alternative to the presently available methods. Immunocontraceptive techniques are being rapidly developed and diversified, and likely hold the most promise for widespread fertility control in feral cats. Vaccines against reproductive proteins or tissues can target eggs, sperm, or other parts of the reproductive tract. Zona pellucida, the matrix surrounding oocytes, eggs and embryos, is to date the most commonly targeted site for immunocontraception. Immunization with zona pellucida (ZP) proteins can cause an immune response that results in temporary or permanent sterility, and ZP vaccines have been used in feral horses, white tailed deer, fallow dear, seals, and elephants, as well as a variety of captive, exotic species in zoos (Brown et al. 1997; Fayrer-Hosken et al. 2000; Kirkpatrick et al. 1993; Kirkpatrick et al. 1997; Kirkpatrick et al. 1996). Porcine ZP (pZP), which is readily obtainable as a slaughterhouse by-product, has been used to formulate ZP vaccines, due to conservation of ZP epitopes and generally good cross-reactivity among different species. Unfortunately, even though pZP is immunogenic in the domestic cat, immunization with pZP does not reduce fertility because of unique regions of the feline ZP that are involved in sperm binding and fertilization (Pohajdak et al. 2004). Felid-specific ZP proteins are currently being investigated as alternatives. (Gorman et al. 2002; Jewgenow et al. 2004; Jewgenow et al. 2000).

Gonadotropin releasing hormone (GnRH) is produced by the hypothalamus and initiates the cascade that results in gonadal regulation and gamete production in both males and females. Blocking GnRH prevents ovulation and spermatogenesis, and prevents behaviors associated with reproduction, which in feral cats include commonly cited nuisance behaviors like fighting and caterwauling (Ross et al. 2004). Because GnRH is not naturally immunogenic, the molecule must be altered to promote recognition as a foreign antigen. This is commonly done by conjugating it to carrier molecules, such as large proteins, immunomodulating peptides, and lipids, and then mixing the conjugate with a variety of adjuvants for additional immunostimulation (Baker et al. 2004; Ferro et al. 2004; Ferro & Stimson 1998). A variety of GnRH-based vaccines have been experimentally tested in male and female adult cats, as well as prepubescent kittens, causing atrophy of ovaries and testes, declines in testosterone and progesterone levels, and suppression of reproductive behaviors. Responses to vaccination are still variable, with up to 1/3 of cats in some tests failing to respond even after booster vaccines. Nonetheless in some cases immunity lasts up to 2 years (Baker et al. 2004; Levy et al. 2004; Robbins 2004; Robbins et al. 2004; Ross et al. 2004). Further vaccine refinement in experimental settings is necessary before field trials with feral cats can be conducted.

Additional targets for immunocontraception under investigation include follicle stimulating hormone (FSH), leutinizing hormone (LH), sperm acrosomal membrane protein, lutropin (LH) receptor, and a variety of egg-associated proteins that regulate sperm binding (Coonrod 2002; Hao et al. 2004; Herr 2004; Saxena et al. 2003). Besides specific concerns associated with each contraceptive vaccine, overall progress to date has been restricted by the variability of the immune response after immunization, the ability to attain and maintain effective antibody titers, time lag to achieve effective antibody titers, and uncertainty regarding the duration of immunity. An ideal vaccine would rapidly provide lifelong immunity after a single dose.

If an effective immunocontraceptive is developed, the final hurdle to overcome will be a delivery system for feral cats. While administration by injection is adequate for experimental purposes under laboratory conditions, it is not practical for feral animals. The delivery mechanism could be a bait or self-spreading vector such as a virus or bacteria. Theoretical modeling has demonstrated the utility of these systems, and testing of eventually developed vaccines on island populations of feral cats has been proposed (Courchamp & Cornell 2000; Hood et al. 2000). The delivery system should also be species-specific and environmentally benign (Tuyttens & Macdonald 1998; Tyndale-Biscoe 1994). Most work to date has focused on bacterial and viral vectors as potential delivery systems for orally available vaccines that could be formulated into bait or food. Vaccine strains of *Salmonella*, *E. coli*, vaccinia virus, and adenovirus have been considered and tested to some degree, but are not adequately species-specific for further development. A vaccine-approved strain of feline herpesvirus is the current focus of research efforts, due to its narrower host range (Boyle 2004; Boyle et al. 2004; Han et al. 2004), but the possibility of impacts on native felids remains.

Until an effective, orally available, single-dose chemical or immunosterilant can be developed, surgical sterilization is more reliable and is considered the “gold standard” for feral cat fertility control. It is also potentially a good choice for small populations of carnivores that can be trapped (Tuyttens & Macdonald 1998), and while national numbers of feral cats are estimated to be large, individual aggregations of cats are generally small (Centonze & Levy 2002; Levy et al. 2003; Rees 1981; Zasloff & Hart 1998).

Programs to trap, neuter (spay and castrate) and return feral cats back to their original environments have been employed in Europe and the United Kingdom since the early 1970s and are increasing in popularity in the United States. The concept behind such management is that neutered cats will no longer breed and will defend their territories and resources against potential immigrants. Neutering also decreases the incidence of spraying, fighting and caterwauling, the behaviors of feral cats that most people find objectionable (de Boer 1977; Hart 1973; Passanisi & Macdonald 1990; Tabor 1981). Limited studies, mostly anecdotal, suggest this approach may stabilize colony population and lead to reductions over time (Centonze & Levy 2002; Levy & Crawford 2004; Levy et al. 2003; Neville & Remfry 1984; Passanisi & Macdonald 1990; Tabor 1981; Zaunbrecher & Smith 1993). Home ranges of male cats may shrink after neutering, and neutered males may have a higher turnover rate than neutered females, although the observations are again mostly anecdotal (Passanisi & Macdonald 1990; Rees 1981; Tabor 1989; Zaunbrecher & Smith 1993). Sterilization by vasectomy in males and tubal ligation in females has been used in other vertebrate species, in an effort to minimize behavioral changes due to hormonal alterations in gonadectomized animals (Bromley & Gese 2001a; Ramsey 2005; Saunders et al. 2002; Spence et al. 1999; Twigg et al. 2000).

As an alternative to castration in feral cats, is has been suggested that hormonally intact vasectomized males might better defend territory, prevent immigration by intact males, and provide better colony stabilization, but the evidence available to date is not conclusive (Kendall 1979; Mahlow 1995; Mahlow & Slater 1996; Passanisi & Macdonald 1990; Tabor 1989).

Project Overview

I designed this project to comprehensively evaluate a feral cat trap-neuter-return program. I initially studied nine feral cat colonies in Randloph County, North Carolina, under three different management strategies. I sterilized three colonies by ovariohysterectomizing females and castrating males, to mimic a typical trap-neuter-return program; I sterilized an additional three colonies by ovariohysterectomizing females and vasectomizing males, to compare the management impacts of the two different male neutering techniques; and I left the final three colonies as reproductively intact controls. I collected blood and fecal samples for infectious disease testing, and censused colony and collected home range data for two years. At that time I sterilized the control colonies by ovariohysterectomizing females and castrating males and enrolled two additional control colonies. The eleven colonies were monitored intensively for another two years, and then sporadically thereafter for a maximum of seven years follow-up time.

I described in Chapter Two the initial trapping and enrollment portion of the project, and report the time and financial costs of that effort. I compared the prevalence of the potentially zoonotic pathogens *Bartonella henselae*, *Toxoplasma gondii*, *Cryptosporidium, Giardia*, and *Toxocara* in feral and pet domestic cats and presented those results in Chapter Three. In Chapter Four I assessed feral cat fecundity and kitten survival based on breeding females studied prospectively as part of my research, and on retrospective analysis of records from a high-volume trap-neuter-return program. I used census methods with a staggered entry design to evaluate survival times cause-specific mortality, and immigration events for individual cats in colonies managed by the three different strategies, and reported those results in Chapter Five. Chapter Six compares the home ranges of male and female cats among the management treatments. I organized a series of feral cat stakeholder meetings in three counties, where stakeholders with different backgrounds and agendas worked together to reach agreements about feral cat management options, and acceptable circumstances under which different options could be chosen. The experiences of and outputs from those meetings are presented in Chapter Seven. Finally, I built and tested a simple population viability analysis model using VORTEX 9.57 software. Data generated by my research were used to parameterize the model, which was then refined to represent intact breeding feral cat colonies periodically harvested at different levels, and neutered colonies with varying proportions of cats remaining intact.

The results of my research provide important information to support sound feral cat management. More meaningful comparisons of the pros and cons of trap-neuter-return programs with other management options are now possible.

References

Alterio, N. 2000. Controlling small mammal predators using sodium monofluoroacetate (1080) in bait stations along forestry roads in a New Zealand beech forest. *New Zealand Journal of Ecology* **24**:3-9.

Ash, S. J. 2001. Ecological and sociological considerations of using the TTVAR (trap, test, vaccinate, alter, return) method to control free-ranging domestic cat, *Felis catus*, populations. Page 71. Wildlife and Fisheries Sciences. Texas A&M University.

Ash, S. J., and C. E. Adams. 2003. Public preferences for free-ranging domestic cat (*Felis catus*) management options. *Wildlife Society Bulletin* **31**:334-339.

American Humane Association. 1993. Euthanasia stats remain stable. *Shoptalk* **11**:1-2.

American Pet Products Manufacturers Association. 2005. National Pet Owners Survey 2005-2006. American Pet Products Manufacturers Association, New York.

Biodiversity Group Environment Australia. 1999. *Threat abatement plan for predation by feral cats*. Environment Australia under the Natural Heritage Trust.

Baker, H. J., B. Griffin, B. F. Smith, and T. D. Braden. 2004. Immunization of cats and dogs with an anti-GnRH protein vaccine with molecular adjuvantation. Pages 96-98. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Bester, M. N., J. P. Bloomer, R. J. van Aarde, B. H. Erasmus, P. J. J. van Rensburg, J. D. Skinner, P. G. Howell, and T. W. Naude. 2002. A review of the successful eradication of feral cats from sub-Antarctic Marion Island, Southern Indian Ocean. *South African Journal of Wildlife Research* **32**:65-73.

Bloomberg, M. 1996. Surgical neutering and non-surgical alternatives. *Journal of the American Veterinary Medical Association* **208**:517-519.

Boyle, S. M. 2004. Recombinant microorganisms as a means to deliver contraceptive vaccines. Pages 140-142. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Boyle, S. M., H. Brunk, and B. Purswell. 2004. On the use of recombinant micro-organisms to deliver contraceptive antigens to cats. Pages 138-139. *Proceedings* *of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Bromley, C., and E. M. Gese. 2001a. Effects of sterilization on territory fidelity and maintenance, pair bonds, and survival rates of free-ranging coyotes. *Canadian Journal of Zoology* **79**:386-392.

Bromley, C., and E. M. Gese. 2001b. Surigical sterilization as a method of reducing coyote predation on domestic sheep. *Journal of Wildlife Management* **65**:510-519.

Brown, R. G., W. D. Bowen, J. D. Eddington, W. C. Kimmins, M. Mezei, J. L. Parsons, and e. al. 1997. Temporal trends in antibody production in captive grey, harp, and hooded seals to a single administration immunocontraceptive vaccine. *Journal of Reproductive Immunology* **35**:53-64.

Burrows, N. D., D. Algar, A. D. Robinson, J. Sinagra, B. Ward, and G. Liddelow. 2003. Controlling introduced predators in the Gibson Desert of western Australia. *Journal of Arid Environments* **55**:691-713.

Centonze, L. A., and J. K. Levy. 2002. Characteristics of free-roaming cats and their caretakers. *Journal of the American Veterinary Medical Association* **220**:1627-1633.

Converse, K. A., and J. J. Kennelly. 1994. Evaluation of Canada goose sterilization for population control. *Wildlife Society Bulletin* **22**:265-269.

Coonrod, S. 2002. Identification of new contraceptive targets in the oocyte. Pages 54-55. *Proceedings of the 2002 International Symposium on Nonsurgical Methods for Pet Population Control*.

Courchamp, F., and S. J. Cornell. 2000. Virus-vectored immunocontraception to control feral cats on islands: A mathematical model. *Journal of Applied Ecology* **37**:903-913.

Courchamp, F., and G. Sugihara. 1999. Modeling the biological control of an alien predator to protect island species from extinction. *Ecological Applications* **9**:112-123.

Dards, J. 1981. Habitat utilisation by feral cats in the Portsmouth Dockyard. Pages 30-46. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

de Boer, J. M. 1977. Dominance relations in pairs of domestic cats. *Behavioural Processes* **2**:227-242.

Fayrer-Hosken, R., D. Grobler, J. J. Van Altena, H. J. Bertschinger, and J. F. Kirkpatrick. 2000. Immunocontraception in African elephants. *Nature* **407**:149.

Ferro, V. A., R. Costa, K. C. Carter, M. J. Harvey, M. M. Waterston, A. B. Mullen, C. Matschke, J. F. Mann, A. Colston, and W. H. Stimson. 2004. Immune responses to a GnRH-based anti-fertility immunogen, induced by different adjuvants and subsequent effect on vaccine efficacy. *Vaccine* **22**:1024-1031.

Ferro, V. A., and W. H. Stimson. 1998. Investigation into suitable carrier molecules for use in an anti-gonadotrophin releasing hormone vaccine. *Vaccine* **16**:1095-1102.

Garrott, R. A. 1995. Effective management of free-ranging ungulate populations using contraception. *Wildlife Society Bulletin* **23**:445-452.

Gilson, A., T. P. Salmon, and M. S. Kelley. 1987. The potential for feral cat control through cooperation. *Transactions of the Western Section of the Wildlife Society* **23**:46-49.

Gorman, S.-P., J.-K. Levy, A.-L. Hampton, W.-R. Collante, A.-L. Harris, and R.-G. Brown. 2002. Evaluation of a porcine zona pellucida vaccine for the immunocontraception of domestic kittens (*Felis catus*). *Theriogenology* **58**:135-149.

Han, X., D. C. Tang, B. Griffin, H. J. Baker, and K. R. Van Kampen. 2004. Viral and bacterial vectors for contraceptive vaccines. Pages 132-137. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Hao, M., P. Rathnam, and B. B. Saxena. 2004. Human lutropin receptor and chorionic gonadotropin chimera as contraceptive antigen for cats and dogs. Pages 130-131. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Hart, B. L. 1973. Behavioral effects of castration. *Feline Practice* **3**:10-12.

Hearn, C.-M., G. Shaw, R.-V. Short, and M.-B. Renfree. 1998. Effects of cabergoline on reproduction in three families of Australian marsupials. *Journal of Reproduction and Fertility* **113**:151-157.

Herr, J. C. 2004. Proteomics and the discovery of companion animal contraceptive drug and vaccine targets in the sperm and egg. Pages 119-128. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Hood, G. M., P. Chesson, and R. P. Pech. 2000. Biological control using sterilizing viruses: host suppression and competition between viruses in non-spatial models. *Journal of Applied Ecology* **37**:914-925.

Hughes, K. L., M. R. Slater, and L. Haller. 2002. The effects of implementing a feral cat spay/neuter program in a Florida county animal control service. *Journal of Applied Animal Welfare Science* **5**:285-298.

Jewgenow, K., A. Greube, S. Naidenko, and J. Ringleb. 2004. Antigenic and antifertile determinants of feline zona pellucida B protein - a strategy for contraceptive vaccine development. Pages 87-92. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Jewgenow, K., M. Rohleder, and I. Wegner. 2000. Differences between antigenic determinants of pig and cat zona pellucida proteins. *Journal of reproduction and Fertility* **119**:15-23.

Jochle, W., and M. Jochle. 1993. Reproduction in a feral cat population and its control with a prolactin inhibitor, cabergoline. *Journal of Reproduction and Fertility Supplement* **47**:419-424.

Johnson, K. J., L. Lewellyn, and J. Lewellyn. 1994. National Pet Alliance survey report on Santa Clara County's pet population. *Cat Fanciers' Almanac*:71-77.

Kendall, T. R. 1979. Cat population control: vasectomize dominant males. *California Veterinarian* **33**:9-12.

Kirkpatrick, J. F., P. P. Calle, P. Kalk, and e. al. 1993. Immunocontraception in zoo animals: vaccinating against pregnancy. Pages 290-291. *Proceedings of the American Association of Zoo Veterinarians 1993*.

Kirkpatrick, J. F., I. K. M. Liu, and J. W. Turner. 1990. Remotely-delivered immunocontraception in feral horses. *Wildlife Society Bulletin* **18**:326-330.

Kirkpatrick, J. F., J. W. Turner Jr., I. K. M. Liu, R. Fayrer-Hosken, and A. T. Rutberg. 1997. Case studies in wildlife immunocontraception: wild and feral equids and white-tailed deer. *Reproduction, Fertility and Development* **9**:105-110.

Kirkpatrick, J. F., J. W. Turner, I. K. M. Liu, and R. Fayrer-Hosken. 1996. Applications of pig zona pellucida immunocontraception to wildlife fertility control. *Journal of Reproduction and Fertility Supplement* **50**:183-189.

Kristensen, T. 1980. Feral cat control in Denmark. Pages 68-72. *The Ecology and Control of Feral Cats.* Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Levy, J. K., and P. C. Crawford. 2004. Humane strategies for controlling feral cat populations. *Journal of the American Veterinary Medical Association* **225**:1354-1360.

Levy, J. K., D. W. Gale, and L. A. Gale. 2003. Evaluation of the effect of a long-term trap-neuter-return and adoption program on a free-roaming cat population. *Journal of the American Veterinary Medical Association* **222**:42-46.

Levy, J. K., L. A. Miller, P. Cynda Crawford, J. W. Ritchey, M. K. Ross, and K. A. Fagerstone. 2004. GnRH immunocontraception of male cats. *Theriogenology* **62**:1116-1130.

Liberg, O. 1980. Spacing patterns in a population of rural free-roaming domestic cats. *Oikos* **35**:336-349.

Liberg, O., and M. Sandell. 1988. Spatial organisation and reproductive tactics in the domestic cat and other felids. Pages 83-98 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behavior.* Cambridge University Press, New York.

Liberg, O., M. Sandell, D. Pontier, and E. Natoli. 2000. Density, spatial organisation and reproductive tactics in the domestic cat and other felids. Pages 119-147 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Lowe, S., M. Browne, S. Boudjelas, and M. De Poorter 2004. *100 of the World's Worst Invasive Alien Species: A Selection from the Global Invasive Species Database.* The Invasive Species Specialist Group (ISSG) of the Species Survival Commission SSC) of the World Conservation Union (IUCN). www.issg.org/booklet.pdf, accessed 14 July 2005.

Macdonald, D. W., P. Apps, G. M. Carr, and G. Kerby. 1987. Social dynamics, nursing coalitions and infanticide among farm cats, *Felis catus.* in G. M. Burghardt, W. Pflumm, and W. Wickler, editors. *Advances in Ethology Number 28*. Paul Parey Scientific Publishers, Berlin, Germany.

Macdonald, D. W., N. Yamaguchi, and G. Kerby. 2000. Group-living in the domestic cat: its sociobiology and epidemiology. Pages 95-118 in B. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Mahlow, J. C. 1995. The use of vasectomy in stray cat population control. Page 30. Department of Veterinary Anatomy and Public Health. Texas A&M University, College Station, Texas, USA.

Mahlow, J. C., and M. R. Slater. 1996. Current issues in the control of stray and feral cats. *Journal of the American Veterinary Medical Association* **209**:2016-2020.

Marks, C. A., L. Jalkanen, R. Savolainen, and R. V. Short. 2001. Control of red fox (*Vulpes vulpes*) fertility with cabergoline: dose response and timing of intervention. *Reproduction* **122**:147-154.

McDonald, M. 1980. Population control of feral cats using megestrol acetate. *Veterinary Record* **106**:129.

McKnight, T. 1964. Feral livestock in Anglo-America. *University of California Publications in Geography* **16**:1-87..

Molsher, R. L. 2001. Trapping and demographics of feral cats (*Felis catus*) in central New South Wales. *Wildlife Research* **28**:631-636.

Myers, J. H., D. Simberloff, A. M. Kuris, and J. R. Carey. 2000. Eradication revisited: dealing with exotic species. *Trends in Ecology and Evolution* **15**:316-320.

Nassar, R., J. Talboy, and C. Moulton. 1992. Animal shelter reporting study 1990. American Humane Association, Englewood, Colorado, USA. 5 pages.

Natoli, E. 1990. Mating strategies in cats: a comparison of the role and importance of infanticide in domestic cats, *Felis catus* L., and lions, *Panthera leo* L. *Animal Behaviour* **40**:183-186.

Neville, P. 1983. Humane control of an urban feral cat colony. *International Pest Control* **25**:144-145, 152.

Neville, P. F., and J. Remfry. 1984. Effect of neutering on two groups of feral cats. *Veterinary Record* **114**:447-450.

Nogales, M., A. Martin, B. R. Tershy, C. J. Donlan, D. Veitch, N. Puerta, B. Wood, and J. Alonso. 2004. A review of feral cat eradication on islands. *Conservation Biology* **18**:310-319.

Olson, P. N., and S. D. Johnston. 1993. New developments in small animal population control. *Journal of the American Veterinary Medical Association* **202**:904-909.

Olson, P. N., C. Moulton, T. M. Nett, and M. D. Salman. 1991. Pet overpopulation: a challenge for companion animal veterinarians in the 1990s. *Journal of the American Veterinary Medical Association* **198**:1151-1152.

Oogjes, G. 1997. Ethical aspects and dilemmas of fertility control of unwanted wildlife: an animal welfarist's perspective. *Journal of Reproduction, Fertility and Development* **9**:163-168.

Passanisi, W. C., and D. W. Macdonald 1990. *The Fate of Controlled Feral Cat Colonies*. Universities Federation for Animal Welfare, Hertfordshire, Potters Bar, UK.

Patronek, G. J. 1998. Free-roaming and feral cats--their impact on wildlife and human beings. *Journal of the American Veterinary Medical Association* **212**:218-226.

Pohajdak, B., M. Mansour, W. Kimmins, R. Brown, J. Levy, K. Jewgenow, and B. Pohajdak. 2004. Feline ZP as an immunocontraceptive antigen. Page 93. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Ramsey, D. 2005. Population dynamics of brushtail possum subject to fertility control. *Journal of Applied Ecology* **42**:348-360.

Rees, P. 1981. The ecological distribution of feral cats and the effects of neutering a hospital colony. Pages 12-22. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Remfry, J. 1978. Control of feral cat populations by long-term administration of megestrol acetate. *Veterinary Record* **103**:403-404.

Remfry, J. 1996. Feral cats in the United Kingdom. *Journal of the American Veterinary Medical Association* **208**:520-523.

Robbins, S. 2004. Possible mechanism for the breaking of self-tolerance and achieving sustained immunoneutralization of GnRH in male and female cats. Pages 111-118. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Robbins, S. C., M. D. Jelinski, and R. L. Stotish. 2004. Assessment of the immunological and biological efficacy of two different doses of a recombinant GnRH vaccine in domestic male and female cats (*Felis catus*). *Journal of Reproductive Immunology* **64**:107-119.

Ross, M. K., J. K. Levy, L. A. Miller, P. C. Crawford, J. W. Ritchey, and K. A. Fagerstone. 2004. GnRH immunocontraception of male cats. Pages 108-110. *Proceedings of the 2004 Alliance for Contraception in Dogs and Cats International Symposium on Nonsurgical Methods for Pet Population Control*.

Saunders, G., J. Mcilroy, M. Berghout, B. Kay, E. Gifford, R. Perry, and R. van de Ven. 2002. The effects of induced sterility on the territorial behavior and survival of foxes. *Journal of Applied Ecology* **39**:56-66.

Saxena, B. B., A. Clavio, M. Singh, P. Rathnam, E. Y. Bukharovich, T. J. Reimers, Jr., A. Saxena, and S. Perkins. 2003. Effects of immunization with bovine luteinizing hormone receptor on ovarian function in cats. *American Journal of Veterinary Research* **64**:292-298.

Seguin, B. E. 1998. Reproductive system introduction. Pages 977-986 in S. E. Aiello, editor. *The Merck Veterinary Manual*. Merck and Co., Whitehouse Station, NJ, USA.

Short, J., B. Turner, D.-A. Risbey, and R. Carnamah. 1997. Control of feral cats for nature conservation. II. Population reduction by poisoning. *Wildlife Research* **24**:703-714.

Slater, M. R. 2002. *Community Approaches to Feral Cats: Problems, Alternatives, and Recommendations.* Humane Society Press, Washington, D.C., USA.

Spence, C. E., J. E. Kenyon, D. R. Smith, R. D. Hayes, and A. M. Baer. 1999. Surgical sterilization of free-ranging wolves. *Canadian Veterinary Journal* **40**:118-121.

Humae Society of the United States. 2005. Pet overpopulation estimates. Accessed October 21, 2005. http://www.hsus.org/pets/issues_affecting_our_pets/pet_overpopulation_and_ownership_statistics/hsus_pet_overpopulation_estimates.html

Tabor, R. 1981. General biology of feral cats. Pages 5-11. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Tabor, R. 1983. *The Wild Life of the Domestic Cat*. Arrow Books Limited, London.

Tabor, R. 1989. The changing life of feral cats (*Felis catus* L.) at home and abroad. *Zoological Journal of the Linnaean Society* **95**:151-161.

Tuyttens, F. A. M., and D. W. Macdonald. 1998. Fertility control: an option for non-lethal control of wild carnivores? *Animal Welfare* **7**:339-364.

Twigg, L. E., T. J. Lowe, G. R. Martin, A. G. Wheeler, G. S. Gray, S. L. Griffin, C. M. O'Reilly, D. J. Robinson, and P. H. Hubach. 2000. Effects of surgically imposed sterility on free-ranging rabbit populations. *Journal of Applied Ecology* **37**:16-39.

Tyndale-Biscoe, C. H. 1994. Virus-vectored immunocontraception of feral mammals. *Reproduction, Fertility and Development* **6**:281-287.

van Aarde, R. J. 1980. The diet and feeding behaviour of feral cats, *Felis catus* at Marion Island. *South African Journal of Wildlife Research* **10**:123-128.

van Rensburg, P. J. J., and M. N. Bester. 1988. Experiments in feral cat population reduction by hunting on Marion Island, Indian Ocean. *South African Journal of Wildlife Research* **18**:47-50.

van Rensburg, P. J. J., J. D. Skinner, and R. J. van Aarde. 1987. Effects of feline panleucopaenia on the population characteristics of feral cats on Marion Island. *Journal of Applied Ecology* **24**:63-73.

Veitch, C. R. 2001. The eradication of feral cats (*Felis catus*) from Little Barrier Island, New Zealand. *New Zealand Journal of Zoology* **28**:1-12.

Wang, M. 2002. Neutersol: intratesticular injection induces sterility in dogs. Pages 62-65. *Proceedings of the 2002 International Symposium on Nonsurgical Methods for Pet Population Control*.

Wickstrom, M., M. Thomas, R. Henderson, and C. T. Eason. 1999. Development and evaluation of baits for feral cat control. *Science for Conservation*:67-74.

Williamson, S. H. 2004. What is the Relative Value? Economic History Services. Accessed October 31, 2005. http://eh.net/hmit/compare/

Winter, L. 2004. Trap-neuter-release programs: the reality and the impact. *Journal of the American Veterinary Medical Association* **225**:1369-1376.

xe.com. 2005. Interactive Currency Table. Accessed October 31, 2005. http://www.xe.com.

Zasloff, R. L., and L. A. Hart. 1998. Attitudes and care practices of cat caretakers in Hawaii. *Anthrozoos* **11**:242-248.

Zaunbrecher, K. I., and R. E. Smith. 1993. Neutering of feral cats as an alternative to eradication programs. *Journal of the American Veterinary Medical Association* **203**:449-452.

Chapter 2. Time and financial costs of programs for live trapping feral cats

Felicia B. Nutter

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Introduction

Trap, neuter, and release (TNR) programs have been used to manage colonies of feral cats in Europe and the United Kingdom since the early 1970s and are becoming increasingly popular in the United States (American Veterinary Medical Association 1996; Johnson 1996; Kristensen 1980; Neville & Remfry 1984; Tabor 1981). However, techniques for live trapping of feral cats have not been well described in the literature (Bester et al. 2000; Neville & Remfry 1984; Rees 1981; Zaunbrecher & Smith 1993), and although baits and olfactory attractants have been developed, they have not been combined with live-trapping attempts (Clapperton et al. 1994; Edwards et al. 1997; Risbey et al. 1997).

Feral cats are naturally wary of unusual conditions in their environment, meaning that some feral cats may be reluctant to approach and enter traps, regardless of whether they contain bait or olfactory attractants. In an attempt to overcome this problem, some groups have suggested that baited traps that have been rigged so their doors will not close be placed in the cats' environment for several days prior to the initiation of any trapping program (Alley Cat Allies 2002; Operation Catnip 2002; Feral Cat Coalition 2002), as it is thought that this will help to accustom the cats to the traps and increase the likelihood that they will be captured. However, whether this has any effect on trapping efficiency is not known. Furthermore, the costs of programs for trapping feral cats, beyond the initial costs of the traps themselves, have not been evaluated. The study reported here, compares the time and financial costs of two alternative approaches to live trapping feral cats, initiating trapping immediately versus acclimating cats to the traps prior to trapping.

Materials and Methods

Feral cat colonies

The study involved 9 feral cat colonies in Randolph County, NC. Cats in the 9 colonies were live trapped between May and August 1998 as part of a prospective study evaluating the effects of TNR programs on feral cat colonies. Colonies were identified and referred to the investigators by the Randolph County Humane Society. After initial contact was made with the caretakers, all colonies were visited at least twice and assessed for suitability for inclusion in the study. Colonies were included in the study only if they had an established caretaker who provided food and water on a regular basis; cats in the colony had access to adequate shelter, such as a barn, storage shed, carport, basement, or crawl space; the colony consisted of at least 10 adult cats (ie, cats > 6 months old), with at least 3 adult male cats; and the colony was located in a rural or suburban residential area at least 1 km from the nearest 4-lane road.

Trapping protocols

Live traps (Tomahawk live traps #207 and #608, Tomahawk Live Traps, Tomahawk, Wisconsin, USA) lined with clean newspaper and baited with canned mackerel (approx 0.8 oz/trap) were used to trap cats in the 9 colonies. Cats were not fed their regular diet for 24 hours prior to the initiation of trapping efforts. For each colony, 15 traps were set in a radial pattern around the colony's normal feeding site with the trap doors opening towards the center and at least 2 feet between traps. Traps were covered with a light-colored towel for camouflage and to darken the interior of the trap in the hopes that this would help calm cats after capture. No special efforts were made to descent traps because the colonies were all well acclimated to humans providing food. No trapping was conducted during inclement weather (ie, if precipitation was forecasted or if the temperature was expected to be < 0^{o}C [32^{o}F]).

Traps were set at dusk and checked the following morning within one hour of sunrise. Newspapers and leftover bait were removed from the traps, and the traps were closed. At dusk, traps were again baited and set. Trapping was continued in this manner for 5 consecutive nights. After this time, the number of traps was reduced to 5, and trapping was continued until at least 90% of the cats in the colony had been captured or until no more than 1 cat remained untrapped.

To determine whether allowing cats time to acclimate to the traps had an effect on trapping effort or efficiency, 5 colonies were randomly selected to have traps set out for 3 days prior to initiation of trapping. Doors of the traps were tied open during these 3 days so that cats could not be captured, and the regular diet provided by the caretakers was placed in the traps. The traps were checked and newspapers and food were replaced daily.

Statistical analyses

Trapping effort was defined as the mean number of trap-nights per cat captured, and trapping efficiency was defined as the percentage of cats captured per colony. The Wilcoxon rank sum test (Hollander & Wolfe 1973) was used to compare trapping effort and efficiency between colonies in which cats were allowed to acclimate to the traps before initiation of trapping and colonies that were not allowed an acclimation period. The Wilcoxon rank sum test was also used to compare trapping cats between colonies that were allowed an acclimation period and those that were not. For all analyses, values of $P \leq 0.05$ were considered significant.

Results

Trapping effort and efficiency

Mean ± SD number of adult (ie, > 6 months old) cats per colony was 12.8 ± 5.5 cats (range, 10 to 27 cats; mean number of cats for colonies given an acclimation period, 13.4 ± 7.6 cats; mean number of cats for colonies not given an acclimation period, 12.0 ± 0.8 cats). Overall trapping effort during the initial 5 days of trapping was 6.0 ± 3.1 trap-nights per cat captured, but trapping effort during the initial 5 days of trapping was not significantly different between colonies given an acclimation period (6.1 ± 3.3 trap-nights per cat captured) and colonies not given an acclimation period (6.0 ± 3.3 trap-nights per cat captured). Mean overall trapping effort (ie, number of trap-nights until at least 90% of the cats in the colony had been captured or until no more than 1 cat remained untrapped) for the 9 colonies was 8.9 ± 3.9 trap-nights per cat captured. Overall trapping effort was not significantly different between colonies given an acclimation period (10.1 ± 3.8 trap-nights per cat captured) and colonies not given an acclimation period (7.4 ± 4.1 trap-nights per cat captured). For all 9 colonies, mean trapping efficiency during the initial 5 days of trapping was 87.2 ± 10.6%, and overall trapping efficiency was 98.0 ± 4.0%. Trapping efficiency during the initial 5 days of trapping (87.0 ± 8.4% and 87.5 ± 14.4%, respectively) and overall trapping efficiency

(95.8 ± 5.8% and 96.8 ± 4.9%, respectively) were not significantly different between colonies that were provided an acclimation period and colonies that were not.

Trapping costs

Newspapers used to line the traps were obtained at no cost from a recycling center. A single 16-ounce can of mackerel was found to be sufficient to bait 20 traps; therefore, bait cost was calculated to be $0.06/trap-night. One person working alone was able to set the 15 traps at each colony in approximately 1 hour and 15 minutes, including time spent loading and unloading the traps from a transport vehicle, for a time of 5 min/trap. On the basis of the 1998 salary of $7.30/h earned by trap-setters for Randolph County Animal Control, labor cost was calculated to be $9.16, or $0.61/trap, for the initial trap setting. Thereafter, checking the traps each morning, removing newspapers and leftover bait, and closing the traps and returning in the evening to bait and set traps required 45 minutes. Thus, the labor cost to monitor traps was calculated to be $5.50/night, or $0.37/trap/night. After the initial 5 nights, when the number of traps set was reduced to 5 per night, the labor cost to monitor traps was calculated to be $1.83/night ($0.37/trap/night). The labor cost for the 3-day acclimation period was calculated to be $15.50/colony; no additional cost for bait was incurred, as cats were fed the regular diet provided by the caretakers.

Mean ± SD total trapping cost (bait cost plus labor cost) per cat for colonies given an acclimation period ($6.57 ± $1.00) was significantly higher than mean total trapping cost per cat for colonies not given an acclimation period ($3.43 ± $1.74).

Similarly, mean total trapping cost per colony for colonies given an acclimation period ($70.77 ± $11.75) was significantly higher than mean total trapping cost per colony for colonies not given an acclimation period ($37.79 ± $19.66).

Discussion

Results of the present study suggest that the live-trapping protocols that were used were effective, in that in the present study mean overall trapping efficiency was 98% with mean overall trapping effort being 8.9 trap-nights per cat. The success of trapping in these colonies could in part be attributable to the regular feeding schedules and locations maintained by the colony caretakers. During preliminary visits to the colonies prior to the study, we observed that cats gathered at the feeding sites in anticipation of food delivery. It was possible to see most, if not all, resident cats at these times.

Feeding cats their regular diets in the traps for three days prior to the initiation of trapping did not have a significant effect on trapping effort or efficiency in the present study, but was associated with significant increases in trapping costs. However, cats in the present study were used to being visited regularly by their caretakers. Thus, whether providing an acclimation period would be beneficial for colonies not used to regular human contact or for particularly trap-shy cats could not be determined in the present study.

Although the capture of all cats in any given colony is the goal of a TNR program, some cats can be expected to evade capture, and their effect on the success of such programs must be evaluated. In the present study, trapping was continued until at least 90% of the adult (ie, > 6 months old) cats in a colony were captured or no more than 1 adult cat remained untrapped. Additional methods can be used to catch stragglers, but require experience (eg, net capture) or the participation of a veterinarian (eg use of sedative-laced food). Setting the traps used in the present study was straightforward and could have been accomplished by lay volunteers and colony caretakers following minimal instruction.

The purchase of traps represents one of the major start-up costs for TNR programs. Traps used in the present study cost $58.54 or $69.75 each, with volume discounts available from the company. They performed reliably, did not cause injury to the cats, and were easy to clean. Also, they are expected to have a long functional lifespan (≥ 10 years) if properly maintained.

Trapping costs in the present study were specific to these colonies, and costs for trapping other feral cat colonies will vary depending on the traps and bait used and the particular trapping protocol. Nevertheless, results of the present study can be used as general guidelines when calculating the costs of a TNR program.

References

Alley Cat Allies. 2002. Humane trapping instructions for feral cats. Accessed November 12, 2002. www.alleycat.org/pdf/humane.pdf

American Veterinary Medical Association. 1996. Position statement on abandoned and feral cats. *Journal of the American Veterinary Medical Association* **209**:1042.

Bester, M., J. Bloomer, P. Bartlett, D. Muller, M. van Rooyen, and H. Buchner. 2000. Final eradication of feral cats from sub-Antarctic Marion Island, southern Indian Ocean. *South African Journal of Wildlife Research* **30**:53-57.

Operation Catnip. 2002. *The Operation Catnip volunteer guide and policy manual.* Accessed November 12, 2002. www.operationcatnip.com

Clapperton, B. K., C. Eason, R. Weston, A. Woolhouse, and D. Morgan. 1994. Development and testing of attractants for feral cats, *Felis catus* L. *Wildlife Research* **21**:389-399.

Feral Cat Coalition. 2002. Humane trapping instructions. Accessed November 12, 2002. www.feralcat.com/trapins.html#A1.2

Edwards, G. P., K. C. Piddington, and R. M. Paltridge. 1997. Field evaluation of olfactory lures for feral cats (*Felis catus* L.) in central Australia. *Wildlife Research* **24**:173-183.

Hollander, M., and D. A. Wolfe 1973. *Nonparametric statistical methods.* John Wiley and Sons, New York City.

Johnson, K. J. 1996. A report on trap/alter/release programs. *Cat Fanciers' Almanac* **January**:71-77.

Kristensen, T. 1980. Feral cat control in Denmark. Pages 68-72. *The Ecology and Control of Feral Cats.* Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Neville, P. F., and J. Remfry. 1984. Effect of neutering on two groups of feral cats. *Veterinary Record* **114**:447-450.

Rees, P. 1981. The ecological distribution of feral cats and the effects of neutering a hospital colony. Pages 12-22. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Risbey, D.-A., M. Calver, and J. Short. 1997. Control of feral cats for nature conservation. I. Field tests of four baiting methods. *Wildlife Research* **24**:319-326.

Tabor, R. 1981. General biology of feral cats. Pages 5-11. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Zaunbrecher, K. I., and R. E. Smith. 1993. Neutering of feral cats as an alternative to eradication programs. *Journal of the American Veterinary Medical Association* **203**:449-452.

Chapter 3. Seroprevalences of antibodies against *Bartonella henselae* and *Toxoplasma gondii* and fecal shedding of *Cryptosporidium* spp, *Giardia* spp, and *Toxocara cati* in feral and pet domestic cats.

Felicia B. Nutter

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Introduction

The number of feral cats in the United States is difficult to estimate accurately, but the overall population is widely considered to be growing. A major concern expressed about feral cats, especially those resident in groups near human habitation, is that they might serve as a reservoir for infectious agents that can be transmitted to humans (Gross et al. 1996; Hughes 1993; Johnson et al. 1994; Yamaguchi et al. 1996; Zaunbrecher & Smith 1993). Indeed, several zoonotic agents, including *Bartonella henselae*, *Toxoplasma gondii*, *Cryptosporidium* spp, *Giardia* spp, and *Toxocara cati*, have been associated with feral cat populations (August & Chase 1988; Yamaguchi et al. 1996). However, it is difficult to put the potential health risk that feral cats pose into perspective without comparing the health status of feral cats with that of pet domestic cats. The purpose of the study reported here, therefore, was to compare seroprevalences of antibodies against *B. henselae* and *T. gondii* and fecal shedding rates of *Cryptosporidium* spp, *Giardia* spp, and *T. cati* in feral and pet domestic cats.

Materials and Methods

Cats

One hundred feral cats (47 females and 53 males) and 76 healthy pet cats (39 females and 37 males) were included in the study. The study was conducted in conjunction with a project examining the population dynamics of managed feral cat colonies in Randolph County, NC. Feral cats were humanely live-trapped in box-type traps and anesthetized with an IM injection of ketamine, tiletamine, zolazepam, and xylazine. Once cats were anesthetized, a complete physical examination was performed, and blood and fecal samples were collected. Cats were then vaccinated against rhinotracheitis, panleukopenia, calicivirus infection, FeLV infection, and rabies and treated with ivermectin. Only those cats considered to be at least 6 months old on the basis of eruption of the full permanent dentition were included in the study. Feral cats were included in the study on the basis of age and capture with no consideration for state of health at the time of trapping. Traps were thoroughly cleaned between captures by scrubbing with a detergent solution to remove all organic debris and then spraying with 10% bleach solution. Traps were allowed to stand for at least 15 minutes after being sprayed with the bleach solution and were then rinsed with a high-pressure hose.

Pet cats were enrolled in the study during the same period that trapping of feral cats occurred. Owners bringing domestic cats to the Asheboro Animal Hospital in Asheboro, NC, for routine preventative medical examinations or elective surgical procedures were solicited to participate in the study. Cats were manually restrained or anesthetized for collection of blood and fecal samples, depending on the reason for clinical evaluation. Demographic information on the cats was collected through a questionnaire completed by the owners.

Sample collection

Blood samples were collected from all 100 feral cats and all 76 pet cats by means of jugular or saphenous venipuncture. Samples were divided between plain glass and EDTA-containing collection tubes. Samples in plain glass tubes were allowed to clot, and serum was obtained. Serum samples were frozen at $-70^{o}C$ until analyzed. Samples anticoagulated with EDTA were used for determination of CBCs; samples that were not processed within 1 hour after collection were refrigerated until they could be processed. For feral cats, all CBCs were completed within 6 hours after sample collection. For pet cats, all CBCs were completed within 24 hours after sample collection.

Fecal samples were collected from 87 feral cats (39 females and 48 males) and 66 pet cats (31 females and 35 males). For the feral cats, fecal samples were obtained directly from the trap or by means of digital rectal examination. For the pet cats, fecal samples were provided by the owner or obtained by means of digital rectal examination. Fecal samples were placed in neutral-buffered 10% formalin within 24 hours after collection and were held at room temperature until analyzed.

Testing procedures

Serologic testing for antibodies against *B. henselae* was performed as described (Kordick & Breitschwerdt 1997); cats with an antibody titer ≥ 1:64 were considered seroreactive. Frozen serum samples were sent to the USDA Animal Parasitic Disease Laboratory for testing for antibodies against *T. gondii*. A modified agglutination test for IgG (sensitivity, 83%; specificity, 90%) was used (Dubey & Desmonts 1987); cats with an antibody titer ≥ 1:25 were considered seropositive. Blood or serum was tested for FeLV p27 core antigen and FIV antibody with a commercially available diagnostic test kit (SNAP, Idexx, Portland, Maine, USA); all samples were tested according to the manufacturer's directions.

Fecal samples were concentrated by means of formalin–ethyl acetate sedimentation. Concentrated samples were tested for *Cryptosporidium* spp and *Giardia* spp with a commercially available indirect fluorescent antibody test (Merifluor, Meridian Diagnostics, Cincinnati, Ohio, USA), according to the manufacturer's instructions. Concentrated fecal samples were also examined microscopically for *T. cati* ova.

Complete blood counts were performed with an automated hematology machine (Baker System 9110+, BioChem ImmunoSystems, Allentown, Pennsylvania, USA) and differential cell counts were performed manually on stained blood smears (Diff-Quik, Dade-Behring Inc, Deerfield, Illinois, USA). Serum biochemical panels, including determination of alanine transferase, alkaline phosphatase, and amylase activities and albumin, calcium, cholesterol, creatinine, globulin, glucose, potassium, total bilirubin, total protein, and urea nitrogen concentrations, were performed with an automated chemistry analyzer (VetScan Diagnostic Profile Plus, Abaxis Inc, Union City, California, USA).

Statistical analyses

Results of CBCs and serum biochemical analyses, seroprevalences of antibodies against *B. henselae* and *T. gondii*, and fecal prevalences of *Cryptosporidium* spp, *Giardia* spp, and *T. cati* were compared between feral and pet cats. The χ^2 or Fisher exact test was used for dichotomous data, and the Mann-Whitney *U* or Kruskal-Wallis test was used for continuous data. For all analyses, standard statistical software (StatView 5, SAS Institute Inc, Cary, North Carolina, USA) was used; values of $P \leq 0.05$ were considered significant.

Results

According to their owners, most pet cats had originally been obtained as strays (42/76 [55%]) or from shelters (8 [11%]), with smaller proportions having originally been obtained from a friend, neighbor, veterinarian, or classified advertisement (10 [13%]); as a gift (5 [7%]); or from a breeder or pet shop (1 [1%]). Owners of 10 (13%) pet cats did not specify the original source of the cat. Owners of 36 of 76 (47%) pet cats indicated that their cats spent at least part of their time outdoors. Median age of the pet cats was 4 years (range, 3 months to 19 years), with 23 (30%) of the pet cats being ≤ 2 years old, and 39 (51%) being < 6 years old. Owners of 32 (42%) pet cats reported giving their cats an enteric parasiticide at least once a year.

For both the feral and pet cats, results of hematologic and serum biochemical analyses were generally within ranges expected for healthy domestic cats (Aiello & Mays 1998). Values for feral cats were not significantly different from values for pet cats, except that median PCV was significantly lower for feral cats (31%) than for pet cats (38%) and median neutrophil count was significantly higher for feral cats (11,500 cells/μL) than for pet cats (7,800 cells/μL).

Percentages of feral and pet cats with positive FeLV and FIV assay results were low (Table 1), and there were not enough cats with positive results to permit evaluation of whether either organism was associated with co-infection with other organisms. Percentages of feral cats seropositive for antibodies against *B. henselae* and *T. gondii* were significantly higher than percentages of pet cats, with median titers for feral cats (median titer of antibodies against *B. henselae*, 1:128; median titer of antibodies against

T. gondii, 1:50; Figure 1) significantly higher than median titers for pet cats (median titer of antibodies against *B. henselae*, 1:64; median titer of antibodies against *T. gondii*, 0). Percentages of feral cats with *Cryptosporidium* spp, *Giardia* spp, or *T. cati* ova in their feces were not significantly different from percentages of pet cats found to have these organisms in their feces.

For the pet cats, serum titers of antibodies against *B. henselae* were significantly ($P < 0.001$) higher in younger than in older cats; however, titers were not significantly ($P = 0.958$) associated with whether cats had outdoor access. Seroprevalence of antibodies against *T. gondii* was significantly ($P = 0.009$) higher in older than in younger pet cats; however, the actual specific value of the titer did not vary significantly ($P = 0.08$) with age. Seroprevalence of antibodies against *T. gondii* was significantly ($P= 0.04$) higher in pet cats with outdoor access than in pet cats without outdoor access. Among pet cats, prevalence of *T. cati* infection was significantly associated with outdoor access and age, with prevalence being higher in pet cats with outdoor access ($P = 0.03$) and in younger cats ($P = 0.005$). Although a cursory examination of the data would suggest that pet cats with outdoor access have a higher prevalence of *Giardia* spp. and that younger cats might have a higher prevalence *Cryptosporidium* spp., these relationships were not found to be statistically significant at the 95% confidence level. Prevalence of *T. cati* infection was not significantly associated with whether cats received anthelminthic treatment.

Discussion

Feral cats included in the present study were from a limited geographic area in a rural county in North Carolina, and pet cats were drawn from a single clinic in the same county. Overall, our results suggest that these feral and pet domestic cats had similar baseline health status, as reflected by results of hematologic and serum biochemical testing and similar prevalences of infection with FeLV, FIV, *Cryptosporidium* spp, *Giardia* spp, and *T. cati*. Feral cats did have higher seroprevalences of antibodies against *B. henselae* and *T. gondii* than did pet cats, but this likely was related to greater exposure to vectors of these organisms. Our results, therefore, conflict with the common portrayal of feral cats as disease ridden and in poor health and suggest that the health risk to humans through association with feral cats should be expected to vary with the environment (eg, temperature, humidity, and wildlife density) and management protocols the cats experience.

Infection with FeLV and FIV was evaluated as a possible contributing factor to the presence of other infectious diseases in this study, but the overall prevalences of the retroviral infections were too low to permit proper evaluation of possible associations with co-infection. The low prevalences in our study are consistent with recent findings in a large free-roaming cat population from Gainesville, FL, and other studies published studies (Childs et al. 1994; Gurfield et al. 2001; Jameson et al. 1995; Koehler et al. 1994).

Domestic cats are considered the major reservoir for *Bartonella henselae*, and infection in cats in the United States is widespread and common (Breitschwerdt & Kordick 2000; Chomel et al. 1995; Jameson et al. 1995; Koehler et al. 1994).

Approximately half of cats seropositive for antibodies against *B. henselae* are also bacteremic (Chomel et al. 1995; Chomel et al. 2002; Gurfield et al. 2001). As in the present study, previous studies (Allenberger et al. 1995; Baneth et al. 1996; Childs et al. 1994; Chomel et al. 1995; Gurfield et al. 2001) have also documented higher seroprevalences in feral, stray, and shelter cats than in pet cats. Fleas (Chomel et al. 1996; Foil et al. 1998) and, to a lesser extent, ticks (Breitschwerdt & Kordick 2000) are implicated in the transmission of *B. henselae*, and both seropositivity and bacteremia are associated with flea infestation (Chomel et al. 1995; Gurfield et al. 2001; Maruyama et al. 2003). There is also a significant association between age, seropositivity, and bacteremia, with cats < 1 year old more commonly infected (Childs et al. 1994; Chomel et al. 1995; Koehler et al. 1994), as was the case for pet cats in the present study. Although feral cats included in the present study were from managed colonies, they did not receive any ectoparasite control. In addition, feral cats were judged to be between 6 months and approximately 2 years old, whereas pet cats had a median age of 4 years. Thus, it is possible that the higher seroprevalence of antibodies against *B. henselae* in feral cats in the present study could at least partly be explained by the younger age and greater exposure to fleas and ticks for feral cats, compared with pet cats.

The seroprevalence of antibodies against *T. gondii* and the median antibody titer were significantly higher in feral cats than in pet cats in the present study. This is consistent with the assumed greater opportunity for feral cats to prey on intermediate hosts or become infected through contaminated soil or water. A higher seroprevalence in feral versus pet cats has been reported previously (Dubey 1994; Dubey et al. 2002; Dubey et al. 1995), although some studies (DeFeo et al. 2002; Smielewska-Los & Pacon

2002) have found no difference in seroprevalence between the 2 populations. In the present study, pet cats with outdoor access had a higher seroprevalence than did those without outdoor access, against consistent with greater potential exposure to infective prey and contaminated soil and water. Thus, specific life history parameters should be considered as more important risk factors for *T. gondii* infection than broad categorization of domestic cats as feral or pet.

The overall prevalence of *Cryptosporidium* spp. in feces from cats in the present study was 6.5% and did not differ between feral and pet cats. This is consistent with findings from previous studies (Mtambo et al. 1991; Spain et al. 2001), which reported prevalences ranging from 3.8% to 8.1%. One of these studies (Mtambo et al. 1991) also found no difference between feral and pet cat populations. Prevalence was not significantly higher among pet cats with outdoor access than among pet cats without outdoor access in the present study; however, the *P* value (0.06) was close to the cutoff for significance, and it is likely that the small sample size and low prevalence limited the power of this comparison. Because the diagnostic test used in this study has been shown to react with *Cryptosporidium parvum* and *Cryptosporidium felis*, it is not known which *Cryptosporidium* species was detected. Furthermore, it is difficult to speculate about the potential role of cats as reservoirs for human infection (Caccio et al. 2002), as cross-infection studies have produced conflicting results. The recent recognition of the 2 genotypes of *C. parvum* and the identification of *C. felis* as a distinct species raise the possibility that investigators have been working with different genotypes or species (Asahi et al. 1991; Mtambo et al. 1996). Dog ownership, not cat ownership, has been recognized as a risk factor for *Cryptosporidium* infection in HIV-positive people, but it is still sensible to consider cats and particularly kittens as a possible reservoir for human *Cryptosporidium* infection (Glaser et al. 1998).

The overall prevalence of *Giardia* spp in feces from cats in the present study was 5.2% and did not differ between feral and pet cats. Given the current knowledge about *Giardia duodenalis* host range and cross-transmission and that the prevalences of infections in humans and domestic cats in the United States are similar, typically ranging between 2.4% and 7.3%, it is unclear whether cats are reservoirs for human infection or vice versa (Adam 1991; Hill et al. 2000; Kappus et al. 1994; Spain et al. 2001). As with *Cryptosporidium* spp, it is reasonable to consider cats as potential sources for human infection. This is particularly prudent in that a recent study (McGlade et al. 2003) found 32 of 40 (80%) of cats positive for *G. duodenalis* by use of a polymerase chain reaction assay, suggesting that for many cats tested by means of microscopy and staining techniques, results might be falsely negative because of low numbers of cysts in the sample.

The overall prevalence of *T. cati* in feces from cats in the present study was 19.6% and did not differ between feral and pet cats. This is consistent with recent reports (Hill et al. 2000; Spain et al. 2001) in which prevalence ranged between 3.9% and 32.7% for cats in the United States. The association between outdoor access and prevalence among pet cats in the present study likely was related to a greater exposure to contaminated soils or paratenic hosts. Both feral and pet cats can be sources of human infection through contamination of the environment with *T. cati* ova, which can survive for months to years depending on climatic conditions (Luria et al. 2004).

Regional differences in the prevalences of diseases in feral cats have been reported (Luria et al. 2004). Thus, it is important to include appropriate control populations of pet animals when collecting data to assess the zoonotic risk posed by feral or wild carnivores. Simply reporting the prevalence in feral cat populations could potentially erroneously inflate the implied risk of exposure to zoonotic organisms posed by feral cats and inappropriately affect policy decisions made regarding feral cat management and control.

References

Adam, R. D. 1991. The biology of *Giardia* spp. *Microbiology Reviews* **55**:706-732.

Aiello, S. E., and A. Mays 1998. *Merck Veterinary Manual*. Merial, Ltd., Whitehouse Station, New Jersey, USA.

Allenberger, F., M. Schonbauer, and M. P. Dierich. 1995. Prevalence of antibody to *Rochalimaea henselae* among Austrian cats. *European Journal of Pediatrics* **154**:165.

Asahi, H., T. Koyama, H. Arai, Y. Funakoshi, H. Yamaura, R. Shirasaka, and K. Okutomi. 1991. Biological nature of *Cryptosporidium* sp. isolated from a cat. *Parasitology Research* **77**:237-240.

August, J. R., and T. M. Chase. 1988. Toxoplasmosis. *Veterinary Clinics of North America Small Animal Practice* **17**:55-71.

Baneth, G., D. L. Kordick, B. C. Hegarty, and E. B. Breitschwerdt. 1996. Comparative seroreactivity to *Bartonella henselae* and *Bartonella quintana* among cats from Israel and North Carolina. *Veterinary Microbiology* **50**:95-103.

Breitschwerdt, E. B., and D. L. Kordick. 2000. *Bartonella* infection in animals: carriership, reservoir potential, pathogenicity, and zoonotic potential for human infection. *Clinical Microbiology Reviews* **13**.

Caccio, S., E. Pinter, R. Fantini, I. Mezzaroma, and E. Pozio. 2002. Human infection with *Cryptosporidium felis*: case report and literature review. *Emerging Infectious Diseases* **8**:85-86.

Childs, J. E., J. A. Rooney, J. L. Cooper, J. G. Olson, and R. L. Regnery. 1994. Epidemiologic observations on infection with *Rochalimaea species* among cats living in Baltimore, Maryland. *Journal of the American Veterinary Medical Association* **204**:1775-1778.

Chomel, B., R. W. Kasten, K. FLoyd-Hawkins, B. Chi, K. Yamamoto, J. Roberts-Wilson, A. N. Gurfeld, R. C. Abbott, N. C. Pedersen, and J. E. Koehler. 1996. Experimental transmission of *Bartonella henselae* by the cat flea. *Journal of Clinical Microbiology* **34**:1952-1956.

Chomel, B. B., R. C. Abbott, R. W. Kasten, K. A. Floyd-Hawkins, P. H. Kass, C. A. Glaser, N. C. Pedersen, and J. E. Koehler. 1995. *Bartonella henselae* prevalence in domestic cats in California: risk factors and association between bacteremia and antibody titers. *Journal of Clinical Microbiology* **33**:2445-2450.

Chomel, B. B., H. J. Boulouis, H. Petersen, R. W. Kasten, K. Yamamoto, C. C. Chang, C. Gandoin, C. Bouillin, and C. M. Hew. 2002. Prevalence of *Bartonella* infection in domestic cats in Denmark. *Veterinary Research* **33**:205-213.

DeFeo, M. L., J. P. Dubey, T. N. Mather, and R. C. Rhodes, 3rd. 2002. Epidemiologic investigation of seroprevalence of antibodies to *Toxoplasma gondii* in cats and rodents. *American Journal of Veterinary Research* **63**:1714-1717.

Dubey, J. P. 1994. Toxoplasmosis. *Journal of the American Veterinary Medical Association* **205**:1593-1598.

Dubey, J. P., and G. Desmonts. 1987. Serologic responses of equids fed *Toxoplasma gondii* oocysts. *Equine Veterinary Journal* **19**:337-339.

Dubey, J. P., W. J. Saville, J. F. Stanek, and J. M. Reed. 2002. Prevalence of *Toxoplasma gondii* in domestic cats from rural Ohio. *Journal of Parasitology* **88**:802-803.

Dubey, J. P., R. M. Weigel, A. M. Siegel, P. Thulliez, U. D. Kitron, M. A. Mitchell, A. Manelli, N. E. Mateus-Pinilla, S. K. Shen, O. C. Kwok, et al. 1995. Sources and reservoirs of *Toxoplasma gondii* infection on 47 swine farms in Illinois. *Journal of Parasitology* **81**:723-729.

Foil, L., A. E., R. L. Freeland, A. F. Roy, R. Rutledge, P. C. Triche, and K. L. O'Reilly. 1998. Experimental infection of domestic cats with *Bartonella henselae* by innoculation of *Ctenocephalidies felis* (Siphonaptera: Pulicidae) feces. *Journal of Medical Entomology* **35**:625-628.

Glaser, C., S. Safrin, A. Reingold, and T. B. Newman. 1998. Association between *Cryptosporidium* infection and animal exposure in HIV-infected individuals. *Journal of Acquired Immune Deficiency Syndromes and Human Retrovirology* **17**:79-82.

Gross, E. M., G. Hoida, and T. Sadeh. 1996. Opposition to trap-sterilize-release programs for feral cats. *Journal of the American Veterinary Medical Association* **208**:1380-1381.

Gurfield, A. N., H. J. Boulouis, B. B. Chomel, R. W. Kasten, R. Heller, C. Bouillin, C. Gandoin, D. Thibault, C. C. Chang, F. Barratt, and Y. Piemont. 2001.

Epidemiology of *Bartonella* infection in domestic cats in France. *Veterinary Microbiology* **80**:185-198.

Hill, S. L., J. M. Cheney, G. F. Taton-Allen, J. S. Reif, C. Bruns, and M. R. Lappin. 2000. Prevalence of enteric zoonotic organisms in cats. *Journal of the American Veterinary Medical Association* **216**:687-692.

Hughes, J. E. 1993. Feral cats. *Journal of the American Veterinary Medical Association* **203**:1256-1257.

Jameson, P., C. Greene, R. L. Regnery, M. W. Dryden, A. Marks, J. Brown, J. Cooper, B. Glaus, and R. Greene. 1995. Prevalence of *Bartonella henselae* antibodies in pet cats throughout regions of North America. *Journal of Infectious Diseases* **172**:1145-1149.

Johnson, K. J., L. Lewellyn, and J. Lewellyn. 1994. National Pet Alliance survey report on Santa Clara County's pet population. *Cat Fanciers' Almanac*:71-77.

Kappus, K. D., R. G. Lundgren Jr., D. D. Juranek, J. M. Roberts, and H. C. Spencer. 1994. Intestinal parasitism in the United States: update on a continuing problem. *American Journal of Tropical Medicine and Hygiene* **50**:705-713.

Koehler, J. E., C. A. Glaser, and J. W. Tappero. 1994. *Rochalimaea henselae* infection: a new zoonosis with the domestic cat as reservoir. *Journal of the American Veterinary Medical Association* **271**:531-535.

Kordick, D. L., and E. B. Breitschwerdt. 1997. Relapsing bacteremia after blood transmission of *Bartonelle henselae* to cats. *American Journal of Veterinary Research* **58**:492-497.

Luria, B. J., J. K. Levy, M. R. Lappin, E. B. Breitschwerdt, A. M. Legendre, J. A. Hernandez, S. P. Gorman, and I. T. Lee. 2004. Prevalence of infectious diseases in feral cats in Northern Florida. *Journal of Feline Medicine and Surgery* **6**:287-296.

Maruyama, S., H. Kabeya, R. Nakao, S. Tanaka, T. Sakai, X. Xuan, Y. Katsube, and T. Mikami. 2003. Seroprevalence of *Bartonella henselae, Toxoplasma gondii*, FIV, and FeLV infections in domestic cats in Japan. *Microbiology and Immunology* **47**:147-153.

McGlade, T. R., I. D. Robertson, A. D. Elliot, and R. C. Thompson. 2003. High prevalence of *Giarida* detected in cats by PCR. *Veterinary Parasitology* **110**:197-205.

Mtambo, M. M., A. S. Nash, D. A. Blewett, H. V. Smith, and S. Wright. 1991. *Cryptosporidium* infection in cats: prevalence of infection in domestic and feral cats in the Glasgow area. *Veterinary Record* **129**:502-504.

Mtambo, M. M., S. E. Wright, and D. A. Blewett. 1996. Infectivity of *Cryptosporidium* species isolated from a domestic cat (*Felis domesticus*) in lambs and mice. *Research in Veterinary Science* **60**:61-63.

Smielewska-Los, E., and J. Pacon. 2002. *Toxoplasma gondii* infection of cats in epizootiological and clinical aspects. *Polish Journal of Veterinary Science* **5**.

Spain, C. V., J. M. Scarlett, S. E. Wade, and P. McDonough. 2001. Prevalence of enteric zoonotic agents in cats less than 1 year old in central New York state. *Journal of Veterinary Internal Medicine* **15**:33-38.

Yamaguchi, N., D. W. Macdonald, W. C. Passanisi, D. A. Harbour, and C. D. Hopper. 1996. Parasite prevalence in free-ranging farm cats, *Felis silvestris catus. Epidemiology and Infection* **116**:217-223.

Zaunbrecher, K. I., and R. E. Smith. 1993. Neutering of feral cats as an alternative to eradication programs. *Journal of the American Veterinary Medical Association* **203**:449-452.

Table 1. Prevalence of infection with or exposure to various retroviral, bacterial, and protozoal organisms in feral and pet domestic cats from a rural county in North Carolina. Data are given as No. positive/No. tested (%). *Significantly (*P* < 0.05) different from percentage of feral cats.

Organism	**Feral cats**	**Pet cats**
FIV	5/100 (5%)	3/76 (4%)
FeLV	4/100 (4%)	1/76 (1%)
Bartonella henselae	93/100 (93%)*	57/76 (75%)
Toxoplasma gondii	63/100 (63%)*	26/76 (34%)
Cryptosporidium spp.	6/87 (7%)	4/66 (6%)
Giardia spp.	5/87 (6%)	3/66 (5%)
Toxocara cati	18/87 (21%)	12/66 (18%)

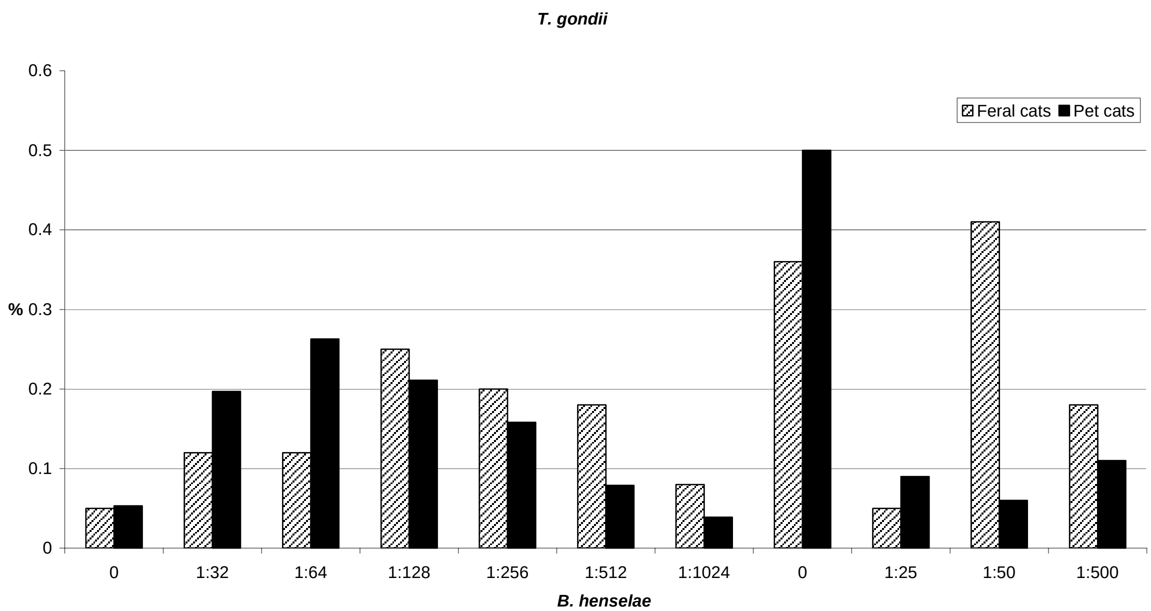

Figure 1. Serum titers of antibodies against *Bartonella henselae* and *Toxoplasma gondii* among 100 feral and 76 pet domestic cats from a rural county in North Carolina.

Chapter 4. Reproductive capacity of free-roaming domestic cats and kitten survival rate.

Felicia B. Nutter

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Introduction

The size of the free-roaming cat population in the United States is unknown, but overpopulation of free-roaming cats is considered to be an important problem because of concerns about animal welfare, wildlife predation, and zoonotic disease transmission (Patronek 1998). Methods for controlling populations of free-roaming cats are controversial, in large part because of a lack of the data needed to assess the various options (Mahlow & Slater 1996; Patronek 1998; Slater 2002). Domestic cats are considered to be prolific breeders, with females capable of bearing their first litter before 1 year of age and able to have multiple litters each year thereafter (Deag et al. 2000; Liberg 1981). However, estimates of the reproductive capacity of female cats and the consequences of unabated reproduction are often extrapolated beyond scientific reliability, as they typically fail to use realistic litter sizes or ignore kitten mortality rates (Luoma 1997; Olson & Johnston 1993). The purpose of the study reported here was to determine reproductive parameters of naturally breeding free-roaming cats. For purposes of the present study, free-roaming cats were considered to be cats that were not confined when outdoors. Feral cats were considered to be a subset of free-roaming cats.

Materials and Methods

Data for the study were collected from 2 sources. Between May 1998 and October 2000, data were collected on 71 sexually intact female cats in 9 managed feral cat colonies in Randolph County, NC. The cats were being monitored to assess the impact of a trap-neuter-return (TNR) program on feral cat colony population dynamics. As each colony was enrolled in the population dynamics study, all cats in the colony were captured, and pregnancy, lactation, and estrus status of the female cats were determined. Colonies were included in the study only if they had an established caretaker who provided food and water on a regular basis and either owned the land on which the colony resided or had the permission of the landowner to tend to the cats; cats in the colony had access to adequate shelter, such as a barn, storage shed, carport, basement, or crawl space; the colony consisted of at least 10 adult cats (ie, cats > 6 months old), with at least 3 adult male cats; the colony was located in a rural or suburban residential area at least 1 km from the nearest 4-lane road; and the colony caretaker agreed to random assignment of the colony to a treatment group (control vs surgical sterilization), ear-tipping of all cats for permanent identification, and regular visits to the colony by the investigators for data collection. At the time of inclusion in the study, cats in the colony were live trapped and anesthetized with an IM injection of ketamine, tiletamine, zolazepam, and xylazine (Williams et al. 2002). Female cats in 6 colonies (n = 44) were surgically neutered. Female cats in the remaining 3 colonies (n = 27) remained intact. All cats in all colonies were vaccinated against rhinotracheitis, panleukopenia, calicivirus infection, FeLV infection, and rabies and treated with ivermectin. Food and water were provided daily. Cats were returned to their colony sites and monitored for a 2-year follow-up period. During that time, census data were collected on the colonies at least twice weekly by the caretakers or the principal investigator. Data collected included parity, birth dates, litter sizes, and outcome of kittens. Parity was estimated on the basis of whether the caretaker had observed the cat to have been pregnant, lactating, or caring for a litter previously and reproductive status of the cat at the time of enrollment in the study. Kittens that survived to 6 months of age were trapped and enrolled in the population dynamics study, but were not enrolled in the present study. Litter size data were collected on 61 litters produced by the 27 control females during the 2-year study period. Data were available on time of birth for all 61 litters, on litter-specific mortality rates for 59 litters, and on litter size for 50 litters. All cats were trapped, neutered, and vaccinated at the end of the population dynamics study and again returned to their colony sites.

Data were also collected on a convenience sample of 2,332 free-roaming female cats trapped and brought by their caretakers to a monthly TNR clinic in Raleigh, NC, (Operation Catnip Inc, Raleigh, North Carolina, USA) between February 1996 and December 2001. Information on living conditions of these cats was not available; however, data on pregnancy status (ie, identification of embryos or fetuses visible without magnification), number of fetuses per pregnancy, lactation status (ie, ability to express milk from teats), and estrus status (ie, ovarian follicle development and uterine status) were collected by veterinary technicians and assistants at the time of neutering and recorded on a standardized recording sheet. Pregnancy status was recorded for 2,281 of the 2,332 cats, and 608 cats were confirmed to be pregnant on the basis of identification of embryos or fetuses in the uterus. Fetus counts were recorded for 317 of the 608 pregnancies. Lactation status was recorded for 2,205 cats, and estrus status was recorded for 2,227.

Data from the population dynamics study were used to determine litter sizes for live births, litters per year, kitten survival rate, and causes of death for kittens that died. Descriptive statistics were calculated, and associations between parity, litter size, kitten survival rate, and litter order (first, second, or third per year) were assessed with *z* tests.

Commercial software (StatView 5, SAS Institute Inc, Cary, North Carolina, USA) was used for all calculations; values of $P < 0.05$ were considered significant. Distributions of fetus counts and litter sizes from live births were significantly different ($P = 0.008$; Kolmogorov-Smirnov test), thus analyses were performed separately for each. Fetus counts and litter size were compared with the Mann Whitney *U* test. Distributions of pregnancy, lactation, and estrus status were not significantly different between cats in the population dynamics study and cats examined in the TNR program. Therefore, data were pooled for further analysis.

Survival time for 169 kittens was evaluated by means of the Kaplan-Meier product-limit estimate of the survivor function (Lee & Wang 2003). Observations were right-censored at the end of the 6 months (180 days). Survival times were compared by parity of the queen, litter size, and litter order with the Peto and Peto generalized Wilcoxon test for k samples with censored data (Dexter et al. 2004); values of $P < 0.05$ were considered significant.

Results

Six hundred twenty-five cats in the study (608 in the TNR program and 17 in the population dynamics study) were pregnant. Pregnancies were observed in all months of the year, but the percentage of cats found to be pregnant was highest in March, April, and May (Figure 1) and lowest in November. Distributions of the percentages of cats in estrus and the percentages of cats lactating had similar patterns, with the peak in percentages of cats in estrus preceding the peak in percentage of cats found to be pregnant and the peak in percentage of cats lactating following. Overall, 149 of 2,276 cats (131/2,205 cats in the TNR program and 18/71 cats in the population dynamics study) were reported to be lactating, and 295 of 2,298 cats (277/2,227 cats in the TNR program and 18/71 cats in the population dynamics study) were in estrus.

Information on fetus count was available for 317 cats in the TNR program and 17 cats in the population dynamics study (1,401 total fetuses), and information on litter size was available for 50 litters produced by cats in the population dynamics study (171 total kittens). Fetus count (median, 4; interquartile range [25th to 75th percentile], 2 to 6; range, 1 to 10) was significantly ($P < 0.001$) higher than litter size (median, 3; interquartile range, 2 to 4; range, 1 to 6). Cats in the population dynamics study produced a mean of 1.4 litters/y, with a maximum of 3 litters per year.

Survival data were available for 169 kittens. Overall, 127 of the 169 (75%) of the kittens died (n = 87) or disappeared (40) before 6 months of age. Median litter-specific mortality rate was 75% (interquartile range, 20% to 100%; range, 0% to 100%). Kitten mortality was not significantly associated with maternal parity ($P = 0.19$), litter size ($P = 0.10$), or litter order ($P = 0.38$). Eighty-one of the 169 (48%) kittens died or disappeared before they were 100 days old (Figure 2). Median survival time was 113 days (10th to 90th percentile range, 24 to 180 days). Survival time was not significantly associated with maternal parity ($P = 0.12$), litter size ($P = 0.11$), or litter order ($P = 0.58$). Causes of death were determined for 41 of the 87 (47%) kittens reported to have died. Thirty-seven of the 41 (90%) died as a result of trauma, with attacks by stray and owned dogs (18) and motor vehicle accident (10) being the most common types of trauma. Other types of trauma that resulted in more than one death included falls from hay lofts (n = 2), being stepped on by horses or people (3), and a suspected episode of infanticide (3). Cause of death was not be determined for 46 of the 87 (53%) kittens reported to have died, but many reportedly had signs of disease, including upper respiratory tract disease and diarrhea, prior to death.

For 10 female kittens born into control feral cat colonies, ages at which they produced their first litters were recorded. Median age at first parity was 10.5 months (interquartile range, 8 to 12 months; range, 6 to 15 months).

Discussion

Results of the present study reinforce concerns about the high reproductive capability of free-roaming domestic cats. Although cats are considered to be seasonally polyestrous with a defined anestrus period associated with day length (Hurni 1981; Scott & Lloyd-Jacobs 1959) pregnant cats were identified during all months of the year in the present study, and similar findings have been reported previously (Prescott 1973). However, only 15 pregnancies were identified outside the spring and summer breeding season during the 6 years of the present study. This would support a hypothesis that seasonal births are dependent on optimal environmental conditions (Deag et al. 2000).

In the present study, pregnancies peaked during the spring and late summer, which is consistent with reported patterns in Florida (Scott et al. 2002), Australia (Jones & Coman 1982), and South Africa (van Aarde 1978). Estrus and lactation followed similar seasonal patterns, with estrus peaking prior to the peak in pregnancies, and lactation peaking after the peak in pregnancies, as expected. Estrus and lactation were lower than would be expected given the reported pregnancies, most likely because of the difficulty of identifying estrus and lactation, compared with identifying pregnancy.

Also, estrus lasts a shorter time than either pregnancy or lactation, which would add to a bias for detecting pregnancy during monthly TNR clinics.

Reported values for mean litter sizes for free-roaming, laboratory-raised, and cattery cats vary from 2.1 to 5 kittens per litter, with ranges from 1 to 10 kittens per litter having been reported (Ekstrand & Linde-Forsberg 1994; Kane et al. 1990; Lawler & Monti 1984; Mirmovitch 1995; Povey 1978; Prescott 1973; Robinson & Cox 1970; Root et al. 1995; Scott et al. 1978; van Aarde 1978), and litter sizes in the present study were consistent with these values. Litter size was significantly smaller than fetus count in the present study, which may be an indication of late gestational or early neonatal losses that were not directly observed. Litters of kittens could not always be located immediately after birth, and kittens were typically first counted at 3 to 4 weeks of age, when they began to visit the colony feeding site. This has been the only method used by some researchers to determine litter sizes (Mirmovitch 1995) and, on the basis of our findings, results in conservative estimates of actual reproduction.

On average, cats in the present study gave birth to 1.4 litters/y, although 2 cats had 3 litters in a single year. Production of multiple litters a year has been negatively associated with survival of kittens in the first litter in other studies (Ewer 1973; Wolski 1981), but we did not find a clear association between those variables in our data. However, the 2 females that each produced 3 litters in a single year did have 100% mortality for at least 1 of the first 2 litters in that year. This association makes intuitive sense, but requires a larger data set to appropriately interpret the relationship. Of 10 female cats born into control feral cat colonies and closely followed to determine age at first parity, 9 produced their first litters at < 1 year of age, with 1 cat giving birth at 6 months of age. This young age at first reproduction combined with the potential to produce multiple litters a year contributes to the perception of cats as prolific breeders (Deag et al. 2000; Liberg 1981).

High neonatal and juvenile mortality rates are widely reported for domestic cats. Reported rates of early neonatal deaths (ie, up to 6 or 8 weeks of age) range from 12.8% to 48% (Jemmett & Evans 1977; Scott et al. 1978; van Aarde 1984). In 1 study (van Aarde 1984), up to 90% of kittens died before 6 months of age. Similarly, 81 of 169 (48%) kittens in the present study had died or disappeared before they were 100 days old, and 127 (75%) had died or disappeared before they were 6 months old. Trauma accounted for the death of most kittens for which cause of death was confirmed. Causes of kitten death may be highly dependent on a variety of environmental variables, and considerable variation in these data should be expected between study sites, making generalization difficult. Variations are also likely within causes of death. For example, single or multiple stray dogs were responsible for deaths of kittens in 2 colonies in the present study, whereas a caretaker's dogs were responsible for the deaths of multiple kittens in a third colony. It is likely that both motor vehicle accidents and dog attacks were over-represented as causes of death in the present study, because the noise or graphic visual evidence associated with these causes of death is likely to draw attention. Cats that become debilitated often seek hiding places, making it less likely that cats that die of illness or disease will be identified. Predation of kittens by other animals, such as raptors, foxes, and coyotes, likely resulted in the disappearance of some kittens in the present study, but was not recorded as a cause of death, likely because the carcasses were consumed. Causes of kitten death and the relative rank of contribution to overall mortality rates were reported in a study (Wolski 1981) of farm cats in Ithaca, NY; however, relative rankings were different from rankings in the present study, likely because of differences in study design and environmental conditions of the kittens, such as human population density, road density, road proximity, and climatic conditions.

Examined out of context, our data would tend to reinforce the popular notion that kittens born to free-roaming cats live a marginal existence and have an unreasonably high mortality rate. However, reported kitten mortality was consistent with that reported for similarly sized wild carnivores (Cypher et al. 2000; Fritts & Sealander 1978), suggesting that the living conditions of free-roaming cats are comparable to those of other wildlife. It also suggests that the assessment and management of feral cat colonies with methods developed for studying other small wild carnivores is appropriate. Results of the present study provide information needed to develop reliable estimates of the impact of reproduction by sexually intact free-roaming domestic cats in rural and suburban regions of the southeastern United States.

References

Cypher, B. L., G. D. Warrick, M. R. M. Otten, T. P. O'Farrell, W. H. Berry, C. E. Harris, T. T. Kato, P. M. Mccue, J. H. Scrivner, and B. W. Zoellick. 2000. Population dynamics of San Joaquin kit foxes at the Naval Petroleum Reserves in California. *Wildlife Monographs* **145**:1-43.

Deag, J. M., A. Manning, and C. E. Lawrence. 2000. Factors influencing the mother-kitten relationship. Pages 23-46 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Dexter, N., R. C. Dowler, J. P. Flanagan, S. Hart, M. A. Revelez, and T. E. Lee, Jr. 2004. The influence of feral cats Felis catus on the distribution and abundance of introduced and endemic Galapagos. *Pacific Conservation Biology* **10**:210-215.

Ekstrand, C., and C. Linde-Forsberg. 1994. Dystocia in the cat: a retrospective case study of 155 cases. *Journal of Small Animal Practice* **35**:459-464.

Ewer, R. F. 1973. *The Carnivores*. Weidenfeld and Nicholson, London, UK.

Fritts, S. H., and J. A. Sealander. 1978. Reproductive biology and population characteristics of bobcats (*Lynx rufus*) in Arkansas. *Journal of Mammalogy* **59**:347-353.

Hurni, H. 1981. Daylength and breeding in the domestic cat. *Laboratory Animal Science* **15**:229-231.

Jemmett, J. E., and J. M. Evans. 1977. A survey of sexual behavior and reproduction in female cats. *Journal of Small Animal Practice* **18**:31-37.

Jones, E., and B. J. Coman. 1982. Ecology of the feral cat *Felis catus* in Southeastern Australia 2. Reproduction. *Australian Wildlife Research* **9**:111-120.

Kane, E., R. E. allard, and G. M. Douglass. 1990. The influence of litter size on weight change during feline gestation and lactation. *Feline Practice* **18**:6-10.

Lawler, D. F., and K. F. Monti. 1984. Morbidity and mortality in neonatal kittens. *American Journal of Veterinary Research* **45**:1455-1459.

Lee, E. T., and J. W. Wang 2003. *Statistical methods for survival data analysis.* John Wiley and Sons, New York.

Liberg, O. 1981. Predation and social behaviour in a population of domestic cat; an evolutionary perspective. PhD. University of Lund, Sweden. 135 pages.

Luoma, J. 1997. Catfight. *Audobon* **July-August**:84-91.

Mahlow, J. C., and M. R. Slater. 1996. Current issues in the control of stray and feral cats. *Journal of the American Veterinary Medical Association* **209**:2016-2020.

Mirmovitch, V. 1995. Spatial organisation of urban feral cats (*Felis catus*) in Jerusalem. *Wildlife Research* **22**:299-310.

Olson, P. N., and S. D. Johnston. 1993. New developments in small animal population control. *Journal of the American Veterinary Medical Association* **202**:904-909.

Patronek, G. J. 1998. Free-roaming and feral cats--their impact on wildlife and human beings. *Journal of the American Veterinary Medical Association* **212**:218-226.

Povey, R. C. 1978. Reproduction in the pedigree female cat: a survey of breeders. *Canadian Veterinary Journal* **19**:207-213.

Prescott, C. W. 1973. Reproduction patterns in the domestic cat. *Australian Veterinary Journal* **49**:126-129.

Robinson, R., and H. W. Cox. 1970. Reproductive performance in a cat colony over a 10-year period. *Laboratory Animal Science* **4**:99-112.

Root, M., S. D. Johnston, and P. N. Olson. 1995. Estrous length, pregnancy rate, gestation, and parturition lengths, litter size, and juvenile mortality in the domestic cat. *Journal of the American Animal Hospital Association* **31**:429-433.

Scott, F. W., C. Geissinger, and R. Peltz. 1978. Kitten mortality survey. *Feline Practice* **8**:31-34.

Scott, K. K., J. K. Levy, and C. P. Crawford. 2002. Characteristics of free-roaming cats evaluated in a trap-neuter-return program. *Journal of the American Veterinary Medical Association* **221**:1136-1138.

Scott, P. P., and M. A. Lloyd-Jacobs. 1959. Reduction in the anestrous period of laboratory cats by increased illumination. *Nature* **184**:2022.

Slater, M. R. 2002. *Community Approaches to Feral Cats: Problems, Alternatives, and Recommendations.* Humane Society Press, Washington, D.C., USA.

van Aarde, R. J. 1978. Reproduction and population ecology in the feral house cat, *Felis catus*, on Marion Island. *Carnivore Genetics Newsletter* **3**:288-316.

van Aarde, R. J. 1984. Population biology and the control of feral cats on Marion Island. *Acta Zoologica Fennica* **172**:107-110.

Williams, L. S., J. K. Levy, S. A. Robertson, A. M. Cistola, and L. A. Centonze. 2002. Use of the anaesthetic combination of tiletamine, zolazepam, ketamine, and xylazine for neutering feral cats. *Journal of the American Veterinary Medical Association* **220**:1491-1495.

Wolski, T. R. 1981. Country cousin: the life of the barnyard cat. *Feline Health Perspectives* **3**:1-3.

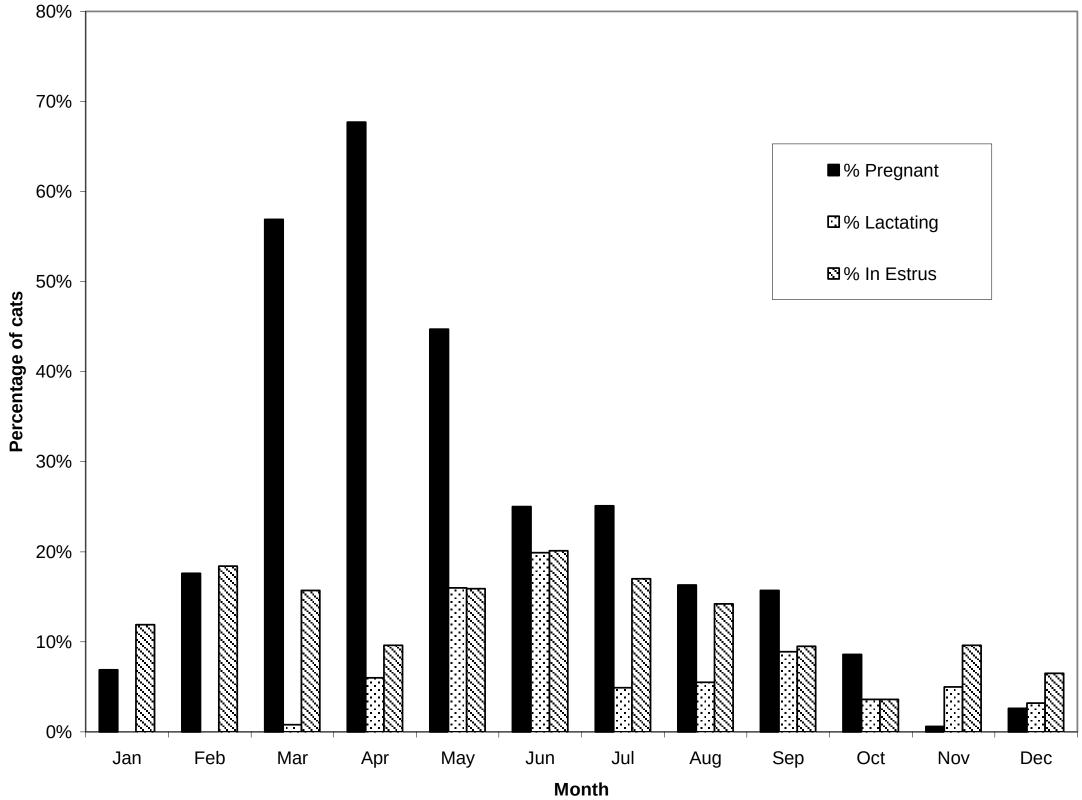

Figure 1—Percentages of free-roaming cats found to be pregnant, lactating, or in estrus as a function of month of examination. Data are based on 2,332 free-roaming female cats brought to a trap-neuter-return clinic for neutering and 71 female cats in managed feral cat colonies.

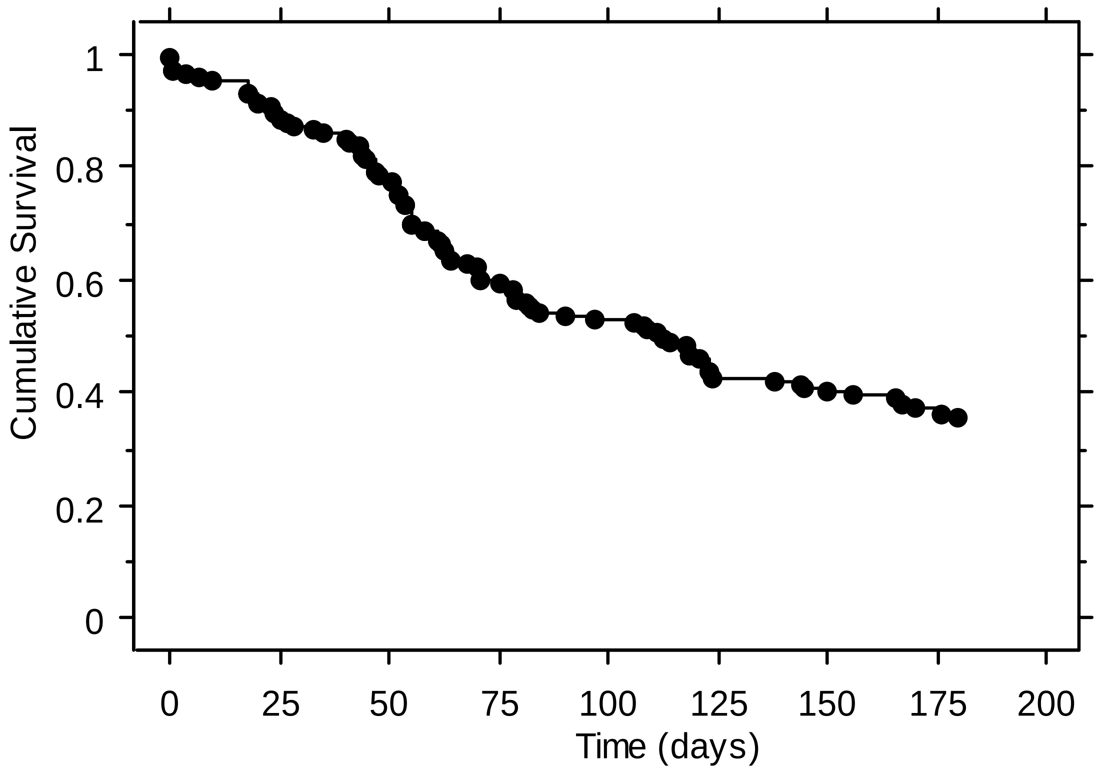

Figure 2—Kaplan-Meier survival estimate for 169 kittens born to free-roaming cats. Kittens were observed for 180 days after birth.

Chapter 5. Survival analysis for feral cat colonies managed by surgical sterilization, with two techniques for neutering males.

Felicia B. Nutter

Introduction

Attempts to compromise or develop consensus plans for managing feral cats are hampered by a paucity of data from objective, controlled research on the potential impact of trap-neuter-return programs. (Patronek 1998; Slater 2002) Prospective controlled studies with sufficient numbers of colonies are needed to evaluate the value of different surgical approaches to male to feral cat colony management. This project examined the changes in population size and composition of colonies of surgically sterilized cats compared to intact cats, and evaluated the effects of two techniques for sterilizing males, castration and vasectomy.

Materials and Methods

Study Design

I enrolled nine pre-existing feral cat colonies in Randolph County, North Carolina were in the study between May and August 1998, and two additional colonies in June and July 2001. Inclusion criteria for the colonies were (1) established caretaker to provide food and water on a regular basis, who either owned the land where the colony resided or had permission of the landowner to tend to the cats, (2) colony access to adequate shelter, such as a barn, storage shed, carport, basement or crawl space, (3) presence of at least ten cats greater than six months old, with at least three adult male cats, (4) location in a rural or suburban residential area, at least 1 km distant from a four-lane road, and (5) agreement of caretakers to the random assignment of colonies to treatment groups (control vs. surgical sterilization), ear-tipping of all cats for permanent identification, and regular visits to the colony by the investigators for data collection.

I captured cats with humane live traps (Tomahawk live traps #207 and #608, Tomahawk Live Traps, Tomahawk, WI, USA) (Nutter et al. 2004c) and anesthetized them for handling and surgery with a single intramuscular injection of ketamine 5mg/kg, tiletamine 3 mg/kg, zolazepam 3mg/kg, and xylazine 1.25 mg/kg. The use of the injectable anesthetic mixture allowed for a very small volume injection (approximately 0.25ml/cat), which provided ease of injection, short handling time and low stress (Williams et al. 2002). I used isoflurane (0.5%-5% by facemask or endotracheal tube) to provide additional anesthesia when necessary. Post-operative analgesia was provided with a single dose of butorphanol 0.40 mg/kg IM.

I randomly assigned the nine colonies enrolled in 1998 to treatment groups. Three colonies served as reproductively intact controls (C1-C3). In three “castration” colonies (SC1-SC3), I castrated males and ovariohysterectomized (spayed) females. In three “vasectomy” colonies (SV1-SV3), I vasectomized males (Herron & Herron 1972) and spayed females. The two colonies enrolled in 2001 were assigned to the control group (C4, C5). I spayed pregnant females using a standard midline approach, while I used a left flank approach for lactating and non-gravid or early-pregnant females (Krzaczynski 1974). I performed castrations using a standard bilateral scrotal approach, and vasectomies via a single pre-scrotal incision. I removed 1cm from the tip of an ear (right for males, left for females) to identify neutered cats and to indicate to local animal control agencies that the cats had been neutered and vaccinated for rabies (Cuffe et al. 1983). I further identified cats by natural markings and placed color-coded collars and tags. I placed colored nylon webbing collars with colored plastic tags as identification on cats in three colonies. After 1 to 4 weeks of wear, varying degrees of injury caused by the collars were noted in 5 of 48 cats, necessitating recapture of all cats and removal of collars. In four cases, the trauma was minimal and consisted of hair loss and superficial abrasions. In one case, surgical debridement and closure of a full-thickness circumferential laceration was required. Nylon collars were replaced with flexible plastic tubing (Tygon® R-3603, AAC00002, Saint-Gobain Performance Plastics, Akron, OH, USA) threaded with round elastic. Tubing was cut to fit individual animals and elastic was tied under moderate tension to allow for escape if collars became entangled and accommodate growth of younger animals. Four of 179 cats entangled one or both forelimbs in the new collars and sustained mild to moderate injuries as the collar migrated under one axilla or around the thorax. Affected cats were recaptured and plastic tubing collars refitted. One cat caught his mandible in the collar and subsequently disappeared.

All animals were vaccinated for rabies (Rabvac-3®, Fort Dodge Animal Health, Overland Park, KS, USA), feline viral rhinotracheitis, calicivirus, and panleukopenia (Felo-Vax®, Fort Dodge Animal Health, Overland Park, KS, USA), and treated with an anthelminthic (IVOMEC®, Merial, Duluth, GA, USA). They were provided with food and water daily. This minimized variation among colonies due to common infectious diseases and food resource fluctuations, and increased the probability that the study would be conducted under growth conditions for colonies. Whole blood or serum samples from 50 males and 50 females were tested for FeLV p27 core antigen and FIV antibody using a commercially available test (SNAP®, Idexx, Portland, ME, USA) to assess the potential impact of feline leukemia virus (FeLV) and feline immunodeficiency virus (FIV) infection on cat survival.

Data Collection

I conducted censuses of all colonies by visually identifying animals at least twice weekly from 1998-2000, and at least once every two weeks from 2000-2002. Colony caretakers collected census data at feeding times, and by the principal investigator during colony visits. Data collected included presence/absence, births, deaths, disappearances, and immigration of new cats. A specific cause of death was recorded if definitively known or determined through carcass inspection or necropsy. The cause was listed as unknown if remains were found but examinations were inconclusive. Emigrations were only recorded if cats were identified at new home sites. Disappearances were recorded if cats were absent from the colony census for four consecutive weeks, but death or emigration was not confirmed. Kittens born into colonies were trapped and enrolled in the study at six months of age. Immigrants were trapped after one month's presence in the colony. Recruited kittens and immigrants received vaccines and anthelminthic, but were not neutered until the end of the study. This allowed evaluation of the effects of these animals on colony population dynamics.

Cats in two of the three original control colonies (C1and C3) were trapped for neutering (males castrated and females spayed) at the end of the initial two-year follow-up period, and were then evaluated as spay/castration colonies for an additional two years, for a total of 4 years of follow-up. The caretaker of C3 declined neutering in 2000, and colony continued as a reproductively intact control until 2002. The fourth (C4) and fifth (C5) control colonies, enrolled in 2001, were followed for slightly less than 2 years (20 and 19 months, respectively) before trapping and neutering. The original castration (SC1-SC3) and vasectomy (SV1-SV3) colonies were followed four years. A single follow-up visit was made to 10 of the 11 colonies in June 2005 (approximately 7 years after enrollment) and census information was collected by combination of caretaker interview and visual observation. One colony (C5) was lost to follow-up at that time because of caretaker non-compliance.

A standard staggered-entry design was used, with the date of cat enrollment in the study set as day zero, and end-points recorded whenever cats disappeared from colonies and emigration could not be differentiated from death, or were right-censored at the end of the two-year follow-up period (730 days) or the four-year follow-up period (1460 days) for each colony. When the exact event date was not available, it was estimated as the date midway between the final observation of cat presence in the colony and the subsequent observation when the cat was noted as absent.

Statistical Analysis

Size and composition of colonies at enrollment were compared using the Kruskal-Wallis test, with an alpha value of 0.05 considered significant. Incidence densities and 95% confidence intervals were used to compare immigrations and causes of death for males and females by colony treatment (control, spay/castration, spay/vasectomy), and calculations were made using computer software (EpiCalc2000, version 1.02). To evaluate the effects of different treatments on colony dynamics the Kaplan-Meier product limit estimates of the survivor function were generated, using the length of colony residence in days as the time to event (Lee & Wang 2003). All survival calculations were made with a statistical software package (StatView® 5). Males and females were considered separately, and then compared by colony treatment using Peto and Peto's generalized Wilcoxon test for K-samples with censored data and an alpha-value of 0.05 (Lee & Wang 2003). In an attempt to differentiate death from emigration, the outcomes for uncensored observations were categorized as either dead or disappeared, and then survival times were compared within sex and treatment as above.

Incidence density, a basic epidemiologic rate of the number of occurrences of a given event per unit time, were calculated for immigration events per colony and final outcomes (disappearance, death, etc.) for individual cats split by sex and treatment. Incidence density ratios (rate ratio) and 95% confidence intervals were used to compare the occurrences of events between or among groups. When the confidence interval of a rate ratio includes 1, there is no significant difference between the rates being compared (Rothman & Greenland 1998).

Results

Initial Colony Sizes and Composition

From May 1998 through October 2002, 344 cats (167 female, 177 male) were enrolled in the study. Initial colony sizes ranged from 10 to 27 with a mean of 13 $\pm$ SD 6 cats per colony (see Table 1 for information by colony). Compositions were similar, with more females than males in all but one colony (SV3). The ratio of males to females ranged from 1:0.43 to 1:4 with a median of 1:1.4.

Recruitment

In the course of the study, 302 kittens were recorded in the research colonies. Some kittens were born into SC or SV colonies during the initial enrollment period prior to completion of surgical intervention. In 1999, kittens were born only in control colonies, but in 2000 an immigrant female in SV3 also produced a single litter of 5 kittens. An intact immigrant male had also joined the same colony and was presumed to have sired the kittens. From 2000-2002, evasive cats in SV3 and in C1 (which had been neutered in 2000) continued to breed. All breeding cats in SV3 were trapped and neutered in late 2002 and early 2003, but some breeding cats remained in C1 in 2005. At the end of follow-up in 2002, one female remained persistently trap-shy in C4. No kittens were produced in 2003, presumably due to lack of an intact male in the colony. One litter of unrecorded size was produced in 2004, with two kittens (1 male, 1 female) recruited. As of June 2005, the original intact female produced a litter of 3 kittens, and the recruited female also produced a litter of 3 kittens. One hundred forty-seven of 302 kittens (48.7%) survived to 6 months of age. Detailed survival analysis for a subset of 171 of these kittens has been presented elsewhere (see Chapter 5, Nutter 2004a).

Immigration and Emigration

Intact immigrant male and female cats were observed in all treatment groups (Table 2). There were no significant differences ($p>0.05$) in the rates of male or female immigration among colony treatments. All immigrant females (n=9) were abandoned at the colony sites, while 5 of 27 males were abandoned and 1 was introduced to the colony (C2) by the caretaker. Immigrations occurred in all months of the year (Figure 1).

For the survival analyses comparing cats categorized as confirmed dead versus disappeared, there were no survival times exceeding two years for intact males or females, or vasectomized males, so the two-year survival times were used. There were several spayed females for which survival exceeded two years, so the four-year survival times were used. The median survival times at 2-years for intact and vasectomized males were not significantly different and so they were pooled into one group of hormonally-intact males and then split into categories for dead (n=26) and disappeared (n=38). The median survival time for the dead category (114 days, 10%=29 days, 90%=349 days) did not differ (p=0.07) to the disappeared category (215 days, 10%=58 days, 90%=589 days). For castrated males, median survival for 15 cats confirmed dead (243 days, 10%=41 days, 90%=436 days) was the same (p=0.65) as that for 16 cats that disappeared (217 days, 10%=68 days, 90%=520 days). For intact female cats, median survival for 14 cats confirmed dead (169 days, 10%=13 days, 90%=511 days) was not significantly different (p=0.31) from the median survival for the 18 cats that disappeared (90 days, 10%=4 days, 90%=590 days). For spayed females, the median survival time of 254 days (10%=21 days, 90%=702 days) for 10 cats confirmed dead was not significantly different (p=0.12) from the median survival time of 568 days (10%=42 days, 90%=820 days) for 19 cats that disappeared.

Survival at Two Years

Median 2-year survival time for males in control colonies was 267 days (range 5-723 days, 10%=41 days, 90%=646 days), and did not differ statistically (p=0.65) from that of vasectomized males (median 265 days, range 21 to >730 days, 10%=29 days, 90%=>730 days). Survival times of control and vasectomized males (both groups hormonally intact) were then pooled (n=103, 34 censored observations) and compared to those for castrated males (n=74, 43 censored observations). Kaplan-Meier estimates

(Figure 2) of survival for hormonally intact males versus castrated males were significantly different (p=0.0001). More than 50% of castrated male cats remained in their colonies at the end of the 2-year period, thus median survival time exceeded 730 days and could not be determined (range 3 to >730 days, 10%=61 days, 90%=>730 days). Hormonally intact males had a median survival of 282 days (range 5->730 days, 10%=41 days, 90%=723 days).

The survival times of spayed females did not differ for those in colonies with castrated versus vasectomized males (p=0.444; spay/castration range 14 to >730 days, 10%=234 days, 90%=>730 days; spay/vasectomy range 24 to >730 days, 10%=32 days, 90%>730 days). Survival times for all spayed females were pooled (n=85, 56 censored observations), and compared to those for intact control females (n=82, 47 censored observations). Estimates of female survival (Figure 3) were significantly different between treatments (p=0.001), with females in control colonies having median survival times of 593 days (range 3 to >730 days; 10%=38 days, 90%>730 days). The majority of spayed females survived beyond the 2-year follow-up period, and their median survival times were thus greater than 730 days and could not be determined (range 14->730 days, 10%=234 days, 90%>730 days).

Survival at Four Years

No intact males had survival times greater than 730 days, and only 4 vasectomized males survived more than 730 days. Of those, 2 were censored at 1460 days. Based on the event times for the remaining two vasectomized males, the median four-year survival was 951 days. Percentiles could not be determined due to the small number of cats evaluated. Twenty-two castrated males (18 censored observations) were evaluated and the median survival time could not be determined since the majority survived beyond 1460 days (10%=991 days, 90%>1460 days). Statistical comparisons between treatments were not reliable because of the small sample size for vasectomized males.

Six intact females were eligible for analysis, but all observations were censored and estimation of survival was not possible. Thirty-nine spayed females were evaluated (35 censored observations), but median survival was not determined because the majority survived beyond 1460 days (10%=918 days, 90%.1460 days). No statistical comparisons between treatments were possible due to the lack of events for intact females. Four-year census data were not available for C4 and C5, which were enrolled in 2001 and neutered in late 2002 and early 2003, at the end of the intensive follow-up portion of the project.

Changes in Colony Size and Composition

Changes in colony and composition (Table 1) and sizes (Table 3) are compared at entry and after two, four and seven years years of follow-up, and are shown as a percentage change in Table 4. The dynamic fluctuations in colony sizes over time are not reflected at the discrete time points, so they are shown for control colonies in Figure 4 and for surgically sterilized colonies in Figure 5. Over two years, the population of control colonies increased to 124% ± 61% (mean ± SD) of the original size, while vasectomy colonies decreased to 53% ± 21% (mean ± SD) and castration colonies to 70% ± 26% of the original size. One control colony (C3) remained reproductively intact for four years, during which it declined to 30% of its original size at two years, and then recovered to 140% of original size by four years, before finally peaking at 220% original size at 4.5 years. At the final post-neutering time-point evaluated (C5 lost to follow-up) all colonies had decreased from their peak sizes, and 8 of 10 had decreased from their entry sizes.

At the two-year and four-year follow-up points, castration and vasectomy colonies consisted predominantly of cats that were present at the outset of the study, while control colonies contained predominantly new cats, the majority were recruits that were born into the colonies and enrolled at six months of age. Composition data were not available for all colonies in 2005, but the majority of cats in neutered colonies were original colony members.

2005 Follow-up

A point-check of colonies was conducted in June 2005, and the specific follow-up time in months for each colony is presented in Table 3 as 7 year follow-up, but varies from 6.8 to 7.1 years of follow-up because of the staggered entry design. Colony size and, in some cases, composition were available but Kaplan-Meier estimates could not be calculated using this data since event time information was not available for individual cats missing from the colonies or entry dates for immigrants and recruits. Narrative accounts for each colony are presented below.

<u>C1</u>: Two trap-shy females remained intact after the remainder of the colony was neutered in 2000. These females and eventually their offspring continued to breed with immigrant male cats, and colony size continued to increase, to a recorded peak of 39 at

51 months follow-up. By June 2005, the number of neutered cats had declined to 22 (from 29 in 2002), with 8 intact cats, for a total colony size of 30. Trapping efforts continue for the intact cats.

C2: The size and composition of the colony were unchanged from 2002.

C3: In 2000 the caretaker declined to have the colony, which had declined to 3 cats, neutered. By 2002 the colony had grown to 14 enrolled cats, which were neutered in 2002. At that time, there were 11 kittens present. Colony size peaked at 22 in January/February 2003 as 8 of 11 (72%) kittens were recruited and subsequently neutered. Colony size in June 2005 was 17, which was a 21% increase from 2002, but was also a 23% decrease from the maximum colony size.

C4: At the end of 4-year follow-up in 2002, one female remained persistently trap-shy. No kittens were produced in 2003, presumably due to lack of an intact male in the colony. One litter of unrecorded size was produced in 2004, with two kittens (1 male, 1 female) recruited. As of June 2005, the original intact female produced a litter of 3 kittens, and the recruited female also produced a litter of 3 kittens. Due to deaths and disappearances of other colony members, the number of adult cats has decreased to 16 from the 2002 pre-neutering peak of 20, a reduction of 20%. Trapping efforts continue for the intact cats.

C5: Lost to follow-up due to caretaker non-compliance.

SC1: Five cats (3 male, 2 female) were killed by a neighbor's free-roaming dogs in late 2004 and early 2005. Three cats (1 male, 2 female) remain, and all are original colony members.

<u>SC2</u>: The caretaker reported that 4 original cats (1 male, 3 females) disappeared during a 2-3 week period in the spring of 2003, and the caretaker suspects poisoning or predation. Eight additional cats have died or disappeared between 2002 and 2005, but the caretaker had no specific information about them. A new intact male cat was abandoned at the colony site (a stable) in the spring of 2005.

<u>SC3</u>: In June 2005 the colony consisted of one neutered female, who was present at the beginning of the study and is reliably estimated by the caretakers to be nine years old. One immigrant male (neutered) who was present in 2002 was displaced by an intact immigrant male in 2003, and the second immigrant male subsequently disappeared in early 2005. The caretaker reports that transient cats are occasionally noted, but suspects that many are owned cats from the neighborhood with variable outdoor access.

<u>SV1</u>: Colony extinct since April 2001.

<u>SV2</u>: Three of the formerly feral cats (1 male, 2 female) became inside-only cats when the caretaker’s indoor cats died. Another former feral (female) became an inside/outside cat. Four cats (1 original female and 3 immigrant males) were euthanized between January 2003 and August 2004 due to chronic debilitating health problems. In June 2005 the colony consisted of one neutered female, who was present at the beginning of the study, and one neutered immigrant male. The caretaker reported that several other immigrant cats had come and gone between 2002 and 2005.

<u>SV3</u>: The colony size was stable at 5 between 2002 and 2005, but 1 original female cat died in April 2005 and the lone remaining vasectomized male disappeared in early 2005 (the caretaker suspects he moved to a neighbor’s house where there are intact female cats). In May 2005 the caretaker added 2 “rescued” cats (both young males) that

she obtained when they were surrendered to the local veterinarian's office where she works. One remaining original female is reliably estimated at between 11 and 12 years of age, and the other 2 cats are castrated males recruited in 2001.

Outcomes and Cause-specific Mortality

Disappearance from the colony and death from trauma were the two most common fates for adult cats (Table 5). Three male cats disappeared with prior signs of illness, one each from the three treatment groups, and two male cats disappeared with signs of injury, one each from a control and spay/vasectomy colony. Most fatal traumatic injuries were the result of vehicle collisions (22 of 33 males, 8 of 14 females) or dog attacks (8 of 33 males, 5 of 14 females). Rate ratios (Table 6) were compared for each sex, by treatment, for the three most common outcomes – disappearance, death caused by vehicle collision, or death caused by dog attack. Intact and vasectomized males were approximately 4 times more likely to disappear from colonies than were castrated males, and vasectomized males were approximately 4 times more likely to be killed by a vehicle than castrated males. There was no significant difference between deaths due to vehicle collision or dog attack for intact or castrated males; no deaths due to dog attack were recorded for vasectomized males and thus no comparisons were possible. Intact females were twice as likely to disappear from colonies as spayed females, and 6.75 times more likely to be killed by a vehicle. There was no difference between intact and spayed females in deaths from dog attack.

Discussion

Managing feral cat colonies by either castrating or vasectomizing males and spaying females resulted in population decreases over the study period, while the control colonies increased during the time they were reproductively intact. One sterilized colony (SV 1) was extinct by the 31 months follow-up visit, and 5 other colonies (SC1, SC3, SV2, SV3, and C2, which was sterilized in 2000) contained 5 or fewer cats by June 2005. All sterilized colonies showed consistent decreases from their peak sizes, and 8 of 10 observed in 2005 had decreased from their entry size. The experimental design used was strict trap-neuter-return, with no removal of sociable and potentially adoptable kittens or adult cats. In reality most programs implement a combination of trap-neuter-return and trap and removal for adoption, which can cause more rapid declines in feral cat colonies (Centonze & Levy 2002; Levy & Crawford 2004; Levy et al. 2003). The efficacy of combining control techniques is recognized in other species (Barlow et al. 1997; Tuyttens & Macdonald 1998) and is an area for further investigation with feral cats.

Colony sizes fluctuated during the follow-up period, due predominantly to reproduction and recruitment in control colonies, and immigration in sterilized colonies. Intact trap-shy cats continued to breed in two former control colonies, and intact immigrant cats bred in a spay/vasectomy colony. In one of the former control colonies (C1) breeding and recruitment caused a steady increase in colony size even though only 2 of 9 females remained intact but continued trapping efforts and attrition of neutered cats have succeeded in mitigating the impact, and the colony is declining in size. The example of C3, the control colony that declined to 30% of entry size after 2 years and rebounded to 733% of that nadir by 4 years, illustrates how quickly feral cat populations can recover after crashes or incomplete removal. Leaving a few intact cats at a colony site after a lethal or non-lethal control effort can result in rapid repopulation. Density-dependent changes in reproductive parameters have been described for other species, and included changes in litter size and number per year, increased recruitment, decreased age at first reproduction, increased survival, and increased immigration (Sinclair 1989; Tuyttens & Macdonald 1998; Twigg et al. 2000). These processes can potentially overwhelm the effects of fertility control, but can also be difficult to demonstrate. Breeding females in C1 and C3 produced 1-2 litters per year, and kitten survival was within the range previously reported (Nutter et al. 2004b). Availability of abundant food and shelter at feral cat colony sites likely removes some of the factors that limit reproduction for other wildlife, and thus reproduction in feral cat colonies may already be near upper limits for the species.

Immigrant cats were observed in all treatment groups and at all times of the year. Most immigrants were intact males, less than a quarter of which were known to have been abandoned at the colony sites. This history contrasts that of female immigrants, all of whom were abandoned or dumped at colony sites, two accompanied by kittens. The role of abandonment in the formation and maintenance of feral cat colonies has been noted previously, particularly for colonies located on public lands where the management efforts are highly visible (Castillo & Clarke 2003; Levy & Crawford 2004; Natoli & De Vito 1991; Passanisi & Macdonald 1990; Tabor 1983; Zaunbrecher & Smith 1993).

Though the project was not specifically designed to find cats that emigrated, emigration was anecdotally confirmed for cats from two different control colonies. In 2002 an adult male, gravid female, and 5 juvenile and young adult (3 male, 2 females) cats from C3 moved to a house across the street from the original colony site. The male moved in April, while the remainder moved in July. The gravid female emigrated one day prior to parturition, which suggests the move may have been motivated at least in part by the search for a good queening site. Quality of queening sites can influence reproductive success through protection from predation, easy access to food, and shared care of young (Liberg et al. 2000; Macdonald et al. 1987). All emigrating cats, except the adult male, were from the same matriline. The homeowner at the new site provided food outside for a pet cat with outdoor access, and increased the food supply when the emigrants arrived, but declined to participate in the study. A single male and a single female cat from C1 also emigrated together and were fed and sheltered by another homeowner not participating in this study. All observed dispersal events occurred in intact control colonies with approximately equal numbers of males (n=5) and females (n=4).

The median survival times for cats that were confirmed dead and for those that disappeared did not differ for any of the sex/treatment groups and, thus, disappearance provided no clues regarding emigration. The rationale for this analysis was based on the possibility that individuals in the "disappeared" category could have either died and not been recovered or emigrated. Assuming cats that disappeared had the same survival probability as cats that died, and that dispersal tends to occur more at certain ages (juvenile/young adult), the survival times for the two categories would be the same only if there were no significant emigration. Similar analysis has been used previously to detect emigration, based on differential survival between “dead” and “disappeared” categories (Devillard et al. 2003), but using a larger data set. With a larger sample size, the analysis for the pooled intact and vasecotmized males may have detected a significant difference, which would support male dispersal. This is the expected strategy for community-living feral cats with either polygynous or promiscuous mating systems (Devillard et al. 2003; Devillard et al. 2004; Dobson 1982; Greenwood 1980). Recent research has demonstrated the behavioral diversity of group-living feral cats, and examples of both male and female biased dispersal, as well as minimal dispersal of either sex, have been described. (Devillard et al. 2003; Kaeuffer et al. 2004; Natoli 1990; Say et al. 2003; Say et al. 2002) The predominance of male immigrants joining colonies supports the prediction of male-biased dispersal, but the observed emigrations contradict the same prediction. It is possible that both observations are valid and reflect existing diversity among different feral cat social groups in the same geographic area. Once again, a larger dataset would help clarify the processes at work. What is clear is that emigrating cats, whether intact or neutered, can join existing colonies (where they appear as immigrants) or serve as sources for new colony establishment if suitable food and shelter resources are found.

Surgically sterilized colonies were stable in composition, with populations at the end of the study period composed mainly of cats that were colony members at the outset. In control colonies, the majority of cats present at the end of the study were born into the colonies, with original members having died or disappeared from the populations. Castration of males reduces roaming, fighting, and urine marking (Hart 1973, 1981;

Macdonald et al. 1998), and sterilization of male and female feral cats increase the cats' tolerance for each other and their friendliness towards humans (Castillo & Clarke 2003; Neville & Remfry 1984; Passanisi & Macdonald 1990; Rees 1981). These behavioral changes, along with the presence of abundant food and shelter, likely contributed to the success of immigrant cats in all types of colonies. The increased friendliness towards human caretakers following sterilization certainly affected the decision of SV2's caretaker to adopt some of the colony cats once space became available in her house. Tubal ligations and vasectiomies have been used in other species to avoid such behavioral changes, since maintenance of normal ranging behaviors, territory defense and social hierarchies are considered integral to the success of fertility control schemes in wildlife (Bromley & Gese 2001a, b; Ramsey 2005; Saunders et al. 2002; Tuyttens & Macdonald 1998). The early literature on surgical sterilization of feral cats cited aggressive territory defense as one of the benefits, with the assumption that neutered cats would exclude immigrants. That may not be desirable in the case of managed feral cat colonies, where the exclusion of cats attempting immigration may just lead to the establishment of colonies elsewhere where they may not be managed. When neutered cats allow immigrant cats to join colonies, the new cats are subject to trap-neuter-return management, which is a preferable outcome.

Castrated male and spayed female cats survived significantly longer than did their reproductively (intact males and females) or hormonally (vasectomized males) intact counterparts. Neutering has long been recognized to increase survival in domestic cats due in part to reductions in illnesses (e.g. pyometra, dystocia) and injuries (e.g. fight wounds) associated with reproduction, as well as to elimination of the metabolic demands of gestation and lactation (Hamilton 1965; Hamilton et al. 1969; Kraft & Danckert 1997; Passanisi & Macdonald 1990; Tabor 1989). Fertility control has also increased lifespan in other wildlife (Ramsey 2005; Saunders et al. 2002; Tuyttens & Macdonald 1998; Twigg et al. 2000). Increased survival of sterilized animals could have unwanted results since colonies will likely persist longer and cats may continue, or if fecundity increases in any remaining intact animals due to release of density-dependent inhibitors. However, since breeding females and younger cats are more active and efficient hunters, the continued presence of sterilized aging cats may actually reduce predation (Bromley & Gese 2001b; Deag et al. 2000; Fitzgerald & Turner 2000; Nutter et al. 2004a).

Vasectomized male cats showed no advantage over castrated male cats in stabilizing colony populations. Vasectomized male cats had colony residence times that were similar to those of intact male cats, which were significantly shorter than those of castrated male cats. Because vasectomized male cats are hormonally intact, they may be leaving colonies with spayed females in search of reproductively intact and responsive females. During the study period multiple anecdotal observations of vasectomized males attempting to force copulation with spayed, anestrus females support this hypothesis. The more time consuming and less commonly performed vasectomy surgery did not provide a benefit related to either colony size reduction or stability comparing to sterilizing male cats by castration. I see no reason to substitute vasectomies for castrations in trap/neuter/return programs was identified.

I collected information to maximize the number of colonies included in the study but this limited my time to watch individual animals closely. My data had greater breadth of observation but limited depth for individual cats. Much of the data on suspected or confirmed causes of death came from caretaker reports. Traumatic causes of death were often observed by the caretakers or confirmed by post-mortem examination. Vehicle collisions were the most common causes of death and are a major cause of mortality in free-roaming cats (Childs & Ross 1986; Kolata et al. 1974; Rochlitz 2003a, b; Warner 1985). Vasectomized males cats in this study were significantly more likely to be killed by a vehicle than either intact or castrated males. This is likely due to their wider ranging (larger home ranges and greater average distances from the feeding site), which I believe is related to the lack of breeding females in their home colonies and a search for breeding females elsewhere. Higher risks of death from vehicle collisions have previously been reported for male cats (Childs & Ross 1986; Kolata et al. 1974; Rochlitz 2003a, b). Intact female cats in this study were also significantly more likely to die from vehicle collisions than spayed females (IDR=6.75), which has not been previously reported. Because intact and spayed females had similarly sized home ranges, the explanation I proposed for the difference in male deaths due to vehicle collision doesn't hold. Both of these findings may also be related to the ages of the cats. Though exact ages for most of the cats were not known, the significantly shorter survival times of intact cats relative to neutered cats suggests a different age structure between the two populations. It's possible that younger, more inexperienced cats are at greater risk of death caused by vehicles, but the data set did not permit specific evaluation of this hypothesis. Dog attacks, by stray dogs as well as dogs owned by caretakers, were the other major cause of fatal traumatic injuries and have also been previously reported as major causes of death for feral and free-roaming cats

(Hughes & Slater 2002; Warner 1985; Wolski 1981). The findings related to deaths by vehicle collisions and dog attacks may also be related to relatively small sample size and inherent detection error in the data. It's likely that both vehicle collisions and dog attacks as causes of death were more commonly detected in this study because associated noise or graphic visual evidence of mortality is likely to draw attention. Cats that become debilitated often seek resting and hiding places, and observations of deaths from illness or disease are likely negatively biased.

The trauma sustained by some of the cats as a result of the identification collars was unfortunate but not completely unexpected. Collar design is a difficult part of any wildlife ecology study and despite three months of testing on free-roaming owned cats, the nylon collars proved unsuitable for feral cats. The nylon collars examined after removal showed evidence of excessive fraying and wear, which led to constriction of the fabric and tightening of the collars around the cats' necks. Much of the fraying appeared to be due to scratching by the cats, probably in response to fleas or ear mites. These parasites were controlled in the owned test cats. Minor complications were initially encountered with the plastic tubing collars, but ceased once experience was gained fitting the collars. Complications for the nylon collars occurred in 10% of cats within four weeks, while complications for the plastic tubing collars occurred in only 2% of cats during the four-year study. Much higher rates of collar-related morbidity and mortality have been reported for other species, with 25% morbidity (Harker et al. 1999) and 5% mortality (Bond et al. 2000) acceptable to some researchers. We designed the collars employed in this project with a goal of 1% or less morbidity and mortality, and the plastic tubing collars approached that benchmark. Zero morbidity and mortality remain the target, but may be difficult to realize when collaring gregarious specious over long time periods. It's important to report collar design and complications encountered, so that designs can be refined and reduced morbidity and mortality achieved.

As expected, the variability among colonies in some parameters examined was large, validating the need for research of this nature to study multiple colonies over time. Many uncontrolled variables contributed to colony diversity, and results from observations of a single colony, even over time, could be misleading. Every reasonable effort was made to standardize the colonies as much as possible, by defining requirements for location, initial minimum population size, shelter, food and water provision, and caretaker involvement. Minimum numbers of male cats were also required since surgical intervention strategies were being compared. However, we could not control the exact male to female ratio, age structure, or familial relationships of the cats, all of which may have played roles in the dynamics of individual colonies. Having replicates within each treatment was extremely important. One of our control colonies decreased in population during the study period. Had we studied only this control colony, we would have been unable to report the trend for population growth shown by the other control colonies and our conclusions would have been different. For the main goals of this project, to evaluate the effects of surgical sterilization on feral cat population size and to compare male neutering techniques, the cohort definition was successful. The study occurred under potential population growth conditions, as evidenced by the average population increases of control colonies, and we were able to show a significant impact of surgical sterilization on feral cat populations.

Surgical sterilization can be used to manage feral cat populations, and the stated goals of trap-neuter-return programs - namely to reduce or eliminate reproduction, stabilize colony composition and cause natural attrition and eventual extinction of colonies – are achievable. The results of surgical sterilization programs also provide data to help evaluate the efficacy of fertility control in general, regardless of how it's achieved. The American Veterinary Medical Association, American Humane Association, Cat Fanciers Association, and Humane Society of the United States have all publicly supported the use of TNR as a humane alternative to trapping and euthanasia or other lethal control measures, and though other organizations such as The Wildlife Society, the National Audobon Society and the American Association of Wildlife Veterinarians are opposed trap-neuter-return, common ground is recognized in the shared objective of fewer feral cats. Until advances in fertility control offer more reliable, easily implemented and cost-effective alternatives to lethal feral cat control, surgical sterilization remains a viable management strategy.

References

Barlow, N. D., J. M. Kean, and C. J. Briggs. 1997. Modelling the relative efficacy of culling and sterilisation for controlling populations. *Wildlife Research* **24**:129-141.

Bond, B. T., J. L. Bowman, B. D. Leopold, et al. 2000. An improved radiocollar for eastern cottontail rabbits. *Wildlife Society Bulletin* **28**.

Bromley, C., and E. M. Gese. 2001a. Effects of sterilization on territory fidelity and maintenance, pair bonds, and survival rates of free-ranging coyotes. *Canadian Journal of Zoology* **79**:386-392.

Bromley, C., and E. M. Gese. 2001b. Surigical sterilization as a method of reducing coyote predation on domestic sheep. *Journal of Wildlife Management* **65**:510-519.

Castillo, D., and A. L. Clarke. 2003. Trap/neuter/release methods ineffective in controlling domestic cat "colonies" on public lands. *Natural Areas Journal* **23**:247-253.

Centonze, L. A., and J. K. Levy. 2002. Characteristics of free-roaming cats and their caretakers. *Journal of the American Veterinary Medical Association* **220**:1627-1633.

Childs, J. E., and L. Ross. 1986. Urban cats: characteristics and estimation of mortality due to motor vehicles. *American Journal of Veterinary Research* **47**:1643-1648.

Cuffe, D. J., J. E. Eachus, O. F. Jackson, P. F. Neville, and J. Remfry. 1983. Ear-tipping for identification of neutered feral cats. *Veterinary Record* **112**:129.

Deag, J. M., A. Manning, and C. E. Lawrence. 2000. Factors influencing the mother-kitten relationship. Pages 23-46 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Devillard, S., L. Say, and D. Pontier. 2003. Dispersal pattern of domestic cats (*Felis catus*) in a promiscuous urban population: Do females disperse or die? *Journal of Animal Ecology* **72**:203-211.

Devillard, S., L. Say, and D. Pontier. 2004. Molecular and behavioural analyses reveal male-biased dispersal between social groups of domestic cats. *Ecoscience* **11**:175-180.

Dobson, F. S. 1982. Competition for mates and predominant juvenile male dispersal in mammals. *Animal Behaviour* **30**:1183-1192.

Fitzgerald, B. M., and D. C. Turner. 2000. Hunting behaviour of domestic cats and their impact on prey populations. Pages 151-176 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the biology of its behaviour*. Cambridge University Press, Cambridge, UK.

Greenwood, P. J. 1980. Mating systems, philopatry and dispersal in birds and mammals. *Animal Behaviour* **28**:1140-1162.

Hamilton, J. B. 1965. Relationship of castration, spaying, and sex to survival and duration of life in domestic cats. *Journal of Gerontology* **20**:96-104.

Hamilton, J. B., R. S. Hamilton, and G. E. Mestler. 1969. Duration of life and causes of death in domestic cats: influence of sex, gonadectomy, and inbreeding. *Journal of Gerontology* **24**:427-437.

Harker, M. B., G. B. Rathbun, and C. A. Langtimm. 1999. Beaded-chain collars: a new method to radiotag kangaroo rats for short-term studies. *Wildlife Society Bulletin* **27**:314-317.

Hart, B. L. 1973. Behavioral effects of castration. *Feline Practice* **3**:10-12.

Hart, B. L. 1981. Effects of neutering and spaying on the behavior of dogs and cats: questions and answers about practical concerns. *Journal of the American Veterinary Medical Association* **198**:1204.

Herron, M. A., and M. R. Herron. 1972. Vasectomy in the cat. *Modern Veterinary Practice* **53**:41-43.

Hughes, K. L., and M. R. Slater. 2002. Implementation of a feral cat management program on a university campus. *Journal of Applied Animal Welfare Science* **5**:15-28.

Kaeuffer, R., D. Pontier, S. Devillard, and N. Perrin. 2004. Effective size of two feral domestic cat populations (*Felis catus* L): effect of the mating system. *Molecular Ecology* **13**:483-490.

Kolata, R. J., N. H. Kraut, and D. E. Johnston. 1974. Patterns of trauma in urban dogs and cats: a study of 1000 cases. *Journal of the American Veterinary Medical Association* **164**:499-502.

Kraft, W., and D. Danckert. 1997. Development of life span in a cat population. *Kleintierpraxis* **42**:21-28.

Krzaczynski, J. 1974. The flank approach to feline ovariohysterectomy. *Veterinary Medicine and Small Animal Clinician* **69**:572.

Lee, E. T., and J. W. Wang 2003. *Statistical methods for survival data analysis*. John Wiley and Sons, New York.

Levy, J. K., and P. C. Crawford. 2004. Humane strategies for controlling feral cat populations. *Journal of the American Veterinary Medical Association* **225**:1354-1360.

Levy, J. K., D. W. Gale, and L. A. Gale. 2003. Evaluation of the effect of a long-term trap-neuter-return and adoption program on a free-roaming cat population. *Journal of the American Veterinary Medical Association* **222**:42-46.

Liberg, O., M. Sandell, D. Pontier, and E. Natoli. 2000. Density, spatial organisation and reproductive tactics in the domestic cat and other felids. Pages 119-147 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Macdonald, D. W., P. Apps, G. M. Carr, and G. Kerby. 1987. Social dynamics, nursing coalitions and infanticide among farm cats, *Felis catus*. *Advances in Ethology Number 28*:1-66.

Macdonald, D. W., N. Yamaguchi, and W. C. Passanisi. 1998. The health, haematology and blood biochemistry of free-ranging farm cats in relation to social status. *Animal Welfare* **7**:243-256.

Natoli, E. 1990. Mating strategies in cats: a comparison of the role and importance of infanticide in domestic cats, *Felis catus* L., and lions, *Panthera leo* L. *Animal Behaviour* **40**:183-186.

Natoli, E., and E. De Vito. 1991. Agonistic behavior, dominance rank and copulatory success in a large multi-male feral cat, *Felis catus* L., colony in central Rome. *Animal Behaviour* **42**:227-242.

Neville, P. F., and J. Remfry. 1984. Effect of neutering on two groups of feral cats. *Veterinary Record* **114**:447-450.

Nutter, F. B., J. P. Dubey, J. F. Levine, E. B. Breitschwerdt, R. B. Ford, and M. K. Stoskopf. 2004a. Seroprevalences of antibodies against Bartonella henselae and Toxoplasma gondii and fecal shedding of Cryptosporidium spp, Giardia spp, and Toxocara cati in feral and pet domestic cats. *Journal of the American Veterinary Medical Association* **225**:1394-1398.

Nutter, F. B., J. F. Levine, and M. K. Stoskopf. 2004b. Reproductive capacity of free-roaming domestic cats and kitten survival rate. *Journal of the American Veterinary Medical Association* **225**:1399-1402.

Nutter, F. B., M. K. Stoskopf, and J. F. Levine. 2004c. Time and financial costs of programs for live trapping feral cats. *Journal of the American Veterinary Medical Association* **225**:1403-1405.

Passanisi, W. C., and D. W. Macdonald 1990. *The Fate of Controlled Feral Cat Colonies*. Universities Federation for Animal Welfare, Hertfordshire, Potters Bar, UK.

Patronek, G. J. 1998. Free-roaming and feral cats--their impact on wildlife and human beings. *Journal of the American Veterinary Medical Association* **212**:218-226.

Ramsey, D. 2005. Population dynamics of brushtail possum subject to fertility control. *Journal of Applied Ecology* **42**:348-360.

Rees, P. 1981. The ecological distribution of feral cats and the effects of neutering a hospital colony. Pages 12-22. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Potters Bar, Hertfordshire, UK.

Rochlitz, I. 2003a. Study of factors that may predispose domestic cats to road traffic accidents: part 1. *Veterinary Record* **153**:549-553.

Rochlitz, I. 2003b. Study of factors that may predispose domestic cats to road traffic accidents: part 2. *Veterinary Record* **153**:585-588.

Rothman, K. J., and S. Greenland 1998. *Modern Epidemiology*. Lippincott-Raven, Philadelphia, Pennsylvania, USA.

Saunders, G., J. Mcilroy, M. Berghout, B. Kay, E. Gifford, R. Perry, and R. van de Ven. 2002. The effects of induced sterility on the territorial behavior and survival of foxes. *Journal of Applied Ecology* **39**:56-66.

Say, L., F. Bonhomme, E. Desmarais, and D. Pontier. 2003. Microspatial genetic heterogeneity and gene flow in stray cats (*Felis catus* L.): a comparison of coat colour and microsatellite loci. *Molecular Ecology* **12**:1669-1674.

Say, L., S. Devillard, E. Natoli, and D. Pontier. 2002. The mating system of feral cats (*Felis catus* L.) in a sub-Antarctic environment. *Polar Biology* **25**:838-842.

Sinclair, A. R. 1989. Population regulation in animals. Pages 197-241 in J. M. Cherrett, editor. *Ecological Concepts*. Blackwell Scientific Publications, Oxford, UK.

Slater, M. R. 2002. *Community Approaches to Feral Cats: Problems, Alternatives, and Recommendations.* Humane Society Press, Washington, D.C., USA.

Tabor, R. 1983. *The Wild Life of the Domestic Cat*. Arrow Books Limited, London.

Tabor, R. 1989. The changing life of feral cats (*Felis catus* L.) at home and abroad. *Zoological Journal of the Linnaean Society* **95**:151-161.

Tuyttens, F. A. M., and D. W. Macdonald. 1998. Fertility control: an option for non-lethal control of wild carnivores? *Animal Welfare* **7**:339-364.

Twigg, L. E., T. J. Lowe, G. R. Martin, A. G. Wheeler, G. S. Gray, S. L. Griffin, C. M. O'Reilly, D. J. Robinson, and P. H. Hubach. 2000. Effects of surgically imposed sterility on free-ranging rabbit populations. *Journal of Applied Ecology* **37**:16-39.

Warner, R. E. 1985. Demography and movements of free-ranging domestic cats in rural Illinois. *Journal of Wildlife Management* **49**:340-346.

Williams, L. S., J. K. Levy, S. A. Robertson, A. M. Cistola, and L. A. Centonze. 2002. Use of the anaesthetic combination of tiletamine, zolazepam, ketamine, and xylazine for neutering feral cats. *Journal of the American Veterinary Medical Association* **220**:1491-1495.

Wolski, T. R. 1981. Country cousin: the life of the barnyard cat. *Feline Health Perspectives* **3**:1-3.

Zaunbrecher, K. I., and R. E. Smith. 1993. Neutering of feral cats as an alternative to eradication programs. *Journal of the American Veterinary Medical Association* **203**:449-452.

Table 1. Composition of feral cat colonies by sex and cat source at discrete follow-up times. orig=original, rec=recruit, immig=immigrant. ‡ indicates follow-up time ranged from 6.8 to 7.1 years due to staggered entry design of the study.

COLONY		ORIGINAL	TWO-YEAR FOLLOW-UP	FOUR-YEAR FOLLOW-UP	SEVEN-YEAR FOLLOW-UP‡
C1	male	6	7 rec, 1 immig	8 rec, 4 immig	(no information)
	female	6	2 orig, 7 rec	1 orig, 17 rec, 1 immig	
C2	male	5	6 rec, 2 immig	1 rec, 1 immig	1 rec, 1 immig
	female	6	3 orig, 2 rec, 1 immig	1 orig, 1 rec	1 orig, 1 rec
C3	male	5	1 rec, 1 immig	5 rec, 1 immig	(no information)
	female	5	1 orig	1 orig, 7 rec	
C4	male	2	5 rec	(no information)	n/a
	female	8	6 orig, 2 rec		
C5	male	5	4 orig, 3 rec	(lost to follow-up)	(lost to follow-up)
	female	17	14 orig, 3 rec		
SC 1	male	11	10 orig, 1 immig	10 orig, 3 immig	6 orig, 4 immig
	female	16	12 orig	12 orig, 2 immig	6 orig
SC 2	male	5	4 orig, 1 immig	3 orig, 1 immig	1 orig
	female	7	5 orig	4 orig	2 orig
SC 3	male	5	2 orig, 1 immig	2 immig	(no males)
	female	5	1 orig	1 orig	1 orig
SV 1	male	3	1 orig	(no males)	(no males)
	female	7	2 orig	(no females)	(no females)
SV 2	male	4	1 immig	3 immig	1 immig
	female	6	6 orig	5 orig	1 orig
SV 3	male	7	2 orig, 1 immig	2 rec	2 rec, 2 immig
	female	3	2 orig, 1 immig	2 orig, 1 rec	1 orig

Table 2. Total numbers of immigrant male and female feral cats observed by treatment, incidence densities (ID) of immigration events, incidence density ratios (IDR), and 95% confidence intervals (CI).

	Immigrants	Colony-years	ID	IDR	95% CI
Males					
Control	8	11.3	0.71	0.81	0.29-2.07
Spay/Castration	14	16	0.88	1.00	--
Spay/Vasectomy	5	12	0.42	0.48	0.13-1.40
Females					
Control	5	11.3	0.44	2.36	0.46-15.20
Spay/Castration	3	16	0.19	1.00	--
Spay/Vasectomy	1	12	0.08	0.44	0.01-5.54

Table 3. Changes in feral cat colony sizes at three discrete follow-up times. * indicates times when control colonies were sterilized. † indicates follow-up time of 20 months for C4, and 19 months for C5. ‡ indicates follow-up time ranged from 6.8 to 7.1 years due to the staggered entry design of the study.

ENTRY SIZE	TWO YEAR FOLLOW-UP	FOUR-YEAR FOLLOW-UP	SEVEN YEAR FOLLOW-UP‡	PEAK SIZE
12	17*	31	30	39
11	14*	4	4	16
10	3	14*	17	22
10	20*†	16	n/a	20
22	27*†	(lost to follow-up)	(lost to follow-up)	27
27	23	27	16	27
12	10	8	3	12
10	4	3	1	11
10	3	0	0	12
10	7	8	2	12
10	6	5	5	10

Table 4: Feral cat colony size at discrete follow-up times, as a percentage of the colony size upon entry. * indicates times when control colonies were sterilized. † indicates follow-up time of 20 months for C4, and 19 months for C5. ‡ indicates follow-up time ranged from 6.8 to 7.1 years due to the staggered entry design of the study.

COLONY	% ENTRY AT TWO YEARS	% ENTRY AT FOUR YEARS	% ENTRY AT SEVEN YEARS‡	% PEAK AT FINAL END POINT
C1	142%*	182%	176%	77%
C2	127%*	36%	36%	25%
C3	30%	140%*	170%	77%
C4	200%*†	80%	n/a	80%
C5	123%*†	(lost to follow-up)	(lost to follow-up)	(lost to follow-up)
SC 1	85%	100%	59%	59%
SC 2	83%	67%	25%	25%
SC 3	40%	30%	10%	9%
SV 1	30%	0%	0%	0%
SV 2	70%	80%	20%	17%
SV 3	60%	50%	50%	50%

Table 5: Outcomes and cause-specific mortality for male and female feral cats by colony treatment.

	Male (n=100)			Female (n=64)	
	Control	**Castrated**	**Vasectomized**	**Control**	**Spayed**
Disappeared	27	16	13	18	19
Trauma					
Vehicle collision	7	8	7	6	2
Dog attack	4	4		2	3
Other trauma	3			1	
Found dead	4	6	1	3	5
Removed by caretaker					
Adopted as pet					3
Euthanized				2	
TOTAL	**45**	**34**	**21**	**32**	**32**

Table 6: Incidence densities (ID), incidence density ratios (IDR), and 95% confidence intervals (CI) for the three most common outcome events for male and female cats by treatment. Cat-years at risk by sex and treatment are indicated, and ID is standardized to a single cat-year.

			Male		
Disappeared	**n**	**cat years**	**ID**	**IDR**	**95% CI**
Castrated	16	122.62	0.130	1.00	--
Control	27	51.74	0.520	4.00	2.08-7.95
Vasectomized	13	27.10	0.480	3.69	1.63-8.15
Vehicle Collision					
Castrated	8	122.62	0.065	1.00	--
Control	7	51.74	0.135	2.07	0.64-6.54
Vasectomized	7	27.10	0.258	3.96	1.22-12.49
Dog attack					
Castrated	4	122.62	0.033	1.00	--
Control	4	51.74	0.077	2.37	0.44-12.72
Vasectomized	0	27.10	0.000	--	--

			Female		
Disappeared	**n**	**cat years**	**ID**	**IDR**	**95% CI**
Spayed	19	181.42	0.105	1.00	--
Control	18	80.63	0.223	2.13	1.06-4.29
Vehicle Collision					
Spayed	2	181.42	0.011	1.00	--
Control	6	80.63	0.074	6.75	1.21-68.38
Dog attack					
Spayed	3	181.42	0.017	1.00	--
Control	2	80.63	0.025	1.50	0.13-13.09

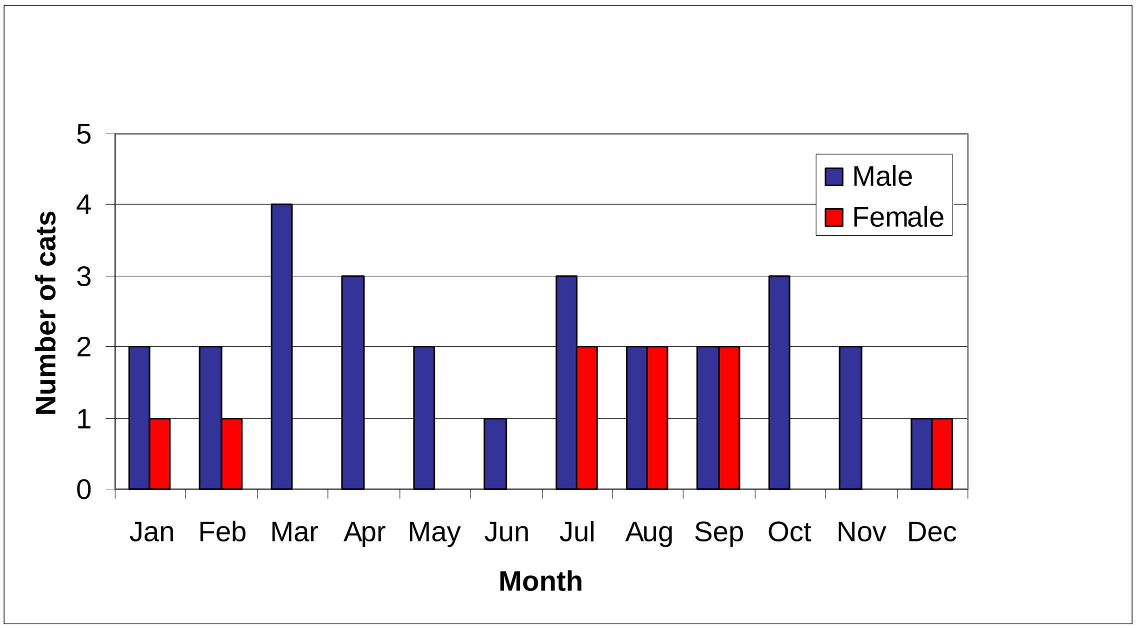

Figure 1: Total numbers of immigrant male and female feral cats observed for all colonies by month.

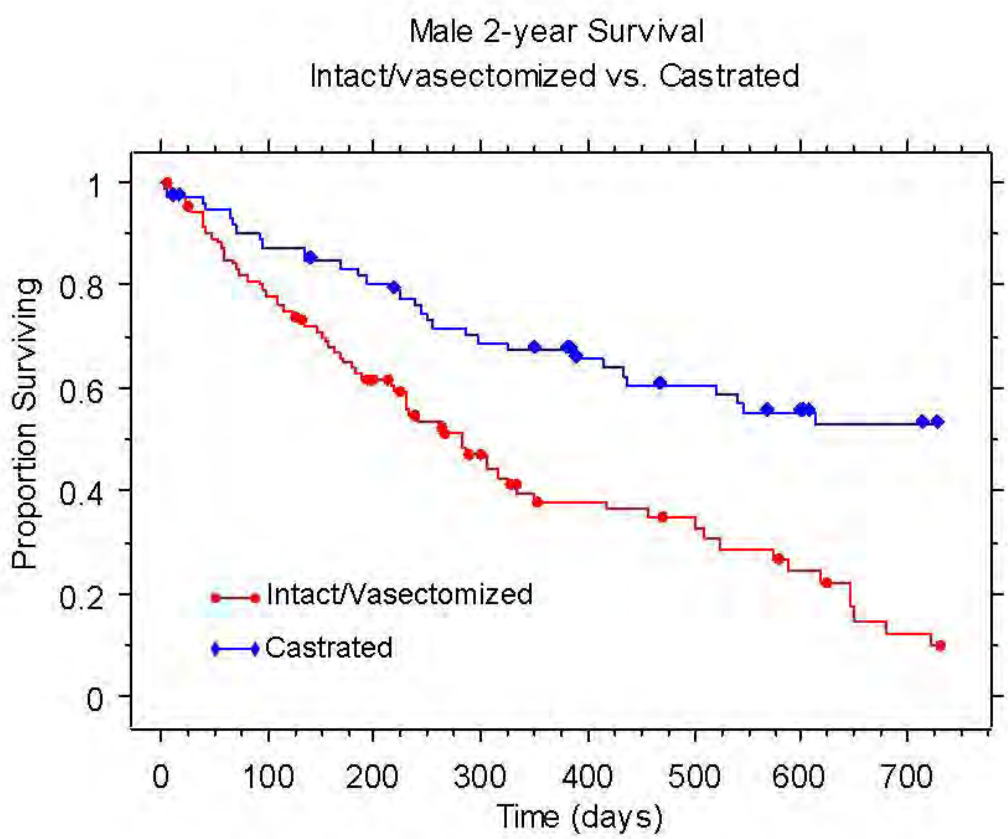

Figure 2: Kaplan-Meier 2-year survival estimate for male cats compared by treatment. Symbols indicate censored observations.

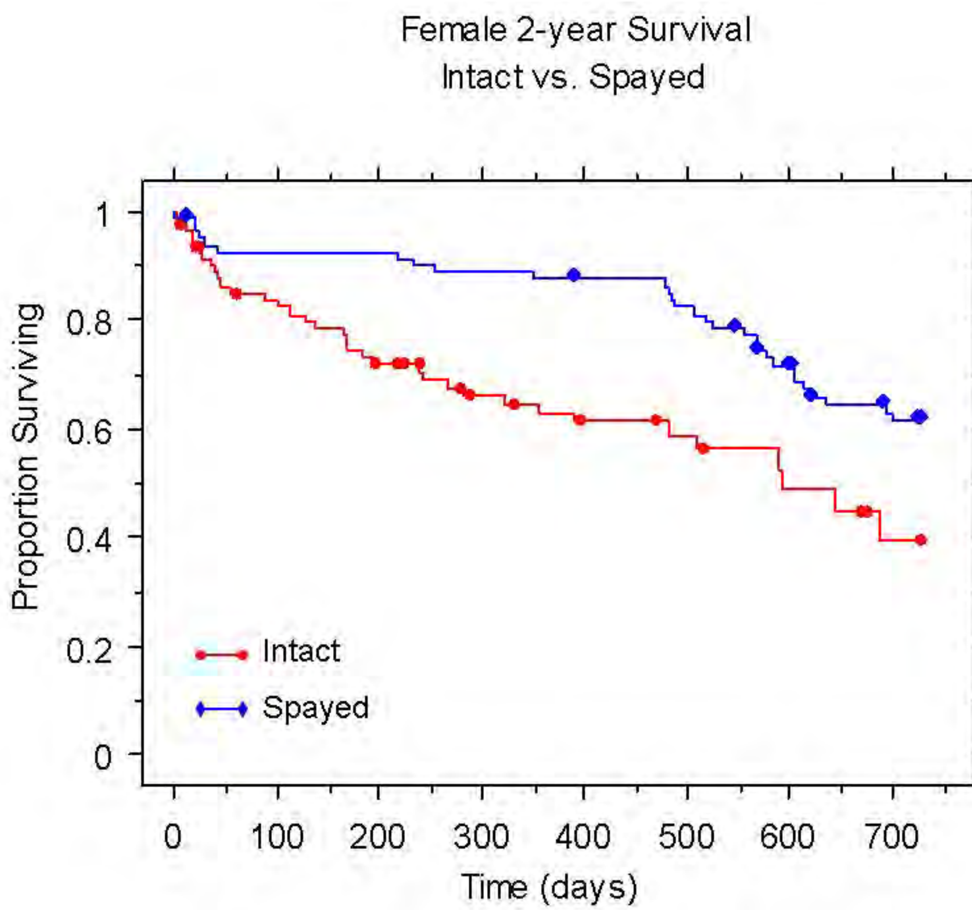

Figure 3: Kaplan-Meier 2-year survival estimate for female cats compared by treatment. Symbols indicate censored observations.

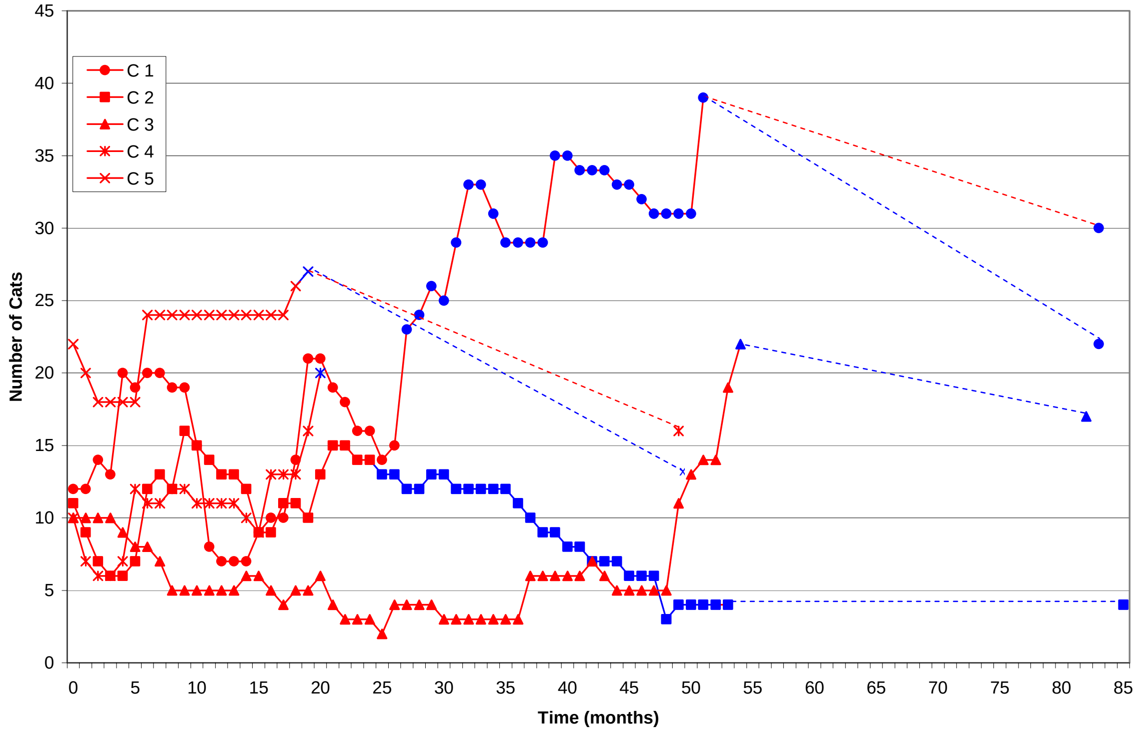

Figure 4. Control colony sizes over time. Symbol color changes from red to blue to indicate colony neutering. Mixed colors for C1 and C4 indicate presence of breeding trap-shy cats. Dashed lines are extrapolations between End 2 and End 3. Dashed red lines for C1 and C4 are for total colony size, and dashed blue lines are for neutered size.

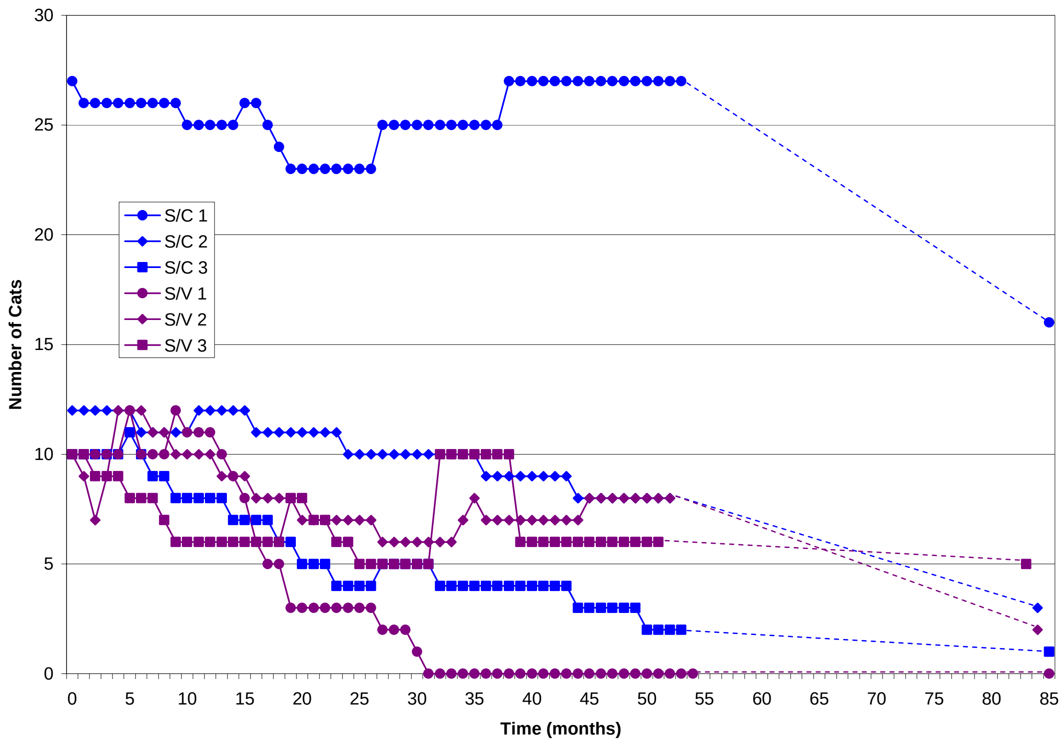

Figure 5. Spay/castration (blue) and spay/vasectomy (purple) colony sizes over time.

Chapter 6. Home ranges of intact and neutered feral cats (*Felis catus*) in managed colonies in Randolph County, North Carolina.

Felicia B. Nutter

Introduction

Feral domestic cats (*Felis catus*) are opportunistic and adaptive, occupying a wide variety of niches and demonstrating very flexible social organizations. Variations of over 1000-fold are reported for home range sizes and population densities (Liberg et al. 2000). Cats live at low densities (<0.04 cats/ha) with home ranges of up to 760 ha in habitats such as forests, scrub, farmland and subantarctic islands where resources are poor and dispersed (Fitzgerald & Karl 1986; Jones & Coman 1982b; Konecny 1987; Say et al. 2002). Where resources are clumped and abundant in suburban and urban areas, cats can form large, dense (>20 cats/ha) multi-male, multi-female groups with home ranges less than 1 ha (Barratt 1997; Haspel & Calhoon 1993; Izawa et al. 1982; Mirmovitch 1995; Natoli et al. 1999; Yamane et al. 1994). Cats are found at the lowest densities and with the largest home ranges where they subsist by hunting, and at the highest densities with the smallest home ranges where they survive by scavenging or are fed by people (reviewed in Liberg et al. 2000). The main resources driving feral cat social organization differ by sex, with food and shelter being the primary determinants for female cats and access to breeding females the primary determinant for males (Devillard et al. 2003; Devillard et al. 2004; Kaeuffer et al. 2004; Liberg et al. 2000; Say et al. 2002).

Across the spectrum of social organization and population densities, feral cats as introduced, exotic predators have negative environmental impacts, which include predation on native wildlife, nuisance issues, and perceived health risks for people (Levy & Crawford 2004; Patronek 1998; Slater 2004; Winter 2004). Unfortunately feral cat management remains largely reactive and is usually undertaken in response to a complaint reported to an animal control agency or humane organization, or as part of a threat abatement plan for wildlife species of concern. Feral cats living in groups at high densities are commonly targeted for control, because they are the most visible.

Trap-neuter-return (TNR) programs for group-living feral cats are being implemented by grass-roots organizations as alternatives to lethal control. The rationale for TNR programs is eventual population decrease through attrition, and territorial defense by resident cats to prevent immigration of intact cats that would breed and repopulate the site (Levy & Crawford 2004; Slater 2002). A clear understanding of home ranges and the spatial organization of feral cats in managed colonies is needed to evaluate the effectiveness of TNR programs fully.

This project evaluated home ranges for intact and neutered cats in managed colonies. Two different techniques for neutering males, castration and vasectomy, were employed to investigate whether hormonally intact but reproductively sterile males might provide better territory defense.

Materials and Methods

Study Design

Nine pre-existing feral cat colonies in Randolph County, North Carolina were included in the study as described in Chapter 5 (Nutter et al. 2004a; Nutter et al. 2004b). Three adult male cats in each colony were fitted with 30-g, motion-sensing transmitter collars, which weighed < 0.01% of cat bodyweight and had an expected 24 month battery life (model RI-2CM(12)sp, Holohil Systems Ltd., Ontario, Canada). Because of financial limitations and the primary interest in evaluating the impact of the two neutering techniques for male cats, no collars were placed on female cats.

Data Collection

I collected visual and radiotelemetry location data at each colony at least twice monthly for two years. Visual locations were recorded from fixed points as bearing to the nearest decimal degree and distance in meters measured by laser rangefinder binoculars, or as proximity to permanent features (building, tree, etc.). Radiotelemetry locations were obtained using the loudest signal technique (Springer 1979) and a hand-held Telonics receiver and two-element antenna (Telonics Inc., Mesa, Arizona). They were only collected if cats were not visually located, and radiolocation efforts ceased if a cat was visually located before three bearings were obtained. Bearings were recorded to the nearest decimal degree from at least 3 fixed points within 15 minutes to minimize error from moving cats. Signal quality was assessed for fluctuations in tone and volume as an indicator of animal movement, and location information was not collected if signal quality was judged poor. All locations were collected by the same investigator.

Location data were analyzed using geographic information system software (ArcView GIS 3.3, Redlands, California). Digital orthophoto quarter quadrangle maps with 3 m resolution were imported into the program and used as a base layer for plotting the fixed points and animal locations. Visual locations were calculated from the bearing and distance information using an ArcView software extension (Distance/Azimuth Tools v. 1.2, Jenness Enterprises, Flagstaff, Arizona) or were hand plotted. Locations estimated by radiotelemetry were triangulated by computer (LOAS, Ecological Software

Solutions), and were the intersections of 2 compass bearings or the 2-dimensional arithmetic means of intersections of 3 compass bearings. I estimated radiotelemetry error by the location error technique (Zimmerman & Powell 1995) using “dummy” collars placed at the colony sites in locations unknown to me. I collected location estimates for the dummy collars and then calculated the absolute distances and bearing error angle between the estimated locations and the known locations using LOAS. Distances from the colony feeding sites to all individual cat locations for each colony were also calculated using Animal Movement v 2.0 extension for ArcView GIS 3.3 (Hooge & Eichenlaub 1997). Home ranges were calculated for individual cats with at least 20 location points each, using the same Animal Movement v 2.0 extension. I calculated minimum convex polygon (MCP) estimates using all points (MCP 100) and also after removal of 5% of outliers by the harmonic mean distance process (MCP 95), and I calculated 95% and 50% fixed-kernel estimates (KE 95, KE50) with the Animal Movement v 2.0. I also calculated MCP 100, MCP 95, KE 95 and KE 50 ranges for each colony, using location data from all cats in the colony, not just the cats for which I estimated home ranges. For all kernel home range estimates, least squares cross-validation (LSCV) was initially used to choose the band width, *h* (the width of the kernel) (Powell 2000).

Cat density was estimated at the colony level and was calculated by dividing the total number of cats per colony (not just the cats for which individual home ranges were estimated) by the various colony home ranges estimates, to yield cats per hectare. An overall cat density across colonies was estimated by dividing the total number of cats (188) by the sum of all 9 colony home range estimates, for each estimation method.

Statistical Analysis

Data sets were evaluated for normality with the Shapiro-Wilk W test before performing additional statistical analyses. Only the data set for the total number of cat locations collected per colony conformed with normality (p=0.20). All other data sets at the individual and colony level were from non-normal distributions (all p<0.05). Accordingly I used non-parametric tests for statistical analyses. Correlations between the number of locations and home range sizes were evaluated with Kendall's rank correlation. The Mann-Whitney U test was used to compare two groups, and the Kruskal-Wallis test was used to compare three groups, with multiple comparisons made using the Dwass-Steel-Chritchlow-Fligner method (Critchlow & Fligner 1991; Hollander & Wolfe 1999). The significance level of $\alpha = 0.05$ was used for all tests. Computer software packages (StatView, SAS Institute, Cary, NC, USA; Stats-Direct version 2.4.5, Cheshire, UK) were used for all analyses.

Results

I collected 4663 locations from a total of 188 cats during the study period. The majority of locations were collected between 0600 and 1800 hours (71%), with 27% collected between 1800 and 2400 hours, and 2% between 2400 and 0600 hours. I estimated home ranges for 91 cats (47 female, 44 male) that had at least 20 locations each. The number of locations per individual cat whose home range was calculated ranged from 20 to 72, with a median of 38, and a mean of 41 (± SD 14). I was successful in locating the individual cats for which home ranges were estimated during a mean of 65% (± 20%) and median of 66% of location attempts, with a range of 26% to

100%. Only visual locations were collected for female cats. Radiotelemetry locations were used in the home range estimates of 11 of 27 radiocollared male cats, with between 1 and 6 radiotelemetry locations per cat (1% to 12% of total locations). For 13 other radiocollared male cats, I used only visual locations. For the remaining 3 radiocollared male cats no home range estimates were generated because not enough locations were obtained. Two of those cats disappeared, and for one the radio failed and the cat subsequently disappeared. The average radiotelemetry error angle was 2°, and the average location error distance was 6 m.

Overall, median home range estimates for individual cats (Table 1 presents median statistics, Table 2 mean statistics) ranged from 0.028 ha to 3.947 ha (MCP 100), 0.020 ha to 3.230 ha (MCP 95), and 0.008 ha to 3.849 ha (KE 95). Core areas (KE 50) ranged from 0.002 ha to 0.386 ha. There was no difference between male and female home ranges for any of the estimators used (MCP 100 $p=0.17$, MCP 95 $p=0.32$, KE 95 $p=0.22$, KE 50 $p=0.16$). When home range sizes were compared by sex without taking into account reproductive status, there was no significant difference for MCP 100 ($p=0.17$), KE 95 ($p=0.27$), or KE 50 ($p=0.21$). When cats were split by sex and then compared by reproductive status, vasectomized male cats had significantly larger ranges than either intact or castrated males for the MCP 100 ($p=0.003$ for both comparisons), KE 95 ($p=0.002$, $p=0.004$ respectively) and KE 50 ($p=0.005$, $p=0.034$ respectively). While there was no difference between intact and spayed females for MCP 100 ($p=0.91$), spayed females had significantly larger KE 95 ($p=0.03$) and KE50 ($p=0.02$) than intact females. The MCP 100, MCP 95, KE 95 and KE 50 home ranges of all cats in the colonies overlapped extensively, and contained the feeding sites within the core areas (see Figure 1 through Figure 10 for individual cat MCP 100 estimates and colony KE 95 and KE 50, presented for each colony).

Home range estimates at the colony level for all treatments combined (Table 3) ranged from 0.281 ha to 8.363 ha (MCP 100), 0.132 ha to 3.806 ha (MCP 95), and 0.024 ha to 0.773 ha (KE 95). Colony core areas (KE 50) ranged from 0.004 ha to 0.060 ha. There were no significant differences among colonies by treatment for any of the home range estimates (MCP 100 p=0.30; MCP 95 p=0.39, KE 95 p=0.06; KE 50 p=0.07).

The number of individual cat locations and resulting MCP 100 area were correlated (p=0.003) for individual cat home ranges. No correlations were found between the number of locations and the areas of individual cat KE 95 (p=0.64) or KE 50 (p=0.50), or between the total number of locations per colony or cats per colony and the areas of colony-level MCP 100 (p=0.92, p=0.76), KE 95 (p=0.61, p=0.48) or KE 50 (p=0.48, p=0.36).

Home ranges for all cats within the same colony overlapped extensively (see Figure 2 through Figure 10) and included the feeding sites and often adjacent buildings. Using colony MCP 100, and dividing the total number of cats by the sum of the home range estimates, a density of 8 cats/ha was derived, while with the MCP 95 the density was estimated as 20 cats/ha (Table 4). With the revised KE 95 the density was 94 cats/ha, and in the revised KE 50 core area, the density was 1039 cats/ha. No significant differences were found cat densities per individual colony compared by treatment (MCP 100 p=0.20, MCP 95 p=0.15, KE 95 p=0.10, KE 50 p=0.25).

Distances from colony feeding sites to individual cat locations (Table 5) ranged from 0.10 m to 290.70 m. There was no difference between the distances moved by males and females ($p=0.29$), but there were differences within the sexes by treatment. Vasectomized male cats moved farther from the feeding site than either intact ($p<0.0001$) or castrated ($p=0.032$) male cats, and castrated male cats moved farther than intact male cats ($p<0.0001$). Spayed female cats moved farther than intact female cats ($p<0.0001$).

Discussion

The feral cats in these managed colonies were generally easy to observe, with a high percentage in attendance at any given time. At least half the cats were located 66% of the time, with more than 1/3 of the cats observed during 75% or more of the colony visits. Similarly high observation success has been reported for urban feral cats in Rome (Natoli & De Vito 1991). The ability of caretakers to observe cats means that abnormalities can be easily noticed (injuries or other health problems) and new cats are likely to be detected quickly. It also means that cats are readily accessible for management activities, such as the initial trapping for TNR programs, follow-up captures for booster vaccinations, or if necessary removal of individual cats or the entire colony.

Cat locations were collected predominantly during daylight or crepuscular hours, and the resulting home ranges most accurately represent diurnal patterns of space use. Though cats are commonly considered to be most active at night, they do alter their activity patterns due to food availability (Fitzgerald & Turner 2000; Haspel & Calhoon 1993; Konecny 1987; Langham 1992). All colonies were fed during the day, and so the locations collected reflect space use related to high food availability and abundance.

Nocturnal ranges have been reported to be larger than diurnal ranges for both neutered pet cats and intact feral cats in Canberra, Australia (Barratt 1997)

Previous studies of feral cat home ranges have most commonly used the MCP method to estimate home range (Liberg et al. 2000). The traditional MCP is sensitive to the total number of locations per individual animal, and ignores the possibility of differential use of regions within the home range (Powell 2000). Large areas that are rarely used by the animal may be included in the calculated home range. However, it is intuitive and easy to calculate, and therefore widely used. The individual cat MCP 100 and MCP 95 home range sizes found here (Table 1 and Table 2) were within the range of those previously reported for feral cats living in environments with rich, clumped food resources (Barratt 1997; Bradshaw 1992; Chipman 1990 cited in Bradshow 1992; Dards 1978; Izawa et al. 1982; Mirmovitch 1995; Tabor 1983; Yamane et al. 1994). The home ranges of all cats within a colony overlapped extensively and included the feeding site and, frequently, adjacent buildings. Only one cat, a spayed female, was routinely observed to cross a road adjacent to the colony site, though several cats from the same colony emigrated to a new site by crossing an adjacent road, and many cats were killed by vehicle collisions (Chapter 5). There are relatively few reports in the literature of home ranges for neutered cats, and the data available are for free-roaming owned cats. MCP 100 ranges of 0.02 ha to 43.56 ha, and MCP 95 ranges of 0.02 ha to 27.93 ha have been reported for 9 neutered suburban cats in Canberra, Australia, with no differences by sex (Barratt 1997). Home ranges of 7 intact feral farm cats from the same study ranged from 0.86 ha to 23.38 ha (MCP 100) and 0.77 ha to 4.46 ha (MCP 95). These cats spent 88-97% of their time in or near farm buildings, paddocks, and yards. Though none of them were ever observed to cross an adjacent road, two were killed by vehicles. Median MCP ranges of 0.076 ha for 52 castrated males and 0.053 ha for 64 spayed females were reported from Manchester, UK (Chipman 1990 cited in Bradshaw 1992), and 0.02 ha for female cats in East London (Tabor 1983). These values are similar to those for the intact and neutered cats in the present study and indicate intensive use of small areas. Roads may play a role in limiting feral cat movements, either because cats avoid the roads, or because many of them are killed by vehicle collisions if they do not.

The correlation between number of locations per individual cat and the resulting MCP 100 size reflects the sensitivity of the MCP method to number of locations and outliers (Powell 2000). Kernel estimates provide better insight into what portions of an individual cat’s or colony’s range are functionally important (Figure 1) (Powell 2000). Feeding sites were contained within the core KE 50 for all individual cats and all colonies, as well as areas in or adjacent to buildings which likely represent resting or shelter sites. A single study (Haspel & Calhoon 1989) has reported a utilization distribution home range estimate for intact feral cats in Brooklyn, NY, but the method used was unclear and so cannot be directly compared to the KE 50 and KE 95 areas that I calculated; those intact urban feral cats had a mean range of 2.6 ha for males and 1.7 ha for females.

The choice to study existing feral cat colonies that were fed on a daily basis meant that by default their ecology was different from feral cats that subsist by hunting alone, or by scavenging from rubbish sites. Variation in food availability, one of the primary drivers of carnivore organization, was elminated (Liberg et al. 2000; Macdonald 1983). In the managed feral cat colonies in this study, food and water were provided daily and shelter was abundant. Basic requirements were thus met, leaving social issues as the remaining major influence on home range.

The home ranges of intact and castrated male cats in this study were similar in size. Castrated male cats were located significantly farther from the feeding site than intact male cats, but the real difference (between either the mean or median distances) of less than 1 m is unlikely to be biologically relevant. Home ranges of intact male cats are generally reported to be 3.5 to 10 times larger than female ranges, so that a breeding male encompasses several breeding females in his range (Liberg et al. 2000; Tabor 1983). A study of cats in rural Sweden showed that the home ranges of breeding males contained between 7 and 15 breeding females (Liberg 1980; Liberg 1981; Liberg 1983). In these colonies with multiple females, a male need not increase his home range beyond that of the resident females to find adequate breeding opportunities. There is also often estrus synchronization among females, which makes it impossible for individual males to control reproductive access to all receptive females (Say et al. 2001). Genetic analysis has confirmed that the mating system for such multi-male, multi-female colonies is promiscuous, with a high rate of multiple paternity, where kittens in a single litter are sired by more than one male (Natoli & De Vito 1991; Say et al. 1999). Intact male cats were apparently able to meet their needs for access to females, and required home ranges no larger than those of females or castrated males. Another possible explanation is that other intact females may have been too far away from the existing colonies for the males to either locate or visit regularly.

Vasectomized males had significantly larger home ranges than intact or castrated males. Their locations were, on average, twice as far from the feeding site as either intact or castrated male cats. Though there were also multiple females in the colonies with vasectomized males, they were spayed and presumably not meeting the reproductive demands of the hormonally intact, sterilized males. There were multiple anecdotal observations made by myself and the colony caretakers of vasectomized males attempting to copulate with spayed females that were not exhibiting any signs of estrus. It seems likely that vasectomized males had larger home ranges than either castrated or intact males because they were searching for breeding females, but we have no data specifically supporting this supposition.

There was no difference between the home range sizes of intact or spayed females comparing the 95 or 100 MCP estimates. However, when the kernel estimates were compared, intact females had significantly smaller home ranges than spayed females. Pregnant and lactating females have been shown to reduce their home range size during the breeding season, presumably due to the need to protect and feed kittens (Fitzgerald & Karl 1986; Jones & Coman 1982a, b; Konecny 1987). Though alloparental care and nursing coalitions are described in feral cats and can theoretically help distribute the burden of nursing and guarding kittens (Macdonald 1983; Macdonald et al. 1987; MacDonald et al. 2000), there is little incentive for nursing queens in managed colonies to range widely. However, the greatest distance from the feeding site for any cat, male or female, was 290.70 m, recorded for an intact female nursing a litter of kittens. She was observed hunting at the interface of an open field and a forest block. The short survival times of intact females combined with the low-intensity sampling meant that the dataset for each cat was not large enough for seasonal analysis. More intensive location data collection and seasonal analysis would help better characterize possible differences in home ranges of intact and spayed female cats.

An additional factor in this study that may have influenced the home ranges of intact male and female cats was the presence of cat-aggressive dogs at all three control colonies. This is one of the factors that could not be controlled during the project, and dogs were added at two of the three colonies shortly after the research began. Other researchers have also observed the effect of resident dogs on the cats' behavior, noting that they stayed close to buildings or other sites of refuge when the dogs were active (Barratt 1997; Langham 1992).

Home range sizes for the individual cats and the colonies varied by one to two orders of magnitude in this study. Variations of one to three orders of magnitude for individual male and female home ranges from the same environments have been previously reported (reviewed in Liberg et al. 2000). Though the underlying hypothesis is that food is the primary factor driving female home range, and that females in turn determine male home range, such wide variations within studies are likely due to additional factors. Other potential explanations include differences in age, experience, temperament, dominance rank, and motivation to hunt, as well as the locations of favorite sunning, resting, hiding or hunting sites. This study was not designed to address more subtle behavioral and ecological correlates of behavior, and I cannot draw any conclusions about the relative importance of these factors on cat home ranges though they remain questions for future research.

The colony ranges (Table 3) calculated using MCP 100 were larger than the median individual cat range size, because all observations for any cat in the colony were included. The KE 95 and KE 50 colony ranges were similar to the median KE 95 and KE 50 individual ranges. The lack of correlation between the number of cats per colony and the size of the KE 95 and KE 50 confirms the social tolerance and home range overlap in these multi-male, multi-female groups. If there was significant territorial defense or exclusive home ranges for individual cats, one would expect the KE 95 and KE 50 to increase with the number of cats. The lack of territory defense is further supported by observations during the study of successful immigration of intact males into all types of colonies (Chapter 5). The rich, clumped food resource provided to managed feral cat colonies reduces or eliminates the territory defense that is associated with poorer, dispersed resources.(Liberg et al 2000) Lack of territoriality and social tolerance have been previously described for other group-living feral cats with rich, clumped food resources (Barratt 1997; Devillard et al. 2003; Izawa et al. 1982).

Small colony home ranges might help mitigate predation impacts on wildlife species. Though the high cat densities would likely result in increased local impact, the region impacted would be reduced compared to more widely-ranging cats. Farm cats kept specifically for pest control may significantly affect rodent populations only within 50 meters of a farm site (Elton 1953). Free-roaming owned cats fed at home decreased their hunting by approximately 50% compared to feral cats that were not fed (Liberg 1984). Intact female cats with nursing offspring are more efficient hunters, capturing more prey than non-mothers, and also investing fewer pounces per successful kill than non-mothers or males (Fitzgerald & Turner 2000; Turner & Meister 1988). Spaying females for TNR management eliminates reproduction and the associated increases in food requirements and hunting, which might in turn help reduce predation on wildlife.

Cats also tend to hunt less, or perhaps less successfully, as they age. Cats less than five years old bring home the most prey (Churcher & Lawton 1987), and there are decreases in a cat's physical abilities, such as jumping, as they age (Harris 1999). The increased survival times of neutered feral cats relative to intact feral cats (Chapter 5) may therefore also result in hunting reduction over time. Research on the hunting behavior of feral cats before and after neutering would help clarify some of these issues. Molecular genetic techniques are also being developed to identify prey DNA in predator feces, and offer a new method for studying feral cat food habits over time (Deagle et al. 2005; Symondson 2002). Information about cat predation is most useful when it can be related to the abundance of the prey species of interest. When numbers of prey captured by cats are reported out of context there is no way to assess the impact of hunting on native wildlife populations.

The total colony-level densities of cats reported here of 8-94 cats/ha depending on the colony home range estimate used for the calculation (MCP 100, MCP 95, or KE 95), are similar to the range of 3-28 cats/ha reported for other high-density populations (Calhoon & Haspel 1989; Haspel & Calhoon 1989; Izawa 1983; Mirmovitch 1995; Natoli & De Vito 1991). The total density of 1039 cats/ha in the KE 50 core area is among the highest reported, and could be misleading because the core represents the sites where cats gathered during feeding times. Density of 140 cats/ha was reported for the feeding area of a colony of 80 feral cats in Rome (Natoli et al. 1999), and 210 cats/ha for 30 feral cats confined to a walled garden in Amsterdam (Tabor 1989). Such high densities are found in very small areas, usually less than 0.25 ha, and in this study often less than 0.025 ha. Because these density calculations are based on the home range estimates, which vary by one to two orders of magnitude, the density estimates vary similarly, and the variation within treatments is as great as the variation between treatments. Also, this rough method of calculation overestimates the density, because all cats observed during the two-year study were included, but not all cats were present throughout the study nor were individual home ranges estimated for all observed cats. The overestimation is greatest for the control colonies, which had the highest turnover and tallied more total cats during the study.

The violation of the territorial defense assumption made by TNR programs could have both negative and positive impacts on the success of management. When feral cat colonies are managed by TNR in public areas, the lack of territorial defense can lead to increases in colony sizes when cats are abandoned at visible management sites and readily join the group (Castillo & Clarke 2003; Levy & Crawford 2004). However, the ability of immigrant cats to join a colony also means that they are subject to TNR management and thus their breeding potential is eliminated. The provision of a stable food supply to group-living feral cats results in small home ranges, high attendance, and lack of territoriality that can facilitate the management and monitoring of group-living feral cats, though the environmental impacts of the cats and colonies will depend on the management technique chosen.

References

Barratt, D. T. 1997. Home range size, habitat utilisation and movement patterns of suburban and farm cats *Felis catus*. *Ecography* **20**:271-280.

Bradshaw, J. W. S. 1992. *The behaviour of the domestic cat*. CAB International., Wallingford, UK.

Calhoon, R. E., and C. Haspel. 1989. Urban cat populations compared by season, subhabitat and supplemental feeding. *Journal of Animal Ecology* **58**:321-328.

Castillo, D., and A. L. Clarke. 2003. Trap/neuter/release methods ineffective in controlling domestic cat "colonies" on public lands. *Natural Areas Journal* **23**:247-253.

Chipman, P. 1990. Influence on the home range sizes of domestic cats (*Felis catus*), in an urban environment. MSc thesis. Manchester Polytechnic University.

Churcher, P. B., and J. H. Lawton. 1987. Predation by domestic cats in an English village. *Journal of Zoology* **212**:439-455.

Critchlow, D. E., and M. A. Fligner. 1991. On distribution-free multiple comparisons in the one-way analysis of variance. *Communications in Statistics: Theory and Methods* **20**:127-139.

Dards, J. L. 1978. Home ranges of feral cats in Portsmouth dockyards. *Carnivore Genetics Newsletter* **3**:242-255.

Deagle, B. E., D. J. Tollit, S. N. Jarmin, M. A. Hindell, A. W. Trites, and N. J. Gales. 2005. Molecular scatology as a tool to study diet: analysis of prey DNA in scats from captive Stellar sea lions. *Molecular Ecology* **14**:1831-1842.

Devillard, S., L. Say, and D. Pontier. 2003. Dispersal pattern of domestic cats (*Felis catus*) in a promiscuous urban population: Do females disperse or die? *Journal of Animal Ecology* **72**:203-211.

Devillard, S., L. Say, and D. Pontier. 2004. Molecular and behavioural analyses reveal male-biased dispersal between social groups of domestic cats. *Ecoscience* **11**:175-180.

Elton, C. S. 1953. The use of cats in farm rat control. *British Journal of Animal Behaviour* **1**:151-155.

Fitzgerald, B. M., and B. J. Karl. 1986. Home range of feral cats (*Felis catus* L.) in forests of the Orongorongo Valley, Wellington, New Zealand. *New Zealand Journal of Ecology* **9**:71-81.

Fitzgerald, B. M., and D. C. Turner. 2000. Hunting behaviour of domestic cats and their impact on prey populations. Pages 151-176 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the biology of its behaviour*. Cambridge University Press, Cambridge, UK.

Harris, M. A. 1999. Individual variation in domestic cat maximum jump performance: Morphological, physiological, and motivational influences. PhD dissertation. The University of Wisconsin Madison.

Haspel, C., and R. E. Calhoon. 1989. Home ranges of free-ranging cats (*Felis catus*) in Brooklyn, New York. *Canadian Journal of Zoology* **67**:178-181.

Haspel, C., and R. E. Calhoon. 1993. Activity patterns of free-ranging cats in Brooklyn, New York. *Journal of Mammalogy* **74**:1-8.

Hollander, M., and D. A. Wolfe 1999. *Nonparametric Statistical Methods*. Wiley, New York, New York, USA.

Hooge, P. N., and B. Eichenlaub. 1997. Animal Movement Extension to ArcView. Alaska Biological Science Center, U.S. Geologic Survey, Anchorage, Alaska, USA.

Izawa, M. 1983. Daily activities of the feral cat *Felis catus*. *Journal of the Mammalogical Society of Japan* **9**:219-228.

Izawa, M., T. Doi, and Y. Ono. 1982. Grouping patterns of feral cats *Felis catus* living on a small island in Japan. *Japanese Journal of Ecology* **32**:373-382.

Jones, E., and B. J. Coman. 1982a. Ecology of the feral cat *Felis catus* in Southeastern Australia 2. Reproduction. *Australian Wildlife Research* **9**:111-120.

Jones, E., and B. J. Coman. 1982b. Ecology of the feral cat *Felis catus* in Southeastern Australia 3. home ranges and population ecology in semi-arid Northwest Victoria. *Australian Wildlife Research* **9**:409-420.

Kaeuffer, R., D. Pontier, S. Devillard, and N. Perrin. 2004. Effective size of two feral domestic cat populations (*Felis catus* L): effect of the mating system. *Molecular Ecology* **13**:483-490.

Konecny, M. J. 1987. Home ranges and activity patterns of feral house cats in the Galapagos Islands. *Oikos* **50**:17-23.

Langham, N. P. E. 1992. Feral cats (*Felis catus* L.) on New Zealand farmland. II. Seasonal activity. *Wildlife Research* **18**:707-720.

Levy, J. K., and P. C. Crawford. 2004. Humane strategies for controlling feral cat populations. *Journal of the American Veterinary Medical Association* **225**:1354-1360.

Liberg, O. 1980. Spacing patterns in a population of rural free-roaming domestic cats. *Oikos* **35**:336-349.

Liberg, O. 1981. Predation and social behaviour in a population of domestic cat; an evolutionary perspective. PhD dissertation. University of Lund, Sweden.

Liberg, O. 1983. Courtship behaviour and sexual selection in the domestic cat. *Applied Animal Etholgy* **10**:117-132.

Liberg, O. 1984. Food habits and prey impact by feral and house-based domestic cats in a rural area in southern Sweden. *Journal of Mammalogy* **65**:424-432.

Liberg, O., M. Sandell, D. Pontier, and E. Natoli. 2000. Density, spatial organisation and reproductive tactics in the domestic cat and other felids. Pages 119-147 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Macdonald, D. W. 1983. The ecology of carnivore social behaviour. *Nature* **301**:379-384.

Macdonald, D. W., P. Apps, G. M. Carr, and G. Kerby. 1987. Social dynamics, nursing coalitions and infanticide among farm cats, *Felis catus*. *Advances in Ethology Number 28*:1-66.

MacDonald, D. W., N. Yamaguchi, and G. Kerby. 2000. Group-living in the domestic cat: its sociobiology and epidemiology. Pages 95-118 in B. Turner, and P.

Bateson, editors. *The Domestic Cat: the Biology of its Behaviour*. Cambridge University Press, Cambridge, UK.

Mirmovitch, V. 1995. Spatial organisation of urban feral cats (*Felis catus*) in Jerusalem. *Wildlife Research* **22**:299-310.

Natoli, E., and E. De Vito. 1991. Agonistic behavior, dominance rank and copulatory success in a large multi-male feral cat, *Felis catus* L., colony in central Rome. *Animal Behaviour* **42**:227-242.

Natoli, E., M. Ferrari, E. Bolletti, and D. Pontier. 1999. Relationships between cat lovers and feral cats in Rome. *Anthrozoos* **12**:16-23.

Nutter, F. B., J. F. Levine, and M. K. Stoskopf. 2004a. Reproductive capacity of free-roaming domestic cats and kitten survival rate. *Journal of the American Veterinary Medical Association* **225**:1399-1402.

Nutter, F. B., M. K. Stoskopf, and J. F. Levine. 2004b. Time and financial costs of programs for live trapping feral cats. *Journal of the American Veterinary Medical Association* **225**:1403-1405.

Patronek, G. J. 1998. Free-roaming and feral cats--their impact on wildlife and human beings. *Journal of the American Veterinary Medical Association* **212**:218-226.

Powell, R. A. 2000. Animal home ranges and territories and home range estimators. Pages 65-110 in L. Boitani, and T. K. Fuller, editors. *Research Techniques in Animal Ecology*. Columbia University Press, New York City, New York, USA.

Say, L., S. Devillard, E. Natoli, and D. Pontier. 2002. The mating system of feral cats (*Felis catus* L.) in a sub-Antarctic environment. *Polar Biology* **25**:838-842.

Say, L., D. Pontier, and E. Natoli. 1999. High variation in multiple paternity of domestic cats (Felis catus L.) in relation to environmental conditions. *Proceedings of the Royal Society of London Series B, Biological Sciences* **266**:2071-2074.

Say, L., D. Pontier, and E. Natoli. 2001. Influence of oestrus synchronization on male reproductive success in the domestic cat (*Felis catus* L.). *Proceedings of the Royal Society of London Series B, Biological Sciences* **268**:1049-1053.

Slater, M. R. 2002. *Community Approaches to Feral Cats: Problems, Alternatives, and Recommendations.* Humane Society Press, Washington, D.C., USA.

Slater, M. R. 2004. Understanding issues and solutions for unowned, free-roaming cat populations. *Journal of the American Veterinary Medical Association* **225**:1350-1354.

Springer, J. T. 1979. Some sources of bias and sampling error in radio triangulation. *Journal of Wildlife Management* **43**:926-935.

Symondson, W. O. C. 2002. Molecular identification of prey in predator diets. *Molecular Ecology* **11**:627-641.

Tabor, R. 1983. *The Wild Life of the Domestic Cat*. Arrow Books Limited, London.

Tabor, R. 1989. The changing life of feral cats (*Felis catus* L.) at home and abroad. *Zoological Journal of the Linnaean Society* **95**:151-161.

Turner, D. C., and O. Meister. 1988. Hunting behaviour of the domestic cat. Pages 111-121 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the biology of its behaviour*. Cambridge University Press, Cambridge, UK.

Winter, L. 2004. Trap-neuter-release programs: the reality and the impact. *Journal of the American Veterinary Medical Association* **225**:1369-1376.

Yamane, A., Y. Ono, and T. Doi. 1994. Home range size and spacing pattern of a feral cat population on a small Island. *Journal of the Mammalogical Society of Japan* **19**:9-20.

Zimmerman, J. W., and R. A. Powell. 1995. Radiotelemetry error: location error method compared with error polygons and confidence ellipses. *Canadian Journal of Zoology* **73**:1123-1133.

Table 1. Home range estimates for intact and neutered male and female feral cats in managed colonies by 100% and 95% minimum convex polygon (MCP), and 95% and 50% kernel. Data are reported as median, interquartile range (minimum-maximum). * and † indicate statistically significant differences between groups, by sex.

			MCP (ha)		Kernel (ha)	
	# Cats		100%	95%	95%	50%
Males						
Intact	14	median, IQR (min-max)	0.152, 0.165* (0.035 -1.229)	0.108, 0.089* (0.027-0.399)	0.072, 0.118* (0.022 - 0.665)	0.010, 0.008* (0.004 - 0.107)
Castrated	13	median, IQR (min-max)	0.157, 0.068† (0.071 -1.776)	0.109, 0.054† (0.053-0.527)	0.121, 0.057† (0.063 - 0.536)	0.016, 0.012† (0.007 - 0.086)
Vasectomized	17	median, IQR (min-max)	0.593, 1.640*† (0.184 - 3.947)	0.396, 1.185*† (0.160-3.230)	0.474, 1.401*† (0.090 - 3.849)	0.050, 0.187*† (0.009 - 0.386)
Females						
Intact	17	median, IQR (min-max)	0.227, 0.150 (0.034 -2.486)	0.125, 0.100 (0.032-0.398)	0.092, 0.047* (0.008 -0.708)	0.010, 0.006* (0.002 -0.119)
Spayed	30	median, IQR (min-max)	0.176, 0.339 (0.028 -0.844)	0.133, 0.306 (0.020-0.754)	0.155, 0.280* (0.010 -1.064)	0.019, 0.027* (0.002 -0.269)

Table 2. Home range estimates for intact and neutered male and female feral cats in managed colonies by 100% and 95% minimum convex polygon (MCP), and 95% and 50% kernel. Data are reported as mean ± SD (95% CI), and are presented to facilitate comparisons with existing publications.

			MCP (ha)		Kernel (ha)	
	# Cats		100%	95%	95%	50%
Males						
Intact	14	mean ± SD (95% CI)	0.241± 0.316 (0.058-0.423)	0.134 ± 0.111 (0.070-0.198)	0.141 ± 0.163 (0.047-0.235)	0.019 ± 0.026 (0.004-0.034)
Castrated	13	mean ± SD (95% CI)	0.318 ± 0.440 (0.092-0.545)	0.167 ± 0.142 (0.093-0.240)	0.161 ± 0.113 (0.103-0.219)	0.023 ± 0.020 (0.129-0.033)
Vasectomized	17	mean ± SD (95% CI)	1.111 ± 1.23 (0.430-1.792)	0.840 ± 0.916 (0.286-1.393)	1.129 ± 1.271 (0.574-1.897)	0.131 ± 0.138 (0.048-0.214)
Females						
Intact	17	mean ± SD (95% CI)	0.334 ± 0.563 (0.045-0.624)	0.143 ± 0.089 (0.097-0.189)	0.126 ± 0.159 (0.044-0.208)	0.018 ± 0.028 (0.004-0.033
Spayed	30	mean ± SD (95% CI)	0.268 ± 0.215 (0.187-0.348)	0.223 ± 0.201 (0.148-0.298)	0.284 ± 0.296 (0.173-0.395)	0.043 ± 0.061 (0.020-0.066

Table 3. Home range estimates for managed colonies of feral cats: 100% and 95% minimum convex polygon (MCP) and 95% and 50% Kernel.

			100% MCP		95%MCP	
Colony	# Cats	# Locations	Area (ha)	Mean + SD (median)	Area (ha)	Mean + SD (median)
C1	43	781	0.688		0.427	
C2	32	752	3.977	1.649 + 2.027	0.947	0.502 + 0.41
C3	16	310	0.281		0.132	
S/C 1	30	834	1.131		0.613	
S/C 2	13	436	3.098	1.544 + 1.395	1.111	0.657 + 0.43
S/C 3	11	399	0.402		0.246	
S/V 1	15	236	8.363		3.806	
S/V 2	16	472	3.747	4.516 + 3.526	1.917	2.021 + 1.73
S/V 3	12	443	1.437		0.341	
Total	**188**	**4663**	**23.124**	**2.569 + 2.60 (1.437)**	**9.540**	**1.060 + 1.169 (0.613)**

			95% Kernel		50% Kernel	
Colony	# Cats	# Locations	Area (ha)	Mean + SD (median)	Area (ha)	Mean + SD (median)
C1	43	781	0.024		0.004	
C2	32	752	0.088	0.055 + 0.032	0.011	0.007 + 0.004
C3	16	310	0.053		0.007	
S/C 1	30	834	0.118		0.012	
S/C 2	13	436	0.184	0.120 + 0.063	0.021	0.013 + 0.007
S/C 3	11	399	0.059		0.007	
S/V 1	15	236	0.581		0.060	
S/V 2	16	472	0.773	0.495 + 0.330	0.042	0.040 + 0.022
S/V 3	12	443	0.130		0.017	
Total	**188**	**4663**	**2.010**	**0.223 + 0.266 (0.118)**	**0.181**	**0.020 + 0.019 (0.012)**

Table 4. Estimated cat densities for each colony, calculated using the various home range estimates.

Colony	# Cats	100% MCP		95%MCP	
		Area (ha)	Cats/ha	Area (ha)	Cats/ha
C1	43	0.688	63	0.427	101
C2	32	3.977	8	0.947	34
C3	16	0.281	57	0.132	121
S/C 1	30	1.131	27	0.613	49
S/C 2	13	3.098	4	1.111	12
S/C 3	11	0.402	27	0.246	45
S/V 1	15	8.363	2	3.806	4
S/V 2	16	3.747	4	1.917	8
S/V 3	12	1.437	8	0.341	35
Total	**188**	**23.124**	**8**	**9.540**	**20**

Colony	# Cats	95% Kernel		50% Kernel	
		Area (ha)	Cats/ha	Area (ha)	Cats/ha
C1	43	0.024	1792	0.004	10750
C2	32	0.088	364	0.011	2909
C3	16	0.053	302	0.007	2286
S/C 1	30	0.118	254	0.012	2500
S/C 2	13	0.184	71	0.021	619
S/C 3	11	0.059	186	0.007	1571
S/V 1	15	0.581	26	0.060	250
S/V 2	16	0.773	21	0.042	381
S/V 3	12	0.130	92	0.017	706
Total	**188**	**2.010**	**94**	**0.181**	**1039**

Table 5. Distances in meters from the colony feeding site to locations for individual intact and neutered male and female feral cats. † and ‡ indicate statistically significant differences between treatment groups, by sex.

	# Locations	Median, IQR (min-max)	Mean ± SD (95% CI)
Males			
Intact*‡	836	9.18, 18.03 (0.17-155.70)	14.28 ± 15.62 (13.22-15.34)
Castrated*†	871	9.68, 12.42 (0.15-179.65)	15.18 ± 17.17 (14.04-16.33)
Vasectomized†‡	577	22.86, 37.00 (0.23-255.62)	34.41 ± 39.13 (31.21-37.61)
Total	2284	11.18, 19.92 (0.15-255.62)	19.71 ± 25.71 (18-66-20.77)
Females			
Intact*	1007	8.12, 17.61 (0.13-290.70)	14.88 ± 20.04 (13.63-16.11)
Spayed*	1372	12.78, 27.71 (0.10-189.56)	24.03 ± 26.96 (22.60-25.46)
Total	2379	10.83, 21.6 (0.10-290.70)	20.16 ± 24.69 (19.17-21.15)
Overall Total	**4663**	**11.04, 20.76 (0.10-290.70)**	**19.94 + 25.19 (19.22-20.66)**

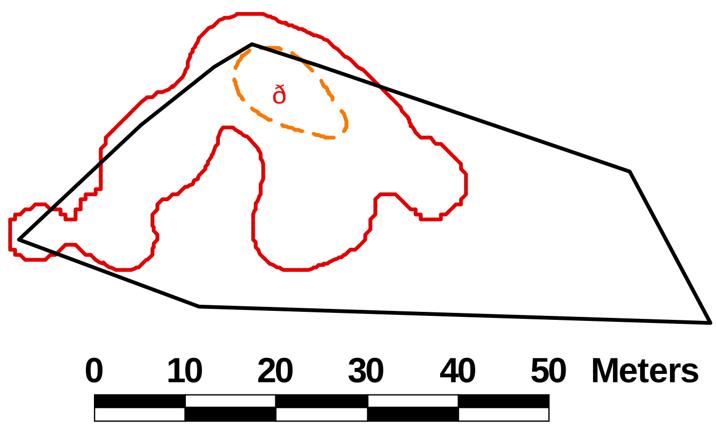

Figure 1. Example of MCP 100 home range (solid black line) and KE 95 (solid red line) and KE 50 (yellow dashed line) for castrated male cat. j indicates feeding site.

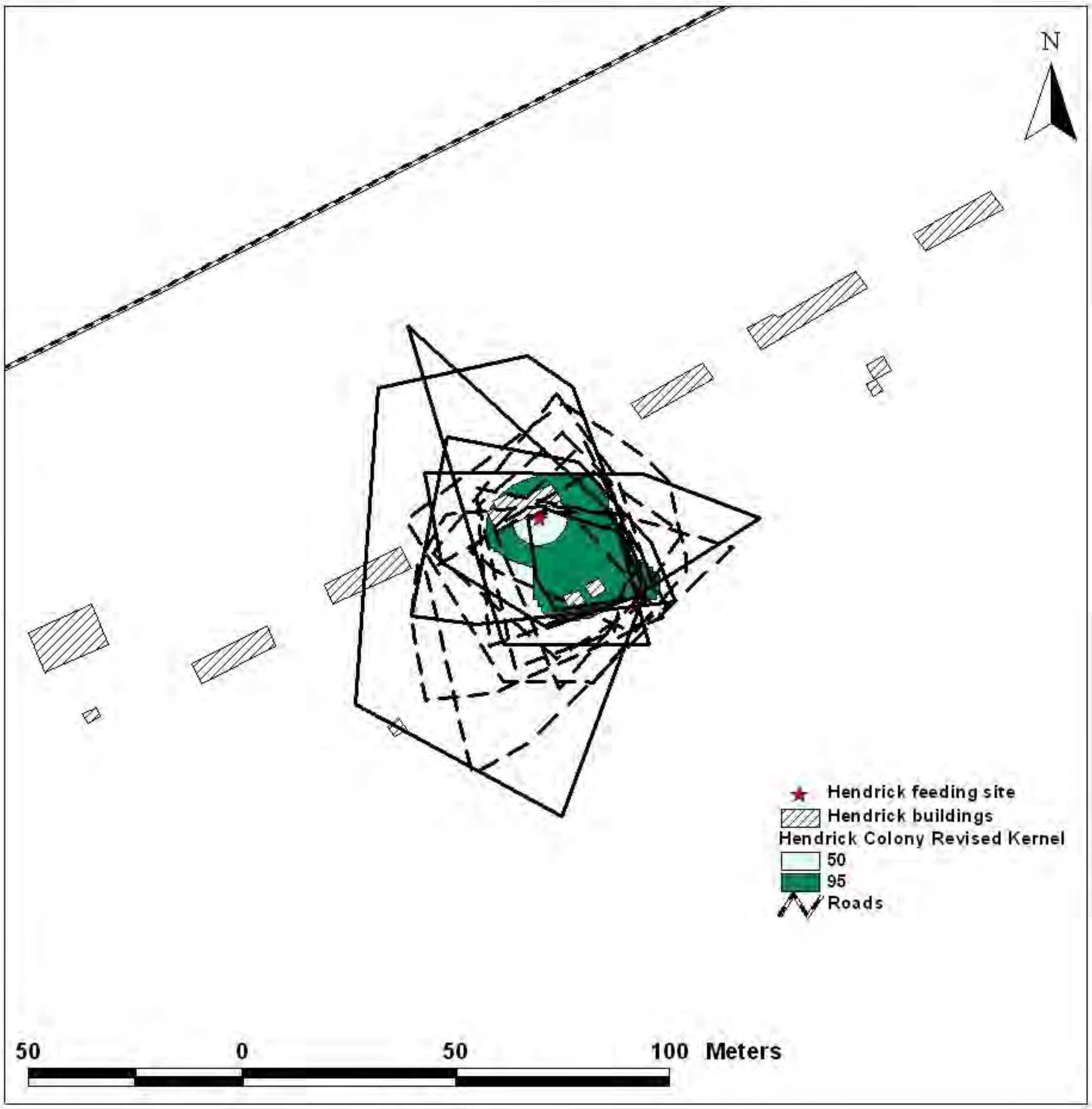

Figure 2. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from C1, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

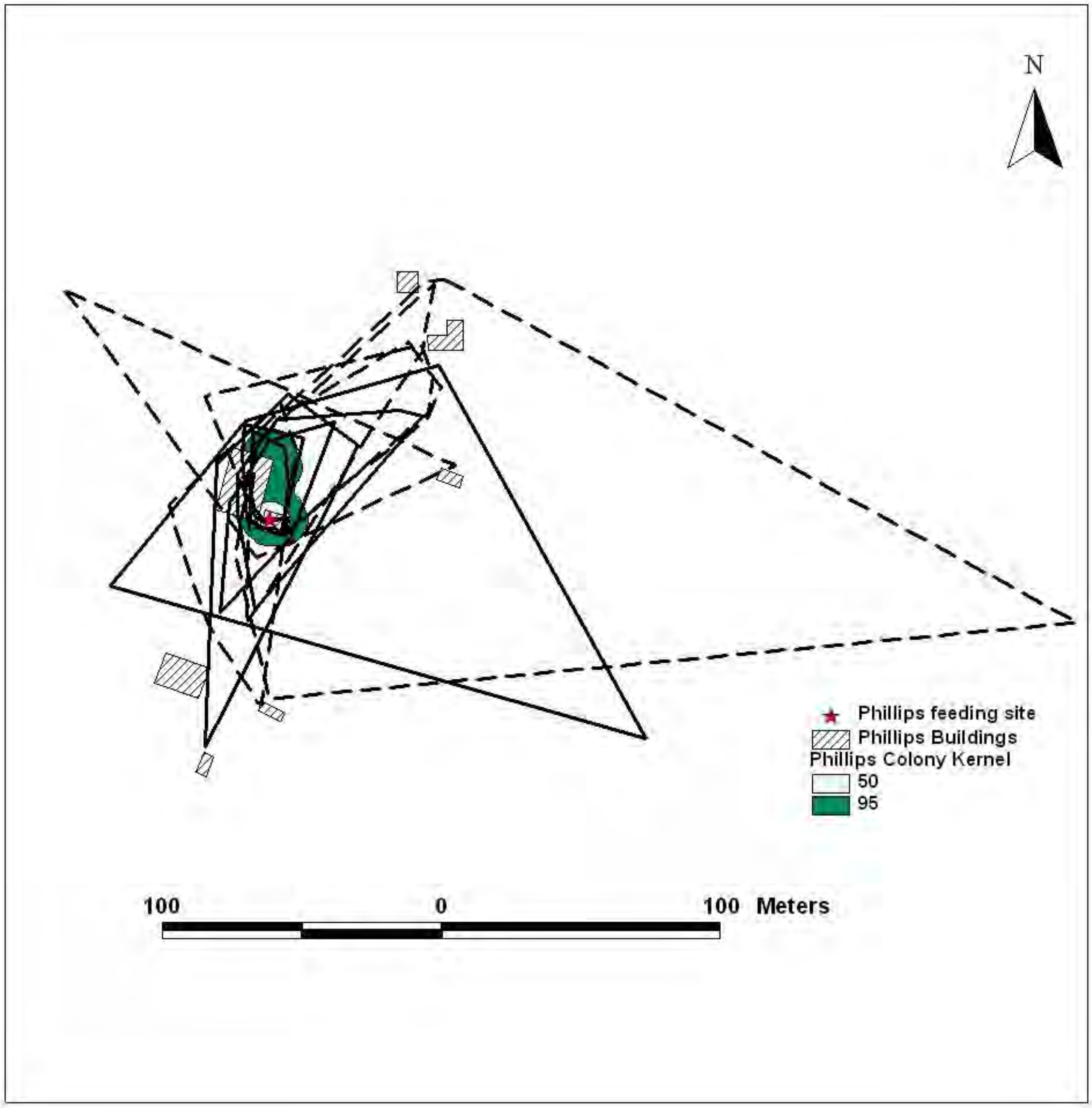

Figure 3. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from C2, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

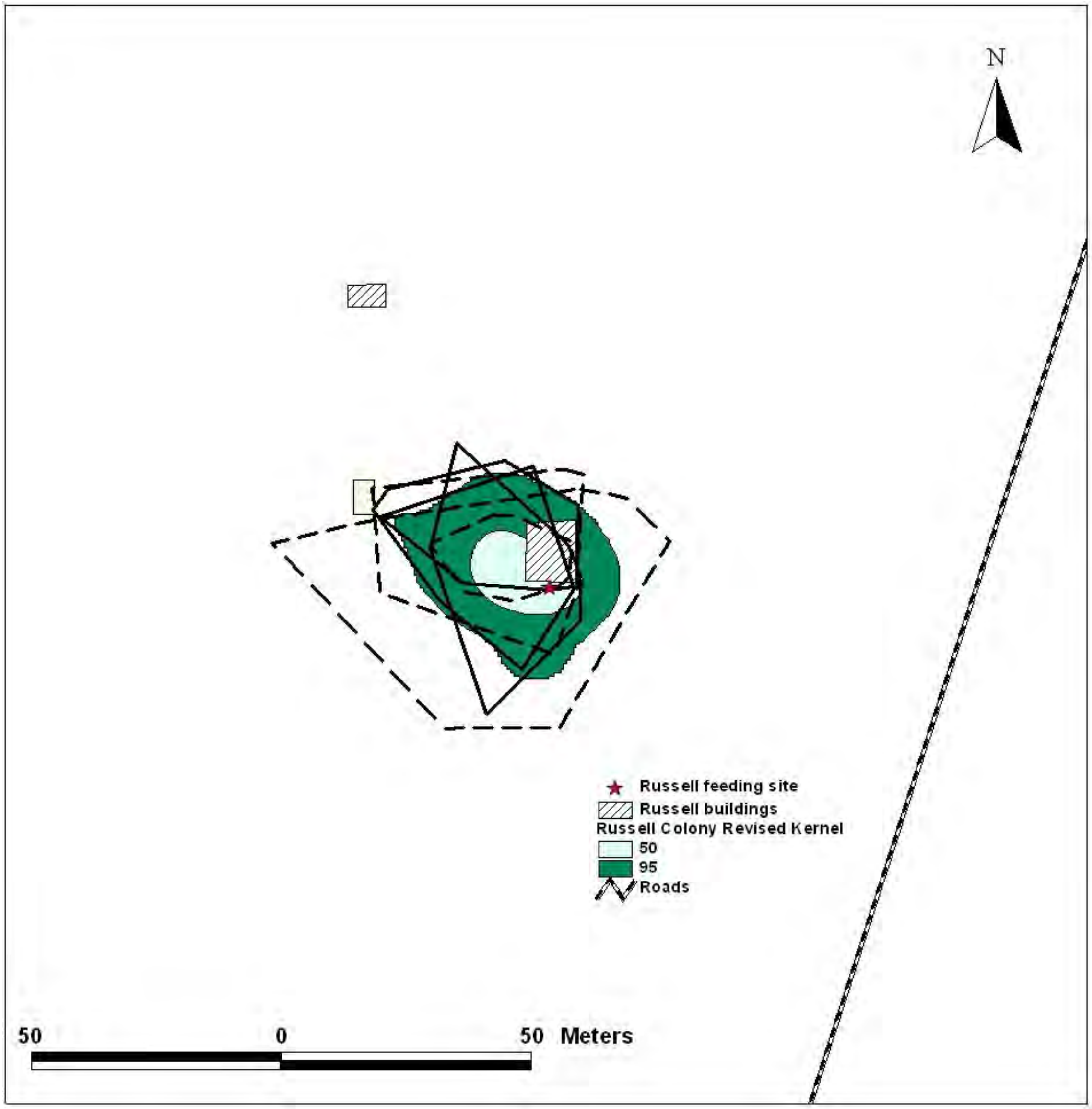

Figure 4. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from C3, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

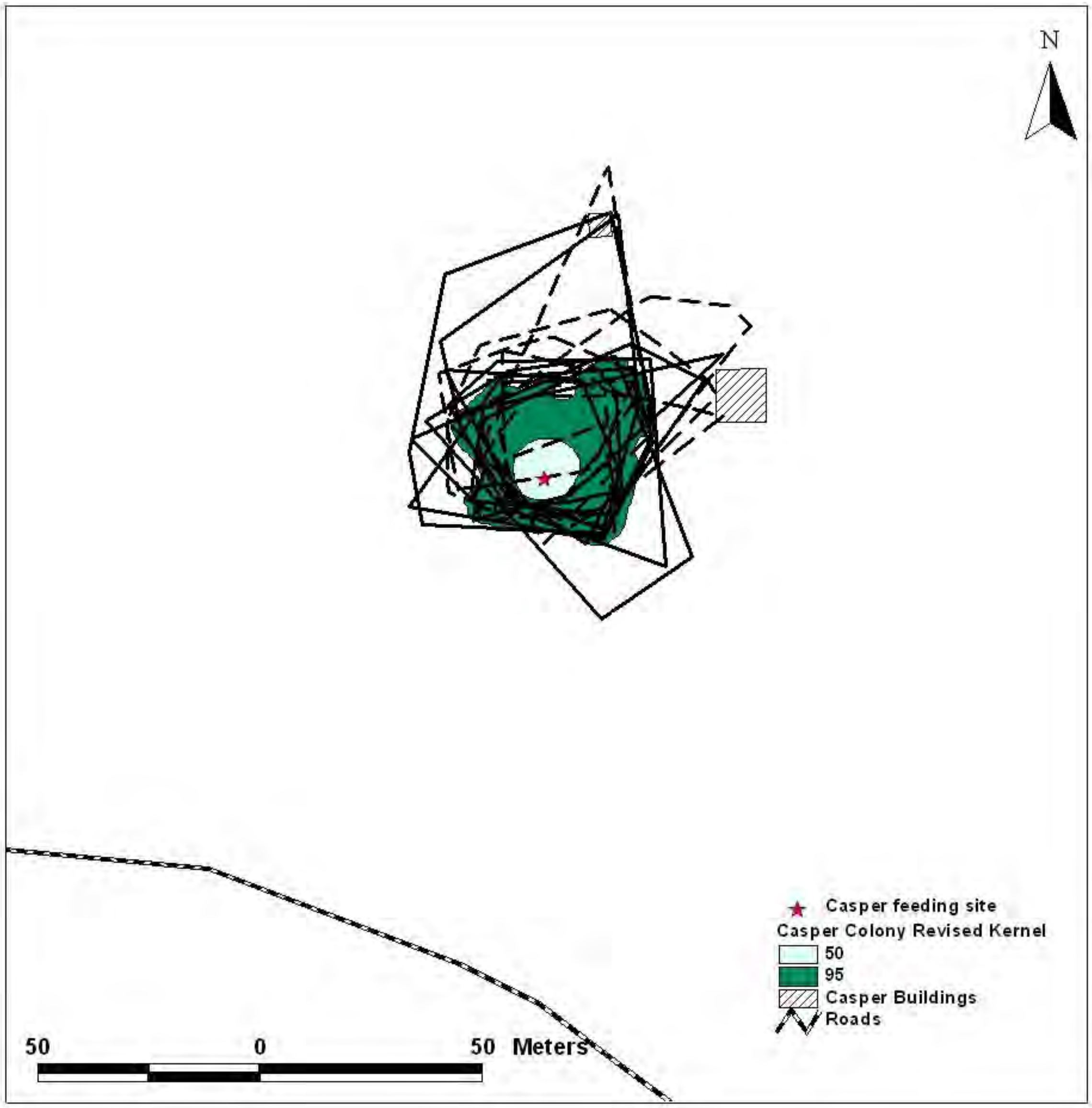

Figure 5. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/C 1, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

Figure 6. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/C 2, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

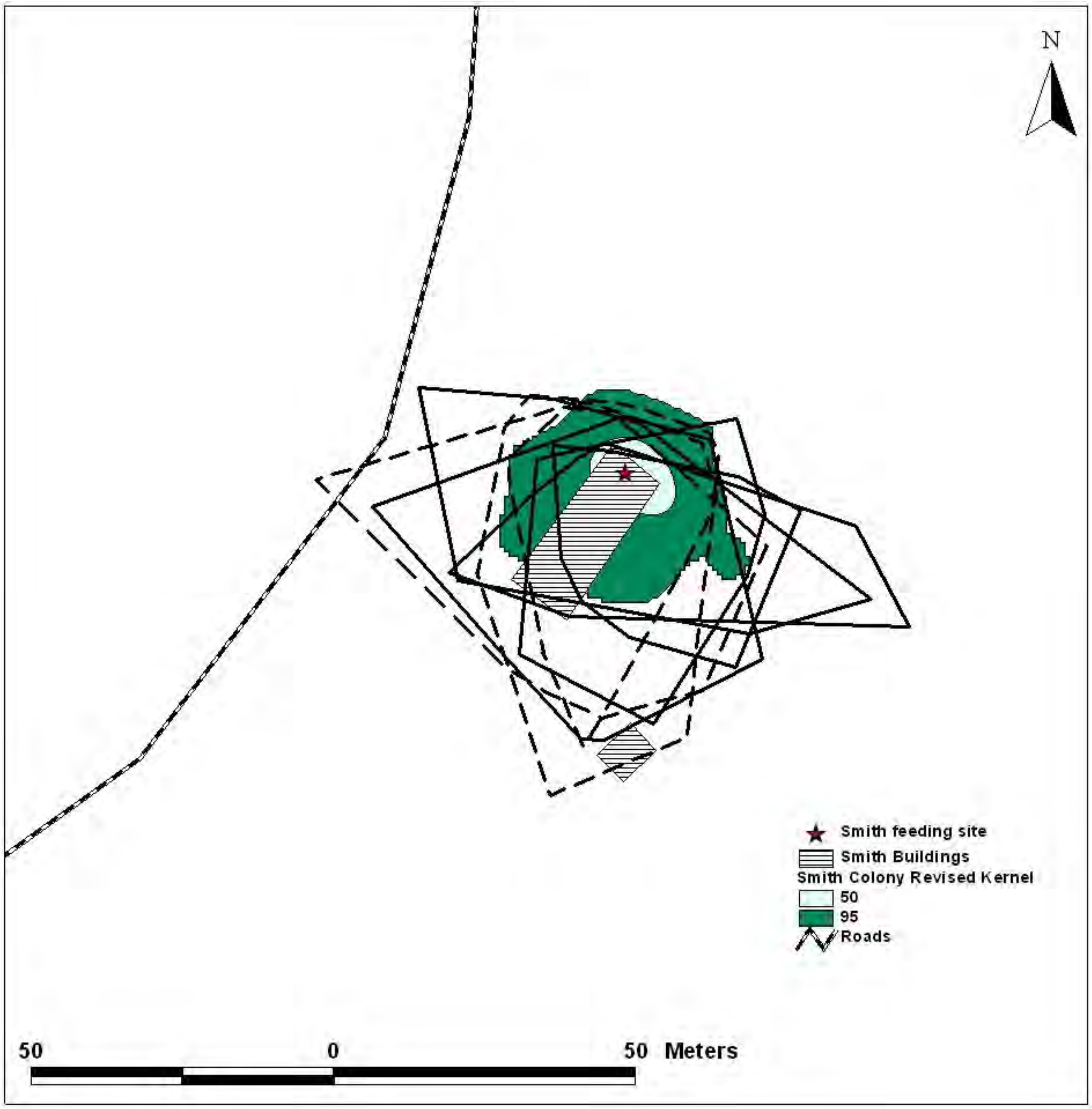

Figure 7. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/C 3, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

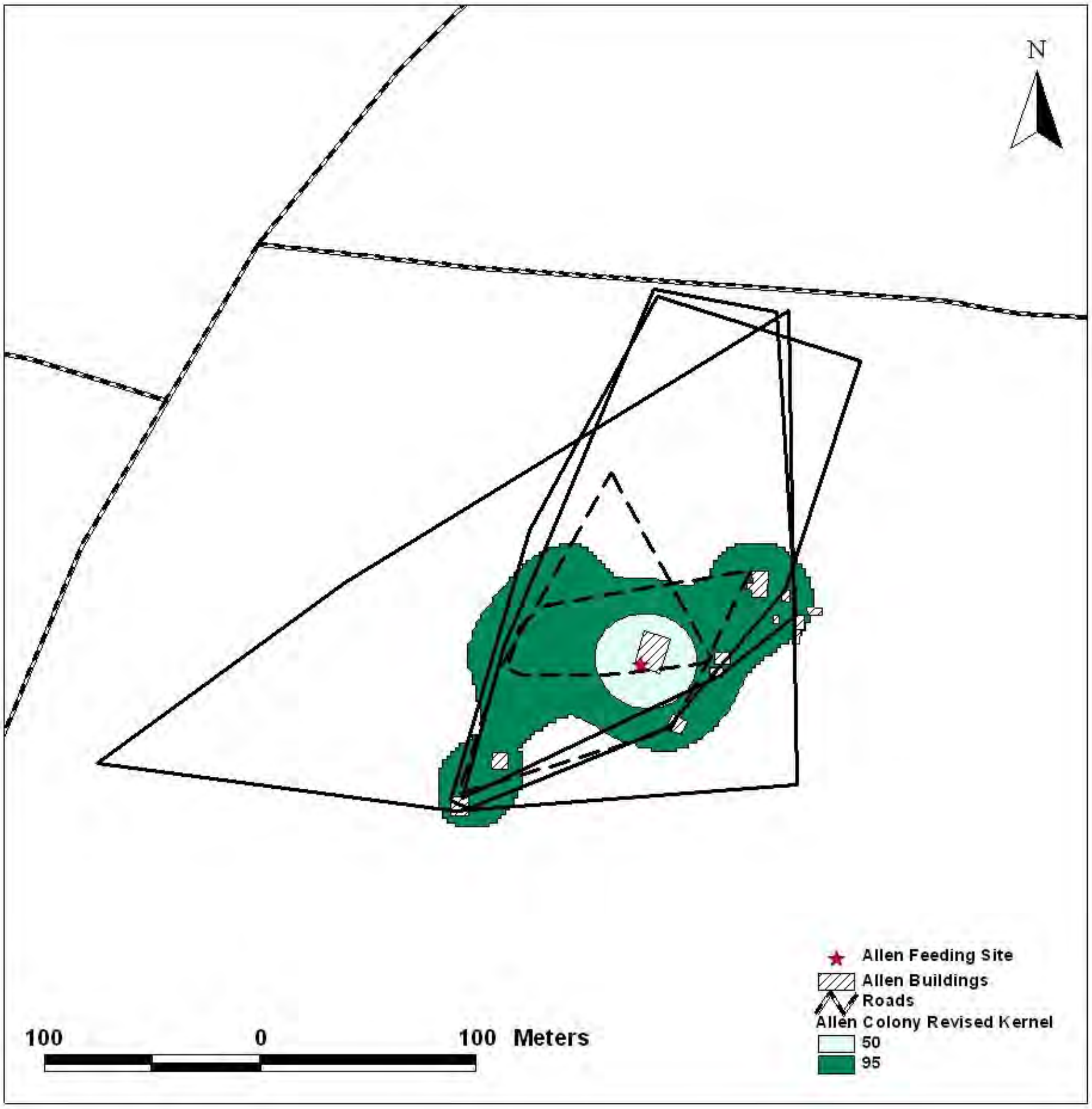

Figure 8. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/V 1, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

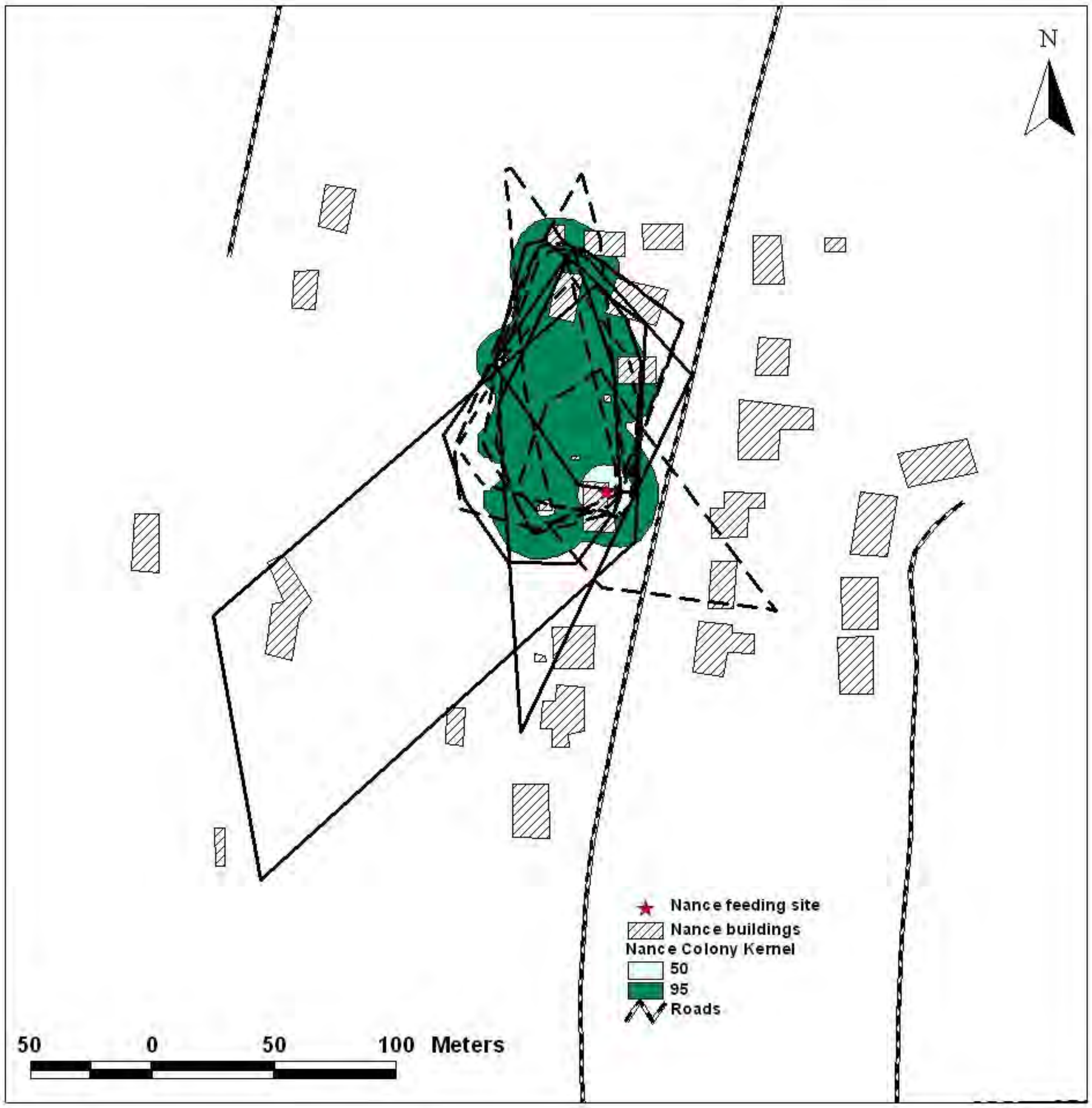

Figure 9. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/V 2, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

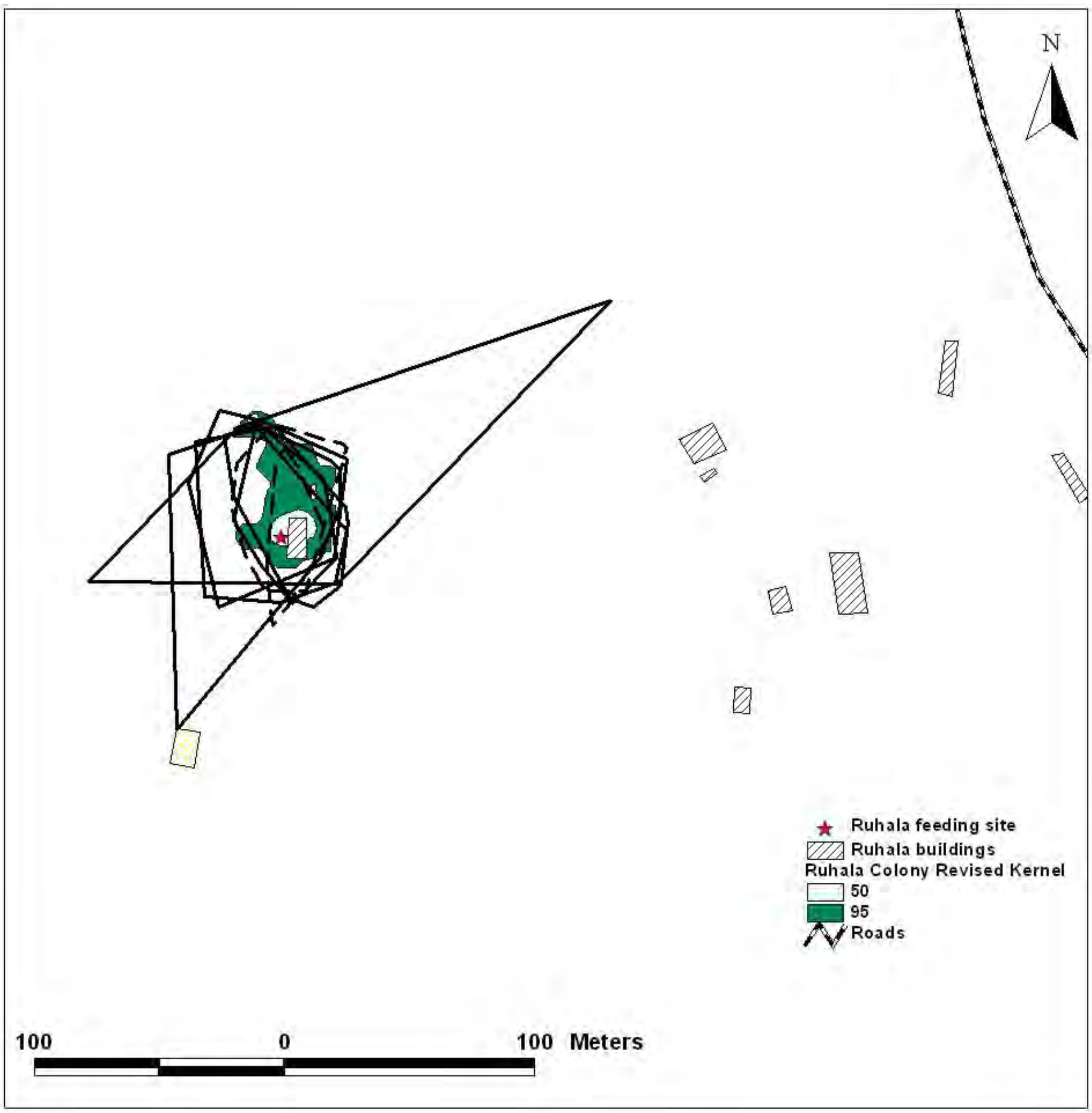

Figure 10. MCP 100 home ranges for male (solid outline) and female (dashed outline) cats from S/V 3, shown with the colony KE 95 (green) and KE 50 (pale green) range estimates.

Chapter 7: Community meetings to facilitate consensus on feral cat management

Felicia B. Nutter

Introduction

The appropriate management of feral cats is debated in large part because organizations and individuals have very different opinions regarding feral cats (Jessup 2004b; Levy & Crawford 2004; Patronek 1998; Slater 2002; Winter 2004). Polarization is not unique to the subject of feral cats and characterizes many issues where human interactions with animals and our environment are considered beneficial by some and detrimental by others – from the intentional and accidental movements of plant and animal species (McNeely 2001) to the development of automobile fuel efficiency standards (Auto Alliance 2005; Doniger et al. 2002).

Features common to polarized issues include limited information about some of the factors influencing choices, diverse parties that may be affected by decisions, potentially serious consequences arising from decisions, parties that may share common goals yet have different preferences for how to achieve them, and a need to develop consensus since individual parties cannot achieve the common goal alone (Maguire & Boiney 1994). Conflict resolution and decision analysis techniques were developed to address such situations and are commonly used to help solve seemingly intractable problems (Clemen 1999; Coleman & Deutsch 2000). Because these have been used successfully to mediate discussions about a variety of human/animal interactions (Maguire 1986; Maguire & Boiney 1994; Maguire & Servheen 1992; Redpath et al. 2004; Slenning 1997), stakeholder meetings were organized in Orange, Randolph and Wake counties, North Carolina, to apply similar methods to the discussion of feral cat management.

Materials and Methods

I contacted stakeholder groups by telephone and invited them to participate in community meetings to discuss feral cat management issues. A "snowball" technique was used to develop the participant lists, where each stakeholder contacted was asked to suggest other stakeholders to include in the meeting. If a particular stakeholder was mentioned more than once I added the organization or person to the list (Shmueli 2003). The final stakeholders contacted were representatives from public health agencies, animal control agencies, humane organizations, feral cat organizations, and feral cat caretakers. To foster an intimate working environment and encourage active participation by all parties, target attendance at each meeting was 10 to 15 people.

I conducted each meeting in a participatory format with assistance from B. Slenning. At the start of each meeting participants completed basic information forms and indicated their primary work or volunteer experience with feral cats. Participants then completed a 32-item self-administered survey designed to assess attitudes on a variety of feral cat issues. The survey was scored on a Likert-type scale, where response options corresponded to *strongly agree, agree, don't know, disagree*, and *strongly disagree* with the 32 presented statements. The moderators were available to answer questions and provide clarifications if needed. Two weeks after the meeting, identical surveys were mailed to all participants. Telephone follow-up and a second mailing occurred two weeks later for initial non-responders. Internal validity of the survey was evaluated with Cronbach's alpha test for reliability (Cronbach 1951). Changes in scores between the initial and follow-up surveys were evaluated using the sign test, with an alpha value of 0.05 considered significant (Roberson et al. 1995). Frequencies of responses to 32 statements were compared by county using the Mann-Whitney U test, with an alpha value of 0.05 considered significant.

Selected results from the initial questionnaires were presented to the meeting participants to demonstrate areas of agreement among participants. Participants were then asked to provide input for the following exercises:

(1) Develop a consensus definition for “feral cat”

(2) List attributes of feral cats that are liked and disliked

(3) List currently available options for feral cat management

(4) Choose the two most viable options for feral cat management and list pros and cons for each

(5) Develop a consensus list of conditions under which the two chosen management options are acceptable or preferred

(6) List reasons for failure of feral cat management programs

Using the participants’ inputs the meeting facilitators developed a decision diagram for feral cat management options, and then presented it to the working groups as a single text for negotiation (Spangler & Burgess 2003). Participants were asked if the diagram could be improved, and suggested improvements were discussed until consensus was reached and the diagram amended accordingly. The process was repeated until no additional improvements were suggested.

Results

There were 12 participants at the Orange County meeting, and 13 at the Wake County meeting, with representatives from most of the target stakeholder groups (Table 1). Attendance at two separate attempted meetings in Randolph County failed to achieve sufficient numbers and diversity to support productive discussions, with the same two feral cat caretakers attending both meetings.

All participants completed the surveys at the beginning of the meetings. There were no significant differences among frequencies of responses between Orange and Wake counties, and the results have been pooled for presentation (Table 2). Internal validity of the questionnaire was high, with a Cronbach's alpha of 0.91. There was no significant difference in the proportion of individuals in Orange (8 of 12, 67%) and Wake (9 of 13, 69%) that responded to the survey.

A scientifically accurate consensus definition (Liberg & Sandell 1988; McKnight 1964; Slater 2002) for feral cat was developed by both working groups (Table 3). Other attributes of feral cats that participants considered relevant but not necessary components of the definition addressed the health and reproductive status of the typical feral cat, as well as aspects of biology and behavior.

The lists of attributes of feral cats that are liked and disliked were almost identical between counties (Table 4), as were the lists of management options (Table 5). Both Orange and Wake county working groups chose to discuss the pros and cons of traditional feral cat control by trapping and removal (usually with subsequent euthanasia) and management by a trap, neuter and return program (Table 6). The consensus lists of conditions under which the two management options are acceptable or preferred (Table 7) and the lists of reasons for management failure (Table 8) were also very similar between counties.

The decision diagrams developed using the iterative process were identical except for the additional step included by the Wake County group for suitability of the environment where the cats are located (Figure 1).

Discussion

The initial response from all stakeholder groups contacted was enthusiastic and encouraging, but it proved difficult to schedule the meetings to assure adequate representation from the various stakeholder groups. This difficulty was predominantly due to high turnover in positions with both municipal governments and with animal rescue and advocacy groups, which is a recognized challenge in the animal care and control trade (Antoniades 2005; Figley 1995). Meetings in all three locales were rescheduled several times, and eventually successful meetings were only held in Orange and Wake Counties.

The working group compositions differed between the counties. In Wake County, representatives were present from all target stakeholders, but in Orange County there were no participants from the public health or wildlife sectors. This difference is most clearly reflected in the failure of the Orange Country group to include items about environmental suitability and sensitive wildlife species in Table 7, and the similar lack of an Orange County decision node on suitability of the environments for the maintenance of neutered feral cat colonies. Discussions about environmental suitability in the Wake County group encompassed a diversity of issues, including the possible presence of wildlife species of concern, location of colonies on public vs. private land, and proximity of colony sites to busy roads or other areas considered possibly dangerous to the cats and input from the wildlife sector was important. Other stakeholders raised public health issues at the Orange County meeting, and while a public health sector representative may have contributed additional information, the meeting outputs addressing public health were similar between the two counties. These results support the need to be as complete as possible in identifying and including stakeholders.

Responses received to the initial survey questions were encouraging because areas of agreement and common goals were identified. The common responses to questions 1-3 and 16, where 100% of responses were in two adjacent categories, and questions 5, 9, 11, 17, 21, 24, and 30, with the majority of responses in a single category, were used to demonstrate to meeting participants the existing areas of agreement and shared goals among stakeholders. Important points to highlight were that participants felt that stakeholder collaboration was important, feral cat management could be improved, and that traditional trapping and euthanasia of feral cats was not always the best nor the only option available. While the majority of meeting participants (19 of 25) were from the humane, feral cat organization or feral cat caretaker sectors, responses to the survey statements showed a diversity of opinion within these parties. For example, 15 of 25 participants disagreed or strongly disagreed that trapping and euthanasia was the best management option (Question 5). So even if all 15 were from humane or feral cat sectors, at least 4 of 19 were neutral or agreed with the statement. Similarly for Question 12, only 5 of 25 respondents disagreed that trapping and euthanasia can be the most appropriate option under some circumstances; Question 17, where 20 of 25 agreed that TNR can be the best option under some circumstances, and Question 30, where 20 of 25 agreed that pet cats should be kept indoors. Within any group there will be diverse opinions, and while some people's positions may be inflexible there will likely be others who are willing to collaborate and work towards consensus. Resources should be invested in working with those who are open to new information and the possibility of change, and who may have a better chance of influencing the "closed fanatics" than perceived opposition parties (Slenning 1997). The areas where there were more "disagreements" or diversity of responses were related to the costs and effectiveness of different interventions (Questions 12, 14, 15, 19) the role of feral cats in disease transmission and native wildlife predation (Questions 4, 6, 8, 10, 13, 18, 20, 27), how feral cats relate to different disciplines such as ecology and animal control (Questions 7, 22, 25, 32), and the "rights" of feral cats and relationships with caretakers (Questions 26, 28, 29,). This diversity is not surprising, because these topics are either lacking hard data to inform assessments, or are properly characterized as personal value judgements. When these results were presented to meeting participants, many were pleasantly surprised at the amount of common ground. Comments were offered about the assumptions that many participants had regarding the opinions and preferences of "the other side," and the inability of the stakeholders to work together. Starting the meetings with this positive atmosphere likely contributed to the generally constructive working environment.

By using pre and post meeting surveys, we were able to assess changes in attitudes that might have been influenced by the participatory meeting, but found no significant differences. The lack of change in attitude or opinion does not necessarily indicate that the stakeholder meeting was unsuccessful. Most of the areas of "disagreement" or diverse opinion, as discussed above, pertained to topics that lack solid foundation data for evaluating the impacts of possible choices.

Both working groups developed similar consensus definitions for feral cats, based upon their origin as domestic cats and their reversion to free-living states. During the related discussion both groups also agreed that stray cats were different from feral cats, and were characterized by having been "owned" during their lifetime, and generally behaving in a friendly manner towards humans. The other feral cat attributes that stakeholders felt were important exemplified the diversity that exists within feral cats (for tolerance to people, food sources, etc.), and highlighted the influence of that diversity on the choice of management option. The definition developed by the working groups is consistent with that proposed by other researchers (Clarke & Pacin 2002; Levy & Crawford 2004; Slater 2002), and the groups recognized that feral cats are a subset of free-roaming cats.

Working groups developed similar lists of feral cat management options, predominantly focused on direct interventions. Legislative options, including mandatory pet cat sterilization, limits on the number of pet cats per owner, and "leash" laws, as well as public education programs, were also included and are related to the importance of the pet cat population as the ultimate source of feral cats. Participants in both meetings were able to reach a consensus that trapping and removal, even with possible euthanasia of trapped cats, was an appropriate management option under certain circumstances, and both groups defined acceptable circumstances similarly. Important circumstances included the need for rapid feral cat population reductions in the face of disease, the presence of feral cats in unsuitable environments (public areas, adjacent to busy highways, etc.), or potential impacts on wildlife species of concern. Both groups also concluded that non-lethal programs (relocation or adoption for removed cats, and TNR for remaining cats) were more humane, more acceptable to the general public, and could potentially result in long-term animal control cost reductions and feral cat population declines. The Wake County working group discussed more economic issues of feral cat management than the Orange County group did. Wake County participants mentioned that public expenditures on animal control, which were estimated at $2.5 million for 2002, contributed to people's dislike of feral cats, and cited decreased public expenditures due to grass-roots and volunteer participation as a benefit of TNR programs. It's interesting to note that none of the working groups discussed chemical or immunosterilants as potential control options, even though various methods have been used since the 1970's and new methods are being developed (Chapter 1). This is probably because such methods remain largely theoretical or experimental, and the lay public is not widely aware of them.

A simple decision diagram was developed using the preference information. The Wake County diagram included an additional step related to the environmental suitability of feral cat colony locations. There are multiple additional options available if feral cats are trapped and removed from a site. If trapping and removal is chosen because of a potential human health problem related to the presence of feral cats, such as rabies cases within the colony, then euthanasia is the outcome. For other chronic incurable health problems such as cases of FeLV or FIV, some groups will opt for euthanasia while others will attempt adoption for friendly cats or long-term sanctuary care. For potentially treatable health problems, such as internal or external parasites and respiratory diseases, treatment is an option if resources are available, with adoption, sanctuary care, or relocation to a suitable site with an available caretaker as the final outcomes. The options are similar when cats are removed from unsuitable environments – friendly cats can be offered for adoption, cats can be relocated to suitable sites with a caretaker, cats may be placed in a specific sanctuary, or euthanized if no other option is available. All participants admitted that while euthanasia was considered a last resort option by most of them, it is still the most common result after feral cat removal due to lack of financial resources and adequate space (in shelters, sanctuaries, relocation sites or adoptive homes) to pursue the other options. Similar assessments of options and recommendations have been made by other researchers (Castillo & Clarke 2003; Clarke & Pacin 2002; Hughes & Slater 2002; Slater 2002), but their conclusions have not been reached via the participatory process used here. Building consensus among stakeholders is an important component of fostering good working relationships, and can help facilitate the acceptance and implementation of novel feral cat management options. If consensus is not sought prior to implementation of management strategies such as TNR, antagonistic and confrontational situations can arise among various stakeholders (Levy 2003).

There was agreement that feral cat management programs fail, regardless of their methodology, because of financial and personnel shortages, lack of public awareness and interest, and irresponsible human behavior. Some discussions occurred regarding local ordinances which in some municipalities made TNR programs illegal or at least difficult to administer. For example, feral cat caretakers may be considered owners if they provide food or shelter for the cats beyond a specified length of time and can be held liable for damages caused by the cats. Participants agreed that TNR programs could still be implemented even when local ordinances were violated if there was good communication and cooperation among animal control, humane organizations, and TNR programs. Such ordinances can be impractical and difficult to enforce, particularly with feral cat colonies on private property. If the caretakers are unwilling to implement lethal control methods, they are unlikely to identify themselves to animal control or other regulatory agencies, and the colonies will probably only come to attention if a neighbor files a nuisance complaint. Additional discussions also focused on the lack of communication and cooperation among the groups, due in part to long-term mistrust and perceived extremist attitudes in all groups. The high turnover that we observed in many organizations contributes to a lack of good communication and difficulties in developing successful working relationships. Both groups suggested that better coordination of programs would lead to better feral cat management. They suggested that a “neutral” third party could effectively fill a coordination roll, but also realized that the scarcity of existing financial and personnel resources made creation of a new position challenging. None of these issues is novel or surprising, and they too have been discussed by other feral cat researchers (Levy & Crawford 2004; Slater 2002, 2004).

Though feral cat management is an important issue for stakeholders, it remains a more marginal issue for wider audiences. Without good documentation of the costs of feral cats (related to current financial expenditures, human health risks, wildlife impact, etc.) there is no great motivation for additional public expenditures for improved feral cat management. Also, the ultimate source for feral cats is irresponsible pet cat owners, and the problem will never be successfully addressed in the long-term without reducing the influx of new cats into the free-roaming and feral population. Changing human behavior, however, is probably much more difficult and expensive than periodically trapping and removing cats from colony sites, or implementing alternative management strategies.

The working groups considered the meetings useful, particularly because they helped clarify stakeholder agreement on the common goals of decreasing feral cat populations and decreasing the number of cats euthanized, while acknowledging different methods for achieving those goals. The focus on existing areas of agreement and shared goals helped participants realize that their positions were not as polarized as many had assumed. The emphasis on common goals and consensus-building, in which the importance of diverse opinions was acknowledged and discussions continued until acceptable options were identified, helped foster good will and desire to work for positive outcomes. A working decision diagram was developed without using hard data, but based on preferences and consensus on circumstances under which certain management options were acceptable or unacceptable. This basic diagram can be used in more classical decision analysis scenarios to run cost-benefit analyses and develop payoff tables as more hard data become available to inform choices. Meeting participants left with outputs they all agreed they could “live with,” and that they could promote to their respective organizations or communities. Opportunities for collaboration and linkages among groups were identified. The participants felt that regular, facilitated meetings with representation from all stakeholders would help build better working relationships and improve management and control of feral cats.

Stakeholder meetings managed for consensus-building and qualitative decision analysis can improve working relationships among feral cat stakeholders. While some have commented that common ground on this issue is just emerging (Jessup 2004a), it is more accurate to acknowledge that the common ground has long existed but has been obscured by concentrating on the differences among stakeholders rather that highlighting similarities.

References

Auto Alliance. 2005. The facts on improving fuel efficiency. Auto Alliance, Washington, D.C., USA.

Antoniades, K. 2005. Slowing the revolving door: part 2. *Animal Sheltering* **January-February**:16-23.

Castillo, D., and A. L. Clarke. 2003. Trap/neuter/release methods ineffective in controlling domestic cat "colonies" on public lands. *Natural Areas Journal* **23**:247-253.

Clarke, A. L., and T. Pacin. 2002. Domestic cat "colonies" in natural areas: a growing exotic species threat. *Natural Areas Journal* **22**:154-159.

Clemen, R. T. 1999. *Making Hard Decisions: An Introduction to Decision Analysis*. Duxbury Press, Belmont, California, USA.

Coleman, P. T., and M. Deutsch, editors. 2000. *The Handbook of Conflict Resolution: Theory and Practice*. Jossey-Bass, San Francisco, California, USA.

Cronbach, L. J. 1951. Coefficient alpha and the internal structure of tests. *Psychometrika* **16**:297-334.

Doniger, D., D. Friedman, R. Hwang, D. Lashof, and J. Mark. 2002. *Dangerous Addiction: Ending America's Oil Dependence*. Page 53. National Resources Defense Council, Inc., and the Union of Concerned Scientists.

Figley, C. R. 1995. *Compassion Fatigue*. Brunner/Mazel Publisher, New York City, New York, USA.

Hughes, K. L., and M. R. Slater. 2002. Implementation of a feral cat management program on a university campus. *Journal of Applied Animal Welfare Science* **5**:15-28.

Jessup, D. A. 2004a. Some common ground on feral cats may be emerging. *Journal of the American Veterinary Medical Association* **225**:1662.

Jessup, D. A. 2004b. The welfare of feral cats and wildlife. *Journal of the American Veterinary Medical Association* **225**:1377-1383.

Levy, J. 2003. New Florida policy bans TNR - Statement from Dr. Julie Levy read at the hearing of the Florida Fish and Wildlife Commission on the proposed policy to eradicate feral cats in Florida. Best Friends Animal Society. Best Friends Animal Society website, accessed October 31, 2005. http://www.bestfriends.org/allthegoodnews/specialfeatures/ferals1_7.cfm

Levy, J. K., and P. C. Crawford. 2004. Humane strategies for controlling feral cat populations. *Journal of the American Veterinary Medical Association* **225**:1354-1360.

Liberg, O., and M. Sandell. 1988. Spatial organisation and reproductive tactics in the domestic cat and other felids. Pages 83-98 in D. C. Turner, and P. Bateson, editors. *The Domestic Cat: the Biology of its Behavior*. Cambridge University Press, New York.

Maguire, L. A. 1986. Using decision analysis to manage endangered species populations. *Journal of Environmental Management* **22**:345-360.

Maguire, L. A., and L. G. Boiney. 1994. Resolving environmental disputes: a framework incorporating decision analysis and dispute resolution techniques. *Journal of Environmental Management* **42**:31-48.

Maguire, L. A., and C. Servheen. 1992. Integrating biological and sociological concerns in endangered species management: augmentation of grizzly bear populations. *Conservation Biology* **6**:426-434.

McKnight, T. 1964. Feral livestock in Anglo-America. *University of California Publications in Geography*:1-87.

McNeely, J. A. E. 2001. *The Great Reshuffling: Human Dimensions of Invasive Alien Species*. IUCN, Gland, Switzerland and Cambridge, UK.

Patronek, G. J. 1998. Free-roaming and feral cats--their impact on wildlife and human beings. *Journal of the American Veterinary Medical Association* **212**:218-226.

Redpath, S. M., B. E. Arroyo, F. M. Leckie, P. Bacon, N. Bayfield, R. J. Gutierrez, and S. J. Thirgood. 2004. Using decision modeling with stakeholders to reduce human-wildlife conflict: a raptor-red grouse case study. *Conservation Biology* **18**:350-359.

Roberson, P., S. Shema, D. Mundfrom, and T. Holmes. 1995. Analysis of paired Likert data: how to evaluate change and preference questions. *Family Medicine* **27**:671-675.

Shmueli, D. 2003. Conflict Assessment. in G. Burgess, and H. Burgess, editors. *Beyond Intractability*. Conflict Resolution Consortium, University of Boulder, Boulder, Colorado, USA.

Slater, M. R. 2002. *Community Approaches to Feral Cats: Problems, Alternatives, and Recommendations.* Humane Society Press, Washington, D.C., USA.

Slater, M. R. 2004. Understanding issues and solutions for unowned, free-roaming cat populations. *Journal of the American Veterinary Medical Association* **225**:1350-1354.

Slenning, B. D. 1997. Epidemiology without data, or can epidemiology and econometrics help us ask questions? Brucellosis and the Greater Yellowstone Area bison. USDA/APHIS/VS Designated Brucellosis Epidemiology Short Course, Memphis, Tennessee.

Spangler, B., and H. Burgess. 2003. Consensus building. in G. Burgess, and H. Burgess, editors. *Beyond Intractability*. Conflict Research Consortium, University of Colorado, Boulder, Colorado, USA.

Winter, L. 2004. Trap-neuter-release programs: the reality and the impact. *Journal of the American Veterinary Medical Association* **225**:1369-1376.

Table 1: Participants in stakeholder meetings by field.

	Orange County (%)	Wake County (%)
Public health	0 (0)	1 (8)
Animal control	2 (17)	1 (8)
Wildlife organnization	0 (0)	2 (15)
Humane organnization	7 (58)	3 (23)
Feral cat organnization	1 (8)	4 (31)
Feral cat caretaker	2 (17)	2 (15)
Total	**12**	**13**

Table 2: Likert-type survey administered to stakeholder meeting participants, and resulting total frequencies of responses and response by participant sector (feral cat sector/regulatory sector). Feral cat sector includes participants from humane and feral cat organzations and feral cat caretakers. Regulatory sector includes animal control, public health, and state wildlife organizations.

	QUESTION	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
1	I am interested in feral cat population control issues.	80%	20%	0%	0%	0%	Stongly Agree
		16/4	3/2	0/0	0/0	0/0	
2	Feral cats are not a problem in this county.	0%	0%	0%	8%	92%	Strongly Disagree
		0/0	0/0	0/0	0/2	19/4	
3	There should be more public education about feral cat issues.	88%	12%	0%	0%	0%	Strongly Agree
		17/5	2/1	0/0	0/0	0/0	
4	Feral cats have a detrimental impact on native wildlife.	28%	20%	20%	12%	20%	Neutral
		5/2	2/3	5/0	2/1	5/0	
5	The best way to manage feral cats in this county is by trapping and euthanasia.	4%	12%	24%	4%	56%	Strongly Disagree
		0/1	1/2	5/1	0/1	13/1	
6	Feral cats are beneficial because they help control rodent populations	20%	20%	32%	16%	12%	Neutral
		5/0	4/1	5/3	2/2	3/0	
7	Feral cat control is a conservation and ecology issue.	16%	40%	24%	16%	4%	Agree
		3/1	6/4	6/0	3/1	1/0	
8	Feral cats are a public health risk.	20%	36%	20%	16%	8%	Agree
		3/2	7/2	4/1	3/1	2/0	
9	There are too many feral cats in this county.	60%	24%	8%	4%	4%	Strongly Agree
		11/4	5/1	1/1	1/0	1/0	
10	Feral cats may help protect some native wildlife populations by controlling other introduced predators.	4%	16%	48%	24%	8%	Neutral
		1/0	2/2	12/0	3/3	1/1	

Table 2: continued

	QUESTION	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
11	Feral cat control is an animal welfare issue.	52%	24%	16%	0%	8%	Strongly Agree
		12/1	4/2	2/2	0/0	1/1	
12	In some situations, trapping and euthanasia is the most appropriate way to manage feral cat populations.	24%	32%	24%	8%	12%	Agree
		3/3	6/2	5/1	2/0	3/0	
13	Feral cats are a greater public health risk than pet domestic cats.	20%	36%	20%	16%	8%	Agree
		3/2	7/2	5/0	2/2	2/0	
14	The best way to decrease the number of feral cats in this county is by trapping, surgical sterilization and subsequent release.	52%	20%	16%	8%	4%	Strongly Agree
		12/1	3/2	4/0	0/2	0/1	
15	Trapping and euthanasia is a cost-effective method of feral cat population control.	8%	16%	20%	20%	36%	Disagree
		1/1	2/2	5/0	2/3	9/0	
16	Animal control, public health, veterinarians, humane organizations, and concerned citizens should work together to control feral cats.	80%	20%	0%	0%	0%	Strongly Agree
		16/4	3/2	0/0	0/0	0/0	
17	In some situations, trapping, surgical sterilization and subsequent release is the most appropriate way to manage feral cat populations.	60%	20%	12%	4%	4%	Strongly Agree
		15/0	3/2	1/2	0/1	0/1	
18	Feral cats are responsible for causing a significant decline in native songbird populations.	8%	24%	32%	8%	28%	Neutral
		1/1	3/3	6/2	2/0	7/0	
19	Trapping, surgical sterilization, and subsequent release is a cost-effective method of feral cat population control.	40%	16%	32%	8%	4%	Agree
		10/0	2/2	7/1	0/2	0/1	
20	People who feed and care for feral cats are not educated about the risks involved.	0%	28%	20%	20%	32%	Disagree
		0/0	4/3	4/1	4/1	7/1	
21	Feral cat management and control programs could be improved.	80%	12%	8%	0%	0%	Strongly Agree
		15/5	2/1	2/0	0/0	0/0	
22	It's up to Animal Control to reduce the number of feral cats in this county.	4%	12%	16%	24%	44%	Disagree
		0/1	2/1	3/1	6/0	8/3	

Table 2: continued

	QUESTION	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
23	There is more than one way to effectively control feral cat populations.	40% 7/3	24% 4/2	28% 7/0	4% 0/1	4% 1/0	Agree
24	Low-cost spay/neuter programs for pet cats will decrease the number of feral cats in this county.	64% 14/2	28% 4/3	0% 1/0	4% 0/0	4% 0/1	Strongly Agree
25	Feral cat control is a public health issue.	36% 5/4	36% 9/0	0% 4/2	24% 0/0	4% 1/0	Agree
26	Feral cats have a right to live freely in this county.	28% 7/0	12% 3/0	24% 4/2	24% 4/2	12% 1/2	Neutral
27	Feral cats are taking the place of native predators that used to live here.	0% 0/0	28% 6/1	32% 6/2	20% 3/2	20% 4/1	Neutral
28	People who feed and care for feral cats benefit from their relationship with the cats.	48% 11/1	24% 4/2	20% 4/1	8% 0/2	0% 0/0	Agree
29	Feral cat populations only exist because people actively provide food for them.	0% 0/0	0% 0/0	20% 3/2	32% 5/3	48% 11/1	Disagree
30	Pet cats should always be kept indoors.	56% 11/3	24% 5/1	4% 1/0	4% 0/1	12% 2/1	Strongly Agree
31	Feral cats are a reservoir for rabies.	12% 2/1	28% 4/3	28% 5/2	12% 3/0	20% 5/0	Neutral
32	Low cost spay/neuter programs for pet cats should be supported by tax dollars.	40% 10/0	28% 4/3	16% 3/1	8% 2/0	8% 0/2	Agree

Table 3: Stakeholder definition of feral cats, and additional relevant attributes developed during Orange County [O] and Wake County [W] meetings.

Consensus Definition	*Felis catus* with a history of domesticity, but reverted to wild behavior in the current or any previous generation
Other Attributes	Diversity of tolerance for humans[W] Diversity of habitats, population sizes[W] Variable physical condition[W] Usually reproductively intact and unvaccinated[O,W] Opportunistic, can survive without human assistance[O,W]

Table 4: Attributes of feral cats that are liked and disliked, developed during Orange County [O] and Wake County [W] meetings.

Attributes of Feral Cats Disliked by People
Nuisance (noise from fighting and mating, smell from urine spraying, property damage)[O,W]
Potential to spread disease to pets and people[O,W]
Predation on native wildlife[O,W]
Tangible example of human irresponsibility[O,W]
Use of tax money for control[W]

Attributes of Feral Cats Liked by People
Rodent/pest control and secondary disease control[O,W]
Provide outlet for feelings of compassion, responsibility, desire to nuture, desire to help[O,W]
Remind people of their domestic cats[O,W]

Table 5: Feral cat management options identified during Orange County [O] and Wake County [W] meetings.

Feral Cat Management Options
Trap and euthanize[O,W]
Trap and remove (relocate or adopt)[O,W]
Trap, neuter and return[O,W]
Mandatory sterilization for pet cats[O,W]
Legislation to curb pet cat roaming[O,W]
Subsidized or low-cost sterilization for pet cats[O,W]
Legal limit for number of pet cats per owner[O]
Public education[W]

Table 6: Pros and cons of the two primary management options discussed during Orange County[O] and Wake County[W] meetings.

	Trap and Removal	*Trap, Neuter, and Return*
Pros	Quick population reduction[O,W]	Humane, more acceptable to general public[O,W]
	Disease control[O,W]	Shared responsibility for and ownership of the problem[O,W]
		Decreased public cost due to grass-roots and volunteer participation[W]
Cons	Perceived as inhumane by general public[O,W]	Predation on native wildlife continues[O,W]
	Often a short-term solution[O,W]	Does not address all nuisance issues[O,W]
		Does not address all zoonotic disease issues[O,W]
		May violate local ordinances,[W] or involve liability issues[O]
		Not widely available[O,W]

Table 7: Consensus list of conditions under which the two feral cat management options are acceptable or preferred by stakeholders in Orange County [O] and Wake County [W].

Trap and Removal	*Trap, Neuter, and Return*
Rapid depopulation needed (disease concern, caretaker overwhelmed, etc.)[O,W]	Cat population is healthy[O,W]
Presence of friendly cats that can be adopted[O,W]	Dedicated caretaker is available[O,W]
Threatened or endangered species are impacted by the cats[W]	Environment is suitable[W]

Table 8: Reasons for management program failure identified during Orange County [O] and Wake County [W] meetings.

Reasons for Failure of Feral Cat Management Programs
Lack of financial and personnel resources[O,W]
Lack of public interest and awareness[O,W]
Lack of "ownership" of the problem; culture of human irresponsibility, [O,W]
Lack of consensus about management options[W]
Lack of municipal and regulatory support[W]

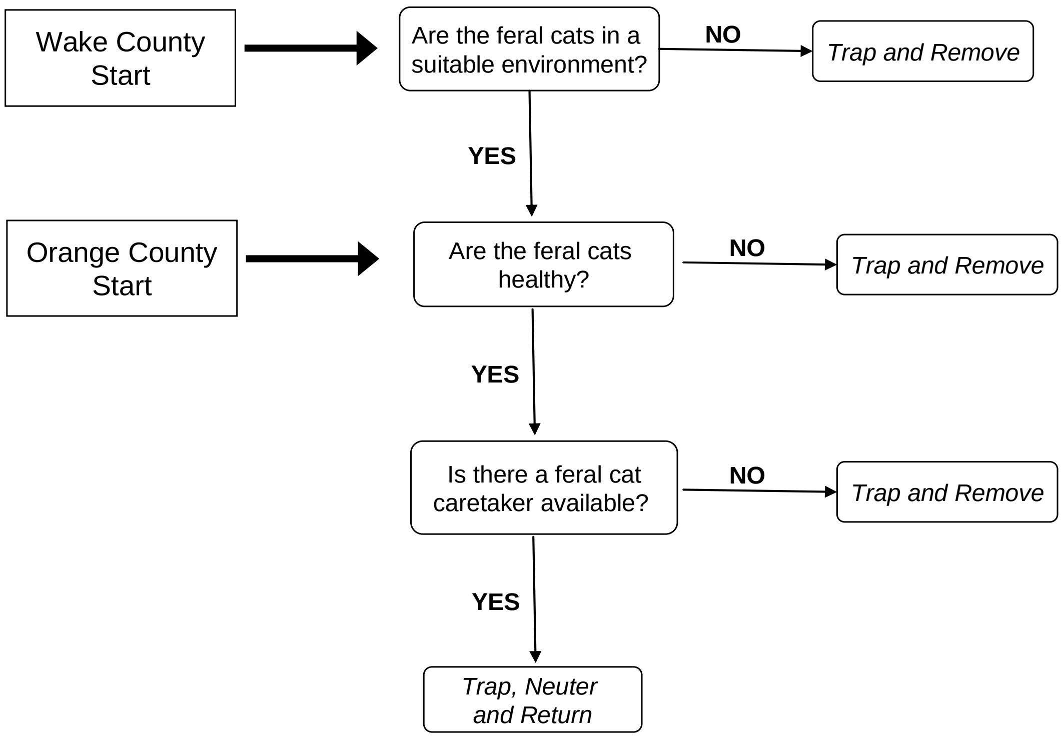

Figure 1: Decision diagram for feral cat management.

Chapter 8. Use of VORTEX population model to estimate the outcome of feral cat colony management by trap-neuter-return

Felicia B. Nutter

Introduction

Extinction of feral cat colonies is the goal of most feral cat management programs, regardless of the technique used. Difficulty in choosing between traditional lethal management and the relatively new trap-neuter-return (TNR) option is complicated by uncertainty about the efficacy and costs of the different strategies. Lethal control programs can eliminate cats from defined areas (Nogales et al. 2004), but the evidence for TNR program effectiveness remains largely anecdotal. A few previous studies have examined large-scale population trends (Centonze & Levy 2002; Levy & Crawford 2004; Levy et al. 2003; Passanisi & Macdonald 1990; Xemar 1997), but more intensive monitoring of managed populations, like the current project, are necessary to build the body of evidence. Quantitative assessment of the effectiveness of TNR management is crucial if informed choices are to be made.

Although direct long-term observations of populations under different management conditions yield the best estimates of vital rates (survival, fecundity, etc.), these life-table methods require decades of data collection to accurately reflect the effects of normal variation in demographic processes or the occurrence of random events (Ferson et al. 1989). Computer-based population viability analysis (PVA) models can be used to explore the viability of populations rapidly with fewer data in hand (Lande 1988; Morris et al. 1999), although the reliability of PVA models is improved with more extensive data on the species of interest (Maehr et al. 2002).

VORTEX is an individual-based PVA simulation software package, where the fate of each animal is tracked as it undergoes demographic events during discrete time intervals (Miller & Lacy 2005). Users specify the mean probabilities of occurrence of each demographic event and the magnitude of annual fluctuation (as standard deviation), and VORTEX uses Monte Carlo simulation to sample from the specified distribution. Stochastic events such as sex determination and survival are modeled by random sampling from a binomial distribution (Miller & Lacy 2005). Various input parameters such as the percent of females breeding or harvest rates can be manipulated to simulate different management programs and explore their theoretical effects.

I used VORTEX with the specific information on kitten mortality, litter size, adult mortality, and immigration for intact and neutered cats generated during the four-year survival study. I modeled the survival of intact and TNR-managed feral cat colonies to help assess the effectiveness of TNR programs as a strategy for feral cat management. Specifically, I explored what harvest levels and time intervals were necessary to cause population decreases for intact colonies, and what proportion of males and females had to be sterilized to cause neutered colonies to decreases.

Materials and Methods

VORTEX 9.57 (Lacy et al. 2005) was used for all PVA. I used a single baseline model with a stable age distribution and excluded inbreeding depression because it has not been demonstrated even in feral cat populations with a high degree of inbreeding (Devillard et al. 2003). I did not specifically model catastrophes since the effects of events I observed that could be called catastrophes (for example dog attacks that killed multiple cats per colony) were already incorporated into the mortality estimates. Table 1 summarizes the remaining input parameters. Maximum breeding age came from anecdotal reports provided by a control colony caretaker who estimated the age of one intact female as 7-8 years old at enrollment; she survived an additional 2.75 years. I used the exact observed frequencies of number of young produced per year (the sum of all kittens produced by a queen in a given year) instead of the mean and standard deviation, as suggested by the VORTEX user's manual for species with small litter sizes (Miller & Lacy 2005). All females were in the breeding pool, and there was no mate monopolization (Say et al. 1999; Say et al. 2001). Mortality for breeding males was calculated by pooling data for intact and vasectomized males, because survival analysis in Chapter 5 did not detect any difference in survival between the two treatments. Supplementation was based on the observed immigration rates reported in Chapter 5. Immigration for males was rounded up to 1 event per colony year, and for females to 1 event per 4 colony years. The function (((Y%4=0)*1)+0)) was used to describe the female supplementation schedule, because male and female supplementations are constrained by VORTEX to occur on an annual basis, but from our data they occur at different rates. This uses the modulus function (signified by the operator %) to supplement 1 female cat every 4 years to the baseline annual supplementation of 0 female cats. The modulus function is a division remainder calculator; so when Y%4, and Year is 5, the remainder is 1 and the expression in the inner parentheses resolves to FALSE and the value in the outer parentheses resolves to 0. When Year is 4 or any multiple of 4, the modulus is 0, the inner expression resolves to TRUE, and the outer expression resolves to 1. Every four years the modulus is 0 and 1 female cat is added to the baseline annual supplementation of 0.

A theoretical carrying capacity of 50 cats was chosen to represent a population size at which colonies would likely be targeted for population reduction. When the carrying capacity is exceeded, VORTEX adds mortality risk to each individual so that the population will on average return to the carrying capacity. The baseline models were varied to represent feral cat colony management by two different strategies, periodic trapping and removal (baseline=100% breeding) or TNR (baseline=100% neutered), with varying success capturing the cats. Harvests were implemented every 1, 2, 3, 4, or 5 years at levels ranging from 25% to 100% of the extant population to simulate traditional trapping and removal programs. The proportion of sterilized cats varied from 5% to 95% to simulate TNR. After preliminary examinations of the results, additional simulations were run to better identify the break-point between resulting negative and positive r values. Initial population size was rounded up to 15 from the observed mean colony size of 13 for convenience. All simulations ran for 25 years, with 1000 iterations each.

Model predictions for neutered colony growth rates were compared with the observed rates for the eight extant neutered colonies (Chapter 5) between the four and seven year follow-up points. Four of the five control colonies were neutered after two years, and all data collected were used to parameterize the model. The only control colony followed for four years was the one that crashed and then rebounded, and those data were important for model parameterization as well. For one colony (C4) the rate was determined between two and four years' follow-up. Because exact survival times for individual cats were not known for these periods, they were estimated using the change in colony size as a proxy for survival. The colony size at the seven-year follow-up was divided by the colony size at the four-year follow up (or for C1 and C3, the peak colony size that occurred shortly after the four-year follow-up), to give the proportion surviving at the seven-year follow-up. The geometric probability distribution was used to approximate the discrete lifetime distribution (Andersen et al. 2004; Hoel et al. 1971). The formula used to calculate survival was $S=exp(ln(1-P)/t)$, where S is the survival per unit time (in this case, 2 or 3 years) and P is the probability that any individual cat will die by time t. So for example, for C1, $S=exp(ln(1\text{-}0.77)/t)=0.61$. S was then used to solve for r in the following equation: $N_t/N_0=e^{rt}$ (Ricklefs 2000).

Results

For the baseline simulation of intact colonies, both the deterministic and stochastic *r* values were positive (Table 3). Even under such growth conditions, the extinction probability was 0.289, with 6.86 years mean time to extinction. Successful recolonizations occurred following extinctions because of immigrating male and female cats. All simulations for intact, breeding feral cat colonies with harvest intervals of 3, 4 or 5 years, regardless of the harvest level, maintained positive population growth rates (*r* values) (Table 2). The deterministic *r* values were stable, because they were based on the same reproductive and mortality rates, but the stochastic r values decreased with increasing harvest levels and frequencies. With annual harvests, the stochastic *r* value switched from positive to negative at a harvest level between 55% and 60%. With harvests every two years, a similar switch occurred at a harvest level between 70% and 75%. The mean number of cats per colony decreased with increasing harvest levels and frequencies. For those colonies that went extinct, the mean time to extinction decreased with increasing harvest levels and frequencies. For those colonies that went extinct, time to recolonization ranged from 1.52 to 3.00 years. This time to re-establish colonies following extinction depended on the immigration rate and was similar across harvest levels.

Simulations for neutered colonies yielded different results related to the proportion of the population that was breeding (Table 2). For the deterministic calculations, *r* switched from negative to positive between 20% and 25% breeding. For the stochastic simulations, that switch occurred between 15% and 20%. Mean cat numbers rose with the percentage breeding. For those colonies that went extinct, mean time to extinction ranged from 11.13-12.96 years, and time to recolonization ranged from 1.91-2.07 years.

The mean geometric population growth from the prospectively observed neutered colonies was -0.28 $\pm$ 0.27 (range 0 to -0.81), which was identical to the deterministic *r* value calculated for neutered colonies with 95% sterilization, and also approximated the stochastic *r* within the standard deviation reported.

Discussion

VORTEX PVA models have been extensively applied to the management of endangered species of plants, invertebrates, and all major vertebrate groups, to help define trends in population behavior, identify missing data, and improve management and decision making (Berger 1990; Boyce 1992; Ginzburg et al. 1990; Harcourt 1995; Hu et al. 2001; Morris & Doak 2002; Towns et al. 2003). The goal in such instances is the prevention of extinction, but the same PVA techniques are equally applicable when extinction is the desired outcome, as with feral cats.

The model I built was a simple single population simulation, using estimates of vital rates from my observational study of feral cat colonies under different management strategies. These rate estimates were generated from two to four years' field data, which is a brief window of time and does not allow full evaluation of the normal variation inherent in any population. Despite this limitation, useful insights were provided by the simulations.

For intact colonies, the baseline model with no harvest produced an estimated r=0.278 with stochasticity, or r=0.364 with deterministic calculations only. The difference between the deterministic and stochastic r values of -0.086 reflects the impact of environmental variation on the population. The negative impact of stochasticity, particularly on small populations such as the theoretical colony of 15 cats in the model, is well known (Lande 2002; Miller & Lacy 2005), and is reflected in the extinction probability for the same model of 28.9%. This estimate corresponded with my observation that one intact (control) colony experienced a population decline of 70% over 2 years (from 10 cats to 3 cats), before rebounding to 170% of initial size at the end of 4 years. Small populations, even those with strong positive growth characteristics, remain at significant risk of extinction due to stochastic variation. This may be a surprising result to those who believe that all feral cats colonies are geometrically increasing populations, as suggested by the often-cited figure that one cat and her offspring can produce 420,000 cats in 7 years (generated from numbers of 3 litters per year, with 4-6 kittens per litter) (Humane Society of the United States 2005). Realistic assessment of the impacts of normal variation on feral cat colony dynamics will lead to better management decisions than unreasonable extrapolations. A recent review of feral cat eradication from islands (Nogales et al. 2004) reported two colonies that went extinct without intervention. In areas where immigration can occur, extinguished colonies are likely to re-establish in a just a few years, particularly if food sources are not eliminated. Breeding will only occur once both intact male and female cats have immigrated, which this model predicts in an average of 2.5 years. The model predictions, the crash observed in this study, and the anecdotal reports of cat populations extinguishing without intervention, beg the question as to how often small, breeding populations of feral cats go extinct. Addressing this question will require the long-term study of numerous intact colonies, but would provide important data for future model refinements.

Annual harvests of at least 60% or semi-annual harvests of at least 70% were required to cause population declines, and of 95% or more to cause extinction. When harvest was implemented at three or four year intervals, the population growth rates remained consistently positive, and only the highest harvest levels led to extinction. The negative population growth rates for the four year harvest at 75-100% harvest levels were artifacts of the harvest occurring on the same schedule as supplementation, which added a male every year, but a male and female only every four years. The restrictions of the model parameterization under such low levels of immigration did not allow variation in female supplementation so that a female could be added *on average* every four years, but where the exact timing of supplementation varied. With harvests every five years, no harvest level was able to eradicate the population for prolonged periods because of continued immigration between harvests, and subsequent breeding.

The absolute abundance of cats fluctuated around the mean by a standard deviation that was, in most cases, approximately equal to or greater than the mean number of cats in the colony. In all simulations, some of the populations reached the theoretical carrying capacity of fifty cats, while others went extinct. This variance might have significant impacts on potential prey populations and has been theoretically shown to have a greater impact on prey populations than the size of predator population itself (Sabo 2005). At-risk prey populations have a difficult time adjusting to variance in predator abundance, but can accommodate better if that variance is removed and they are subjected to more stable predation. Trigger harvest, where cats are removed when the population size reaches a critical threshold, instead of the proportional harvest modeled here, has been suggested as a preferred strategy for controlling invasive predator species in areas with threatened or endangered prey (Sabo 2005). Because of resource constraints, intermittent proportional harvest is often the default management strategy for feral cat control. Implementing a trigger harvest requires even more resources in order to develop good estimates of the critical threshold and to monitor the population to intervene when that threshold is attained (Sabo 2005). Trigger harvest may be feasible for some endangered or threatened species management programs, but is unlikely to be practical for widespread application. In the face of continued, intermittent, proportional harvest, the variation in the feral cat population could have significant negative impact on prey populations, and should be evaluated in future studies of feral cat impacts on wildlife populations.

For neutered colonies, the baseline model generated a very strong negative deterministic r (-99.990) and a more moderate stochastic r (-0.020). While stochasticity had a negative impact on the persistence of breeding colonies, it had a positive impact on the persistence of neutered ones. The extinction probability was 9.1%, with a mean time to extinction of 12.64 years. This lower extinction probability and longer mean time to extinction when compared to the intact colonies is due to the longer survival times (lower mean morality rates and smaller SD) for neutered cats compared to intact cats. When breeding was modeled to simulate the inability to capture all intact cats or the immigration of intact cats, the population growth rates switched from negative to positive. For the deterministic calculations, the switch occurred when between 20% and 25% of cats were breeding, and for the stochastic model the switch occurred at between 15% and 20% breeding cats. This prediction was reflected in my observations of two neutered colonies where breeding cats remained at levels below the predicted break points and both colonies continued to decrease even though kittens were born (Chapter 5). Previous work with a matrix population model (Andersen et al. 2004) predicted the same deterministic break point (must neuter ≥ 75% of the population to cause decrease) found here, but adding stochasticity with the VORTEX model suggested that > 80% of a population should be neutered to cause decline. This sterilization level is also similar to that predicted theoretically for Brandt's voles (Shi et al. 2002) and foxes (Pech et al. 1997), or experimentally for rabbits (Twigg et al. 2000; Twigg & Williams 1999). TNR programs aim to neuter 100% of feral cats in any colony, but trap-shy individuals can reduce the success rate. Predictions of 75% to 80% sterilization rate necessary to effect population decline can help TNR providers decide how to manage their resources to best attain their goals. One previous study (Centonze & Levy 2002) reported that a mean of 55.7% of cats in individual colonies were sterilized by a TNR program, but that 18.6% were neutered elsewhere, likely by a local veterinarian. The total mean colony sterilization rate was then 74.3%, which approximates the break-point identified.

Concurrent adoption of sociable cats was also part of the program described, and contributed substantially to the 26% population reduction reported over 18 months. Many TNR programs allot a fixed number of spaces in a spay/neuter clinic to any given caretaker, instead of allowing a few caretakers to occupy all the space. This strategy maximizes the number of individual colonies that can be served, but depending on the sizes of the colonies it also likely slows the rate at which target neutering levels are reached. There may be circumstances where it would be more appropriate to work with a caretaker to rapidly attain target sterilization levels, for example when colony sizes are above a certain threshold. One shortcoming of the model used was that it did not include different mortality rates for cats that immigrated into TNR colonies and subsequently reproduced. This meant that survival for the breeding subset of the population was overestimated, which resulted in a slower rate of population decline and may also have changed the break-point for the proportion of sterilized cats required to cause decline. The mean times to extinction (range 11.13 to 12.96 years) predicted by the model were close to the working estimates I used from the outset of this project, that at least 10 years of field observation would likely be necessary to document the decline and possible extinction of sterilized feral cat colonies. I observed the extinction of one colony 35 months after sterilization, and 3 others were "micro" colonies of 3 or fewer cats after 7 years follow-up. All of these estimates fall within the range of population trajectories predicted by the VORTEX model. All sterilized colonies were in decline at the last follow-up time, and the mean time to extinction of neutered colonies (12.64 $\pm$ 5.64 years) suggested by the VORTEX model can be used as a working guide for future TNR management and monitoring programs, until additional data can refine the model.

It is important to recognize that feral cats are members of complex ecosystems, and that perturbations in their populations can have both negative and positive effects on other species. While it seems intuitive that removing feral cats from an ecosystem will benefit native wildlife, the actual impacts of such removal depend on what other species are present. The mesopredator release effect has been demonstrated both theoretically via modeling (Courchamp et al. 1999), and has been documented from observations of areas where cats have been removed (Crooks & Soule 1999; Huyser et al. 2000). Conceptually, in a simplified ecosystem with a prey species (for example, a ground-nesting bird), a mesopredator (Norway rat) and a top predator (feral cat), decreasing or eliminating the top predator population can lead to a rapid increase in the mesopredator population, which can then have significantly greater negative effects on the prey species. Cats may also sometimes be the mesopredator, for example in chaparral canyons home to birds, cats, and coyotes, where coyotes are the top predator and their absence in very steep canyons correlated with more rapid bird extirpations presumably caused by cats and foxes (Soule et al. 1988).

The comparison of the *r* values calculated by the model, compared to those observed for neutered colonies, suggests that the VORTEX model is making optimistic predictions for the population trajectory. This is common when models are built from small data sets, which cannot accurately identify long-term trends, rare events, or variance in population sizes (Brook 2000). Nonetheless, even with the limitations of the small data set used to build this model, and the recognition of potential optimistic population predictions, the general trends suggested by the model are useful. For example, the mean numbers of cats were similar between the intact colonies with annual or semi-annual harvests at levels of at least 50% to 65% respectively, and the neutered colonies with 90% to 100% sterilization. The different strategies can achieve similar results, but the effort expended is likely to be quite different. Trapping and surgical sterilization will probably need to be applied less frequently than lethal control, and after the initial intensive sterilization period only immigrant cats will have to be handled, assuming complete sterilization. Other simulation models for wolves (Haight & Mech 1997) and voles (Shi et al. 2002) have predicted similar results. For wolves, periodic trapping for harvest meant that twice as many wolves had to be handled compared to periodic sterilization. With voles, sterilization was more effective than identical levels of lethal control when applied at the right time of year (in autumn, prior to the spring breeding season). Lethal control generally provides more rapid population decreases (Barlow et al. 1997), but also becomes more labor intensive as populations get smaller. Proportionately more effort must be expended to catch the last cat on an island than the first (Courchamp & Cornell 2000). The choice between lethal control and fertility control for feral cats will necessarily take into account many factors, but differences in the required effort, intensity, and long-term costs of trapping and removal compared to sterilization are important issues and will benefit from additional research and clarification.

More prospective, long-term monitoring of feral cat colonies managed with different control programs is necessary to develop the data required to improve estimates of vital rates and population processes. Whenever possible, it is important to study multiple colonies simultaneously under similar conditions to provide more insight into the effects of demographic and environmental stochasticity. Such information can help refine future PVA models and enhance objective evaluations of management options (Maehr et al. 2002). A single management strategy will not serve all situations, and the ability to realistically assess the costs and benefits of different options will ultimately lead to better decision-making.

References

Andersen, M. C., B. J. Martin, and G. W. Roemer. 2004. Use of matrix population models to estimate the efficacy of euthanasia versus trap-neuter-return for management of free-roaming cats. *Journal of the American Veterinary Medical Association* **225**:1871-1876.

Barlow, N. D., J. M. Kean, and C. J. Briggs. 1997. Modelling the relative efficacy of culling and sterilisation for controlling populations. *Wildlife Research* **24**:129-141.

Berger, J. 1990. Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. *Conservation Biology* **4**:91-98.

Boyce, M. S. 1992. Population viability analysis. *Annual Reviews of Ecological Systems* **23**:481-506.

Brook, B. W. 2000. Pessimistic and optimisitc bias in population viability analysis. *Conservation Biology* **14**:564-566.

Centonze, L. A., and J. K. Levy. 2002. Characteristics of free-roaming cats and their caretakers. *Journal of the American Veterinary Medical Association* **220**:1627-1633.

Courchamp, F., and S. J. Cornell. 2000. Virus-vectored immunocontraception to control feral cats on islands: A mathematical model. *Journal of Applied Ecology* **37**:903-913.

Courchamp, F., M. Langlais, and G. Sugihara. 1999. Cats protecting birds: modelling the mesopredator release effect. *Journal of Animal Ecology* **68**:282-292.

Crooks, K. R., and M. E. Soule. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature* **400**:563-566.

Devillard, S., L. Say, and D. Pontier. 2003. Dispersal pattern of domestic cats (*Felis catus*) in a promiscuous urban population: Do females disperse or die? *Journal of Animal Ecology* **72**:203-211.

Ferson, S., L. Ginzburg, and A. Silvers. 1989. Extreme event risk analysis for age-structured populations. *Ecological Modelling* **47**:175-187.

Ginzburg, L. V., S. Ferson, and H. R. Akcakaya. 1990. Reconstructability of density dependence and the conservation assessment of extinction risks. *Conservation Biology* **4**:63-70.

Haight, R. G., and L. D. Mech. 1997. Computer simulation of vasectomy for wolf control. *Journal of Wildlife Management* **61**:1023-1031.

Harcourt, A. H. 1995. Population viability estimates: theroy and practice for a wild gorilla population. *Conservation Biology* **9**:134-142.

Hoel, P. G., S. C. Port, and C. J. Stone 1971. *Introduction to Probability Theory*. Houghton-Mifflin, Boston, Massachusetts, USA.

Hu, D., C. Glidden, J. S. Lippert, L. Schnell, J. S. MacIvor, and J. Meisler. 2001. Habitat use and limiting factors in a population of Hawaiian dark-rumped petrels on Mauna Loa, Hawai'i. *Studies in Avian Biology*:234-242.

Huyser, O., P.-G. Ryan, and J. Cooper. 2000. Changes in population size, habitat use and breeding biology of lesser sheathbills (*Chionis minor*) at Marion Island: Impacts of cats, mice and climate change? Biological Conservation **92**:299-310.

Lacy, R. C., M. Borbat, and J. P. Pollak. 2005. *VORTEX: A Stochastic Simulation of the Extinction Process. Version 9.57.* Chicago Zoological Society, Brookfield, Illinois, USA.

Lande, R. 1988. Demographic models of the Northern Spotted Owl (*Strix occidentalis caurina*). *Oecologia* **75**:601-607.

Levy, J. K., and P. C. Crawford. 2004. Humane strategies for controlling feral cat populations. *Journal of the American Veterinary Medical Association* **225**:1354-1360.

Levy, J. K., D. W. Gale, and L. A. Gale. 2003. Evaluation of the effect of a long-term trap-neuter-return and adoption program on a free-roaming cat population. *Journal of the American Veterinary Medical Association* **222**:42-46.

Maehr, D. S., R. C. Lacy, D. E. Land, O. L. Bass Jr., and T. S. Hoctor. 2002. Evolution of population viability assessments for the Florida panther: a multiperspective approach. Pages 284-311 in S. R. Beissinger, and D. R. McCullough, editors. *Population Viability Analysis*. The University of Chicago Press, Chicago, Illinois, USA.

Miller, P. S., and R. C. Lacy 2005. *VORTEX: A Stochastic Simulation of the Extinction Process. Version 9.50 User's Manual.* Conservation Breeding Specialist Group (SSC/IUCN), Apple Valley, Minnesota, USA.

Morris, W., D. Doak, M. Groom, P. Kareiva, J. Fieberg, L. Gerber, P. Murphy, and D. Thomson 1999. *A practical handbook for population viability analysis.* The Nature Conservancy, Washington, D.C., USA.

Morris, W. F., and D. F. Doak 2002. *Quantitative conservation biology: Theory and practice of population viability analysis.* Sinauer Associates, Sunderland, Massachusetts, USA.

Nogales, M., A. Martin, B. R. Tershy, C. J. Donlan, D. Veitch, N. Puerta, B. Wood, and J. Alonso. 2004. A review of feral cat eradication on islands. *Conservation Biology* **18**:310-319.

Passanisi, W. C., and D. W. Macdonald 1990. *The Fate of Controlled Feral Cat Colonies*. Universities Federation for Animal Welfare, Hertfordshire, Potters Bar, UK.

Pech, R., G. M. Hood, J. McIlroy, and G. Saunders. 1997. Can foxes be controlled by reducing their fertility? *Reproduction Fertility and Development* **9**:41-50.

Ricklefs, R. E. 2000. *The Economy of Nature*. W.H. Freeman and Company, New York City, New York, USA.

Sabo, J. L. 2005. Stochasticity, predator-prey dynamics and trigger harvest of nonnative predators. *Ecology* **86**:2329-2343.

Say, L., D. Pontier, and E. Natoli. 1999. High variation in multiple paternity of domestic cats (Felis catus L.) in relation to environmental conditions. *Proceedings of the Royal Society of London Series B, Biological Sciences* **266**:2071-2074.

Say, L., D. Pontier, and E. Natoli. 2001. Influence of oestrus synchronization on male reproductive success in the domestic cat (*Felis catus* L.). *Proceedings of the Royal Society of London Series B, Biological Sciences* **268**:1049-1053.

Shi, D., X. Wan, S. A. Davis, R. P. Pech, and Z. Zhang. 2002. Simulation of lethal control and fertility control in a demographic model for Brandt's vole *Microtus brandti*. *Journal of Applied Ecology* **39**:337-348.

Soule, M. E., D. T. Bolger, A. C. Alberts, J. Wright, M. Sorice, and S. Hill. 1988. Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands. *Conservation Biology* **2**:75-92.

Humane Society of the United States. 2005. Pet overpopulation estimates. Accessed October 31, 2005. http://www.hsus.org/pets/issues_affecting_our_pets/pet_overpopulation_and_ownership_statistics/hsus_pet_overpopulation_estimates.html

Towns, D. R., G. R. Parrish, and I. Westbrooke. 2003. Inferring vulnerability to introduced predators without experimental demonstration: case study of Suter's skink in New Zealand. *Conservation Biology* **17**:1361-1371.

Twigg, L. E., T. J. Lowe, G. R. Martin, A. G. Wheeler, G. S. Gray, S. L. Griffin, C. M. O'Reilly, D. J. Robinson, and P. H. Hubach. 2000. Effects of surgically imposed sterility on free-ranging rabbit populations. *Journal of Applied Ecology* **37**:16-39.

Twigg, L. E., and C. K. Williams. 1999. Fertility control of overabundant species: can it work for feral rabbits? *Ecology Letters* **2**:281-285.

Xemar, V. 1997. Le chat errant: gestion des populations et etat sanitaire. Veterinary Doctor thesis. Ecole Nationale Veterinaire de Lyon, France.

Table 1. Summary of parameter values used in VORTEX simulations of intact and neutered feral cat colonies.

Parameter	***Input***
Reproductive mode	polygynous
Breeding age of males and females	1 year
Maximum breeding age	10 years
Frequency of # of young per year	1,2=5.71%; 3=22.86%; 4=17.14%; 5=14.29%;6=0%;7,8=11.43%; 9=5.71%; 10,11=2.86%
Kitten mortality % (mean + SD)	67.17 ± 37.14
Adult mortality % (mean + SD)	
Intact and vasectomized males	45.9 ± 24.5
Intact females	39.6 ± 32.9
Castrated males	14.1 ± 20.2
Spayed females	15.5 ± 22.2
Supplementation	
Male	1 per year
Female	1 every 4 years
Carrying capacity	50 cats
Initial population size	15
Duration	25 years
Iterations	1000
Parameters varied between intact and neutered colonies	
% harvesting of intact colonies every 1, 2, 3, 4o r 5 years	25, 50, 75, 95, 100
% sterilization in neutered colonies	5, 25, 50, 75, 80, 85, 90, 95

Table 2. Survival probabilities for neutered colonies, calculated survival rates, and calculated r values.

Colony	Survival probability	Survival rate	r
C1*	0.77	0.61	-0.490
C2*	1.00	1.00	0.000
C3[†]	0.77	0.61	-0.490
C4*	0.80	0.45	-0.805
S/C 1	0.69	0.68	-0.390
S/C 2	0.37	0.86	-0.154
S/C 3	0.33	0.88	-0.133
S/V 2	0.25	0.91	-0.096
S/V 3	1.00	1.00	0.000
mean $\pm$ SD	**0.66 $\pm$ 0.28**	**0.78 $\pm$ 0.20**	**-0.28 $\pm$ 0.27**

Table 3. Summary results of VORTEX simulations of two different feral cat management strategies, removal and neutering. Mean # of cats (extant) includes only populations that have not gone extinct, while mean # of cats (all) includes those populations that are extinct.

Scenario	**Deterministic r**	**Stochastic r**	**SD Stoch (r)**	**Extinction Probability**	**Mean # cats (extant)**	**SD Mean # cats (extant)**	**Mean # cats (all)**	**SD Mean # cats (all)**	**Median time to extinction (years)**	**Mean time to extinction (years)**	**SD Mean time to extinction (years)**
100% Breeding Colony Baseline	0.364	0.278	0.799	0.289	15.35	16.08	11.49	14.86	5	6.86	5.63
25% 1yr harvest	0.364	0.119	0.697	0.281	8.40	11.44	6.50	10.18	5	5.75	4.63
50% 1yr harvest	0.364	0.005	0.655	0.629	3.72	2.63	2.16	2.05	3	4.13	2.99
55% 1yr harvest	0.364	*0.010*	0.641	0.612	3.69	2.08	2.17	1.82	3	3.99	2.91
60% 1yr harvest	0.364	*-0.019*	0.622	0.619	3.37	1.74	2.02	1.55	3	3.78	2.71
75% 1yr harvest	0.364	-0.249	0.614	0.776	2.46	0.58	1.42	0.69	2	2.65	1.51
95% 1yr harvest	0.364	-1.620	0.155	1.000	0.00	0.00	1.00	0.00	2	1.52	0.50
100% 1yr harvest	0.364	0.000	0.000	1.000	0.00	0.00	1.00	0.00	1	1.00	0.00
25% 2yr harvest	0.364	0.182	0.749	0.265	10.61	13.23	8.25	12.01	5	6.28	5.13
50% 2yr harvest	0.364	0.075	0.749	0.559	6.90	9.32	3.81	6.79	5	5.21	4.42
65% 2yr harvest	0.364	*0.007*	0.737	0.599	4.37	4.72	2.51	3.37	3	4.67	3.77
70% 2yr harvest	0.364	*-0.015*	0.736	0.580	3.53	3.33	2.22	2.45	3	4.64	3.62
75% 2yr harvest	0.364	-0.082	0.800	0.762	3.26	2.29	1.67	1.47	3	4.05	3.17
95% 2yr harvest	0.364	-0.735	1.097	1.000	0.00	0.00	1.00	0.00	2	1.90	1.02
100% 2yr harvest	0.364	0.000	0.000	1.000	0.00	0.00	1.00	0.00	1	1.00	0.00
25% 3yr harvest	0.364	0.216	0.774	0.287	12.42	14.90	9.34	13.49	5	6.23	5.22
50% 3yr harvest	0.364	0.144	0.810	0.536	9.89	12.76	5.36	9.67	5	6.14	5.17
75% 3yr harvest	0.364	0.098	0.876	0.689	5.55	6.90	2.55	4.35	3	4.98	4.33
95% 3yr harvest	0.364	0.215	0.991	0.993	2.86	0.69	1.01	0.17	2	2.82	2.48
100% 3yr harvest	0.364	0.653	0.538	1.000	0.00	0.00	1.00	0.00	1	1.00	0.00
25% 4yr harvest	0.364	0.213	0.760	0.280	12.41	14.67	9.44	13.34	5	6.02	5.28
50% 4yr harvest	0.364	0.128	0.789	0.541	9.59	12.76	5.18	9.56	5	5.74	4.88
75% 4yr harvest	0.364	-0.010	0.861	0.736	5.03	6.75	2.25	3.86	5	4.93	4.28
95% 4yr harvest	0.364	-0.386	1.132	1.000	0.00	0.00	1.00	0.04	2	2.56	2.19
100% 4yr harvest	0.364	0.000	0.000	1.000	0.00	0.00	1.00	0.00	1	1.00	0.00
25% 5yr harvest	0.364	0.255	0.779	0.286	15.02	15.82	11.34	14.60	5	6.50	5.54
50% 5yr harvest	0.364	0.212	0.792	0.287	12.14	14.00	9.24	12.70	5	5.88	5.04
75% 5yr harvest	0.364	0.141	0.859	0.293	10.71	12.55	8.10	11.32	3	5.17	4.62
95% 5yr harvest	0.364	0.170	0.969	0.324	7.23	7.99	5.46	7.08	2	3.05	3.00
100% 5yr harvest	0.364	0.378	0.810	0.331	5.64	2.69	4.32	2.94	1	1.00	0.00
100% Neutered Colony Baseline	-99.99	-0.020	0.275	0.091	7.53	2.51	7.22	2.65	13	12.64	5.64
95% neutered	-0.286	-0.020	0.297	0.094	8.29	3.51	7.84	3.65	14	11.13	6.15
85% neutered	-0.093	*-0.008*	0.349	0.064	11.64	8.99	11.13	8.93	19	12.77	6.15
80% neutered	*-0.031*	*0.006*	0.372	0.052	15.40	11.72	14.79	11.72	25	12.41	6.55
75% neutered	*0.023*	0.023	0.394	0.049	18.32	13.90	17.61	13.92	>25	12.64	6.61
50% neutered	0.227	0.121	0.495	0.029	28.63	16.72	27.93	16.98	>25	12.96	7.19
25% neutered	0.384	0.223	0.583	0.020	33.43	16.28	32.83	16.66	>25	12.27	7.08
5% neutered	0.493	0.289	0.645	0.013	34.55	15.76	34.16	16.04	>25	11.63	7.03

Appendix: VORTEX input summary for baseline intact and neutered feral cat colonies

INTACT COLONY BASELINE

1 population(s) simulated for 25 years, 1000 iterations

Extinction is defined as no animals of one or both sexes.

No inbreeding depression

EV in reproduction and mortality will be concordant.

First age of reproduction for females: 1   for males: 1
Maximum breeding age (senescence): 10
Sex ratio at birth (percent males): 50

Population 1: Population 1

Polygynous mating;
% of adult males in the breeding pool = 100

% adult females breeding = 100
EV in % adult females breeding: SD = 0

Of those females producing progeny, ...
5.71 percent of females produce 1 progeny in an average year
5.71 percent of females produce 2 progeny in an average year
22.86 percent of females produce 3 progeny in an average year
17.14 percent of females produce 4 progeny in an average year
14.29 percent of females produce 5 progeny in an average year
0.00 percent of females produce 6 progeny in an average year
11.43 percent of females produce 7 progeny in an average year
11.43 percent of females produce 8 progeny in an average year
5.71 percent of females produce 9 progeny in an average year
2.86 percent of females produce 10 progeny in an average year
2.86 percent of females produce 11 progeny in an average year

% mortality of females between ages 0 and 1 = 67.17
EV in % mortality: SD = 37.14
% mortality of adult females (1<=age<=10) = 39.6
EV in % mortality: SD = 32.9
% mortality of males between ages 0 and 1 = 67.17
EV in % mortality: SD = 37.14
% mortality of adult males (1<=age<=10) = 45.9
EV in % mortality: SD = 24.5

EVs may be adjusted to closest values possible for binomial distribution.

Initial size of Population 1:   15
(set to reflect stable age distribution)

Age 1	2	3	4	5	6	7	8	9	10	Total	
5	1	1	0	0	0	0	0	0	0	7	Males
5	1	1	1	0	0	0	0	0	0	8	Females

Carrying capacity = 50
EV in Carrying capacity = 0

Animals added to Population 1, year 1 through year 25 at 1 year intervals:
females 1 years old: Y%4=0*1+0

```
    males 1 years old: 1
```

NEUTERED COLONY BASELINE

```
  1 population(s) simulated for 25 years, 1000 iterations

  Extinction is defined as no animals of one or both sexes.

  No inbreeding depression

  EV in reproduction and mortality will be concordant.

  First age of reproduction for females: 1   for males: 1
  Maximum breeding age (senescence): 10
  Sex ratio at birth (percent males): 50

Population 1: Population 1

  Polygynous mating;
    % of adult males in the breeding pool = 0

  % adult females breeding = 0
   EV in % adult females breeding: SD = 0

   Of those females producing progeny, ...
     5.71 percent of females produce 1 progeny in an average year
     5.71 percent of females produce 2 progeny in an average year
    22.86 percent of females produce 3 progeny in an average year
    17.14 percent of females produce 4 progeny in an average year
    14.29 percent of females produce 5 progeny in an average year
     0.00 percent of females produce 6 progeny in an average year
    11.43 percent of females produce 7 progeny in an average year
    11.43 percent of females produce 8 progeny in an average year
     5.71 percent of females produce 9 progeny in an average year
     2.86 percent of females produce 10 progeny in an average year
     2.86 percent of females produce 11 progeny in an average year

   % mortality of females between ages 0 and 1 = 67.17
    EV in % mortality: SD = 37.14
   % mortality of adult females (1<=age<=10) = 15.5
    EV in % mortality: SD = 22.2
   % mortality of males between ages 0 and 1 = 67.17
    EV in % mortality: SD = 37.14
   % mortality of adult males (1<=age<=10) = 14.1
    EV in % mortality: SD = 20.2

    EVs may be adjusted to closest values possible for binomial distribution.

  Initial size of Population 1:       15
    (set to reflect stable age distribution)
 Age 1     2     3     4     5     6     7     8     9    10    Total
     7     0     0     0     0     0     0     0     0     0       7  Males
     8     0     0     0     0     0     0     0     0     0       8  Females

  Carrying capacity = 50
    EV in Carrying capacity = 0

  Animals added to Population 1, year 1 through year 25 at 1 year intervals:
    females 1 years old: Y%4=0*1+0
    males 1 years old: 1
```

Conclusions

With this research project I evaluated the effectiveness of trap-neuter-return management for feral cat colonies, and specifically examined the prevalence of selected infectious diseases, population dynamics, and home ranges for feral cats under different management strategies.

I used an effective trapping method and captured 98% of the target cats with 8.9 trap nights per cat. I showed that feral cats and pet domestic cats had similar baseline health status and fecal prevalences of infections with *Cryptosporidium* spp., *Giardia* spp. and *Toxocara cati*. Feral cats had higher seroprevalences of *Bartonella henselae* and *Toxoplasma gondii*, and these findings are likely related to greater exposure of feral cats to the vectors or hosts of these organisms.

Survival analysis of individual intact and neutered cats in 9 colonies showed that castrated male cats and ovariohysterectomized female cats live significantly longer than their breeding counterparts, or than vasectomized males. Colonies managed by trap-neuter-return were stable in composition and declining in size throughout the seven year follow-up period. On average, breeding control colonies increased in size and had high turnover of cats, although one colony did experience a population crash followed by a rebound. Immigration into both breeding and sterilized colonies was consistent but occurred at low levels. One sterilized colony went extinct after 31 months of follow-up, and the several other colonies consisted of 5 or fewer cats after 7 years of follow-up.

The home ranges of the managed feral cats were small, usually less than 1 hectare, regardless of sex or reproductive status. Vasectomized male cats had significantly larger home ranges than intact or castrated male cats, but the sizes of intact and castrated male cat home ranges were similar, as were the home ranges of intact and spayed female cats. Vasectomized males moved significantly greater distances from the feeding sites than intact or castrated males, and spayed females moved farther than intact females though the difference for females may not be biologically important. The larger home range size and greater distance moved from feeding sites for vasectomized male cats are likely related to their search for breeding females, since the females in their home colonies were spayed.

Community-level stakeholder meetings were successful in fostering consensus among participants with different backgrounds, preferences and agendas, and the need for multiple feral cat management options to address a diversity of situations was recognized.

I used the data generated during the monitoring phase of this project to set up and run a population viability analysis model with VORTEX 9.57 software. I simulated the potential fates of intact breeding colonies subjected to various harvest levels and harvest intervals, and of sterilized colonies with different proportions of breeding adults. The models suggested that harvesting breeding colonies every one or two years at very high levels can keep colonies small, but will not lead to long-term reduction in the numbers of cats because colonies can re-establish due to immigration. The models of neutered colonies suggested that sterilization levels of at least 75% to 80% are necessary to cause population decline and eventual colony extinction, assuming that immigrant cats are also sterilized. The mean estimated time to extinction of 12.8 years fits well with ongoing observations of steady decline in the colonies managed by trap-neuter-return.

Overall, the trap-neuter-return strategy is effective and provides a viable option for feral cat management.

APPENDICES

Appendix 1. Results of infectious disease tests for feral and pet domestic cats

Table 1. Feral cat results

CAT	SEX	Bart categ	BhensT1	FeLV	FIV	Toxo	Crypto	Giardia	T. cati
AK-1	M	pos	128	neg	neg	500	neg	neg	neg
AK-10	M	pos	256	neg	pos	500	pos	neg	pos
AK-11	F	neg	32	neg	neg	50	neg	neg	neg
AK-2	F	pos	64	neg	neg	500	neg	neg	neg
AK-3	F	pos	512	neg	neg	500	neg	neg	neg
AK-4	F	pos	512	neg	neg	50	neg	neg	neg
AK-5	M	pos	256	neg	neg	500	neg	neg	neg
AK-6	F	pos	256	neg	neg	500			
AK-7	F	pos	512	pos	neg	500	pos	pos	pos
AK-8	M	pos	128	neg	neg	500	neg	neg	neg
AK-9	M	neg	32	neg	neg	500			
BC-1	M	pos	256	neg	neg	50	neg	neg	pos
BC-11	F	pos	128	pos	neg	0	neg	neg	neg
BC-13	F	pos	512	neg	neg	0	neg	neg	pos
BC-14	M	pos	512	neg	pos	0	neg	neg	neg
BC-15	F	pos	128	neg	neg	25			
BC-16	F	pos	128	neg	neg	50	neg	neg	neg
BC-17	M	pos	128	neg	neg	50	neg	neg	neg
BC-18	F	pos	256	neg	pos	0	neg	neg	neg
BC-22	F	pos	64	neg	neg	25	neg	neg	pos
BC-23	F	neg	32	neg	neg	0	neg	neg	neg
BC-24	M	pos	1024	neg	neg	50	neg	neg	neg
BC-4	F	pos	256	neg	neg	50	neg	neg	neg
BC-5	F	pos	256	neg	neg	50	neg	neg	neg
BC-7	M	pos	128	neg	neg	0	neg	pos	neg
BC-8	M	pos	64	neg	neg	0			
BC-9	M	pos	64	neg	neg	500			
BN-1	F	pos	64	neg	neg	500	neg	neg	pos
BN-11	M	pos	128	neg	neg	0	pos	neg	neg
BN-12	M	pos	256	neg	neg	50			
BN-2	F	pos	512	neg	neg	0			
BN-3	F	pos	125	neg	neg	0			
BN-4	M	pos	128	neg	neg	0	neg	neg	neg
BN-5	M	neg	32	neg	neg	0			
BN-6	F	pos	64	neg	neg	0			
BN-7	M	pos	64	neg	pos	500	neg	pos	neg
BN-8	F	pos	128	neg	neg	50	neg	neg	neg
BN-9	M	neg	32	neg	neg	0	neg	neg	neg
BS-1	M	pos	128	neg	neg	50	neg	neg	neg
BS-10	M	neg	0	neg	neg	25	neg	neg	neg
BS-2	F	pos	256	neg	neg	50	neg	neg	neg
BS-3	F	pos	128	neg	neg	500	neg	neg	pos
BS-4	F	pos	128	neg	neg	50	neg	neg	neg
BS-5	M	pos	512	neg	neg	50	neg	neg	pos
BS-6	M	pos	128	neg	neg	50	neg	neg	neg
BS-7	M	pos	128	neg	neg	50	neg	neg	neg
BS-8	M	pos	256	neg	neg	50	neg	neg	neg
BS-9	M	neg	32	neg	neg	50	neg	neg	neg
KA-1	F	pos	256	neg	neg	50	neg	neg	neg
KA-10	F	pos	512	neg	neg	0	neg	neg	neg

Appendix 1, Table 1, continued.

CAT	SEX	Bart categ	BhensT1	FeLV	FIV	Toxo	Crypto	Giardia	T. cati
KA-3	F	pos	64	neg	neg	0			
KA-4	M	pos	64	neg	neg	0	neg	neg	neg
KA-5	M	pos	64	neg	pos	500	pos	neg	neg
KA-6	F	pos	64	neg	neg	50	neg	neg	neg
KA-7	M	neg	32	neg	neg	0	neg	neg	neg
KA-8	F	pos	256	neg	neg	0	neg	neg	pos
KA-9	F	pos	256	neg	neg	0	neg	neg	neg
KR-1	F	pos	128	neg	neg	50	neg	neg	neg
KR-2	F	pos	128	neg	neg	500	neg	neg	pos
KR-3	M	neg	0	neg	neg	0	neg	neg	neg
KR-4	F	pos	128	neg	neg	0	neg	neg	neg
KR-5	F	neg	0	neg	neg	0			
KR-6	M	neg	32	neg	neg	0	neg	neg	neg
KR-7	F	pos	512	neg	neg	50	neg	neg	neg
KR-8	M	neg	32	neg	neg	25	neg	neg	pos
PH-1	F	pos	256	neg	neg	50	neg	neg	pos
PH-11	M	pos	128	neg	neg	50	neg	neg	neg
PH-12	M	pos	256	neg	neg	500	neg	pos	neg
PH-13	F	pos	128	neg	neg	50	neg	neg	neg
PH-3	F	pos	512	neg	neg	0	neg	neg	neg
PH-33	F	pos	1024	neg	neg	50	neg	neg	neg
PH-34	M	pos	1024	pos	neg	50	neg	neg	neg
PH-35	M	pos	512	neg	neg	50	neg	neg	neg
PH-4	M	pos	1024	neg	neg	50	neg	neg	neg
PH-41	M	pos	1024	neg	neg	50	neg	neg	pos
PH-5	M	pos	512	neg	neg	0	neg	neg	neg
PH-6	F	pos	512	neg	neg	50	neg	neg	pos
PH-7	M	neg	0	neg	neg	500	pos	neg	neg
PH-8	M	pos	128	neg	neg	50	neg	neg	neg
PH-9	F	pos	256	neg	neg	500			
TP-1	F	pos	128	neg	neg	50	neg	neg	neg
TP-10	F	pos	128	neg	neg	0	pos	neg	neg
TP-11	F	pos	64	neg	neg	50	neg	neg	pos
TP-12	M	neg	32	neg	neg	50	neg	neg	neg
TP-14	M	neg	0	neg	neg	50	neg	neg	neg
TP-15	M	pos	1024	neg	neg	50	neg	neg	neg
TP-18	M	pos	512	neg	neg	50	neg	neg	pos
TP-19	M	pos	1024	neg	pos	0	neg	pos	neg
TP-20	M	pos	512	neg	neg	0	neg	neg	neg
TP-21	M	pos	512	neg	neg	0	neg	neg	pos
TP-22	M	pos	256	neg	neg	0	neg	neg	neg
TP-23	F	pos	512	neg	neg	0	neg	neg	neg
TP-24	M	pos	1024	neg	neg	25	neg	neg	neg
TP-4	F	pos	256	neg	neg	50	neg	neg	neg
VR-1	M	pos	512	neg	neg	0	neg	neg	neg
VR-2	M	pos	256	pos	neg	0	neg	neg	neg
VR-3	F	neg	32	neg	neg	50	neg	neg	pos
VR-6	M	neg	32	neg	neg	0	neg	neg	neg
VR-7	F	pos	128	neg	neg	50	neg	neg	neg
VR-8	M	pos	256	neg	neg	0	neg	neg	neg

Table 2. Pet cat results.

Owner Initials	Cat Name	Sex	Neuter	Age(yrs)	Source	#Cats	Range	Bart categ	Bart titer	FeLV	FIV	Toxo	Toxo titer	Crypto	Giardia	T. cati
SA	Bogie	M	Y	7.00	gift	2	in	neg	32	neg	neg	0	0	neg	neg	neg
MA	Curious	F	Y	10.00	friend/neighbor	2	in/out	neg	0	neg	neg	50	50	neg	neg	neg
MA	Lewis	M	Y	4.00	paper	4	in/out	neg	32	neg	neg	0	0	neg	neg	pos
DB	Mirage	M	Y		shelter	41	in	neg	32	neg	neg	0	0	neg	neg	neg
LB	Cruella	F	Y	8.00	stray	4	in	neg	0	neg	neg	500	500	neg	neg	neg
LB	Spot	F	Y	2.00	stray	4	in	pos	256	neg	neg	0	0	neg	neg	neg
TB	August	F	Y	0.75	stray	3	in	pos	1024	neg	neg	500	500	pos	neg	pos
TB	Little Boy	M	Y	8.00	paper	2	in	pos	256	neg	neg	0	0	neg	neg	neg
TB	Maverick	M	Y	6.00	shelter	2	in	pos	64	neg	neg	0	0	neg	neg	neg
SB	Sterling	F	Y	11.00	stray	5	in/out	neg	32	neg	neg	0	0	neg	neg	neg
JC	Lexus	M	Y	3.00	stray			pos	128	neg	neg	500	500	neg	neg	neg
JC	Lilly	F	Y	14.00	stray			pos	64	neg	neg	0	0	neg	neg	neg
JC	Halley	M	Y	2.00	shelter	2	in/out	pos	256	neg	neg	0	0	neg	neg	neg
JC	Roscoe	F	Y	5.00	stray	2	in/out	pos	512	neg	neg	0	0	neg	neg	neg
TD	Abby	F	Y	5.00	stray	11	in/out	pos	64	neg	neg	0	0	neg	neg	neg
TD	Baby	F	Y	5.00	stray	11	in/out	pos	64	neg	pos	25	25	neg	neg	neg
TD	Butch	M	Y	4.00	stray	11	in/out	pos	64	neg	neg	500	500	neg	neg	neg
TD	Maggie May	F	Y	5.00	stray	11	in/out	neg	32	neg	neg	500	500	neg	pos	neg
TD	Smokey	M	Y	7.00	stray	11	in/out	pos	64	neg	neg	0	0	n/a	n/a	n/a
BD	Bernie	F	N	3.00	stray	5	in	pos	64	neg	neg	0	0	neg	neg	neg
BD	Expresso	M	Y	6.00	stray	5	in	pos	64	neg	neg	25	25	neg	neg	neg
BS	Jelly Belly	F	N	3.00	stray	5	in	pos	128	neg	neg	0	0	neg	neg	neg
BS	Leggs	F	Y	3.00	stray	5	in	pos	128	neg	neg	0	0	neg	neg	neg
DD	Nikki	F	Y	0.50	shelter	1	in	pos	256	neg	neg	0	0	neg	neg	pos
KH	Cooper	M	Y		shelter			pos	128	neg	neg	50	50	n/a	n/a	n/a
KH	Duffy	M	Y		stray			pos	128	neg	neg	50	50	neg	neg	neg
KH	Puffy	F	Y		stray			pos	256	neg	neg	0	0	neg	neg	neg
KH	Tuttles	M	Y	0.58	other	32	in/out	pos	128	neg	neg	0	0	neg	pos	neg
MH	Precious	F	Y	1.33	gift	1	in/out	pos	128	neg	neg	0	0	neg	neg	pos
BH	Smokey Jo	F	Y		stray		out	pos	128	neg	neg	50	50	n/a	n/a	n/a
JH	Cameron	M	Y	0.42	stray	2	in/out	pos	512	neg	neg	0	0	neg	neg	pos
CL	Nickie	F	N	0.58	stray	2	in	pos	1024	neg	neg	0	0	neg	neg	pos
PL	Jake	M	Y	11.00	stray	1	in	neg	32	neg	neg	0	0	neg	neg	neg
KL	Baby Doll	F	N	3.00	gift	2	in	pos	64	neg	neg	0	0	n/a	n/a	n/a
CM	Abby	F	N		other	10	in	pos	128	neg	neg	0	0	neg	neg	neg
CM	Mama Cat	F	N		other	10	in	pos	64	neg	neg	500	500	neg	neg	neg
CM	Miranda	F	N		other	10	in	pos	64	neg	neg	0	0	n/a	n/a	n/a
CM	Saraobi	F	N		other	10	in	pos	128	neg	neg	500	500	n/a	n/a	n/a
JM	Patches	F	Y		stray	4	in	neg	32	neg	neg	0	0	neg	neg	neg
JM	Peach	F	Y	1.00	stray	4	in	pos	256	neg	neg	0	0	neg	neg	neg
JM	Pooch	M	Y	6.00	stray	4	in	neg	32	neg	neg	500	500	neg	neg	neg
JM	Punkin	F	Y	10.00	stray	4	in	pos	64	neg	neg	0	0	neg	neg	neg
KM	Scooter	F	Y	1.50	stray	2	out	pos	512	neg	neg	0	0	pos	neg	neg
MM	Lucky	M	Y	7.00	stray	4	in/out	neg	32	neg	neg	500	500	neg	neg	neg
MM	Missy	F	Y	1.00	stray	4	in/out	pos	256	neg	neg	0	0	neg	neg	pos
MM	Nick	M	Y	5.00	friend/neighbor	4	in/out	pos	64	neg	neg	500	500	neg	neg	neg
PM	Baby Kitty	M	Y		vet	23	in	pos	64	neg	neg	0	0	neg	neg	neg
PM	Puffy	F	Y		vet	23	in	pos	128	neg	neg	0	0	neg	neg	neg
RN	Snowball	M	Y		shelter	14	in	neg	32	neg	neg	0	0	neg	neg	neg
MN	Leah	F	Y	1.00	friend/neighbor	3	in	pos	128	neg	neg	25	25	neg	neg	neg
MN	Rachel	F	Y	1.00	friend/neighbor	3	in	pos	64	neg	neg	0	0	neg	neg	neg
FN	Bishop	M	Y	9.00	stray	4	in/out	pos	64	neg	neg	25	25	neg	neg	neg
FN	Sophie	F	Y		stray	4	in/out	pos	256	neg	neg	25	25	n/a	n/a	n/a
FN	Stihlman	M	Y	4.00	stray	4	in/out	pos	128	neg	neg	500	500	neg	neg	pos
FN	Tucker	M	Y	8.00	stray	4	in/out	pos	64	neg	neg	50	50	neg	neg	neg
MP	Harrison	M	Y	6.00	stray	3	in/out	pos	64	neg	neg	25	25	neg	neg	neg
MP	Trapper	M	Y	14.00	stray	3	in/out	neg	32	neg	neg	0	0	neg	neg	neg
SR	Bandit	M	N	19.00	other	3	in	neg	0	neg	neg	0	0	neg	neg	neg
LS	Catapult	M	N	0.58	other	7	in	pos	512	neg	neg	0	0	neg	neg	neg
LS	Scorpion	M	N	0.58	other	7	in	pos	1024	neg	neg	0	0	pos	neg	neg
LS	Smokey Jr.	F	N	0.58	other	7	in	pos	512	neg	neg	0	0	n/a	n/a	n/a
SS	Shadow	M	Y		stray	5	in/out	pos	128	neg	neg	0	0	neg	neg	neg
KS	Bobbie	M	Y	5.00	stray	5	in/out	pos	256	neg	pos	0	0	neg	neg	neg
KS	Fluffer Nutter	M	Y	1.00	stray	5	in/out	pos	512	neg	neg	0	0	pos	neg	pos
KS	Lucy	F	Y	10.00	stray	5	in/out	neg	32	neg	neg	25	25	n/a	n/a	n/a
KS	Misty	F	Y	5.00	stray	5	in/out	pos	64	neg	neg	0	0	neg	neg	neg
KS	Zap	M	Y	12.00	stray	5	in/out	neg	32	neg	neg	0	0	neg	neg	neg
RS	Milo	M	N	1.50	stray	3	in/out	pos	256	neg	neg	50	50	neg	pos	pos
AT	Barnaby	M	Y	10.00	breeder/pet shop	2	in	neg	0	neg	neg	25	0	neg	neg	neg
AT	Patches	F	Y	4.00	shelter	2	in	pos	32	neg	neg	0	25	neg	neg	neg
JT	Gus	M	N	3.00	gift	2	in	pos	128	neg	neg	0	0	neg	neg	neg
RT	Mittens	F	Y	0.50	shelter	2	in/out	pos	256	neg	neg	0	0	n/a	n/a	n/a
RT	Smudge	M	Y	1.00	friend/neighbor	2	in/out	pos	128	neg	pos	0	0	neg	neg	pos
DT	Rafter	F	N	4.00	friend/neighbor	2	in/out	neg	256	pos	neg	25	0	neg	neg	pos
LY	Curious George	M	Y	4.00	gift	3	in	pos	32	neg	neg	0	25	neg	neg	neg
LY	Ms. Cat	F	Y	12.00	other	3	in	neg	64	neg	neg	0	0	neg	neg	neg

Appendix 2. Fecundity and kitten survival data

Table 1. Births from research colony cats

Mother #	Mother Name	Primiparous	Birth Date	Birth Month	Birth Month/Year	Birth Year	Litter Size	Litter of Yr	6 Mo Mort %	Comments
BS2	Gray	Y	15-May-98	May	May-98	1998	3	1	67	
KR1	Baby	N	3-Jul-98	July	Jul-98	1998	4		100	
KR1	Baby	N	1-Apr-99	April	Apr-99	1999	4	1	50	
KR2	Bashful	N	3-Apr-99	April	Apr-99	1999	4	1	100	
KR2	Bashful	N	24-Sep-99	Sept	Sep-99	1999	3	2	66	
KR7	Shannon	N	7-Jul-98	July	Jul-98	1998	4		100	
KR7	Shannon	N	23-Mar-99	Mar	Mar-99	1999	2	1	50	
KR7	Shannon	N	8-Aug-99	Aug	Aug-99	1999	2	2	50	
PH	Hussy		29-Aug-99	Aug	Aug-99	1999			100	kittens never seen
PH10			15-Nov-99	Nov	Nov-99	1999				
PH13			15-Jul-98	July	Jul-98	1998	3		33	
PH13		N	18-May-99	May	May-99	1999		1	100	kittens never seen
PH13		N	6-Aug-99	Aug	Aug-99	1999	3	2	66	
PH18	Dipstick		15-Aug-98	Aug	Aug-98	1998	2		100	PH18 FIV positive
PH18	Dipstick	N	9-Apr-99	April	Apr-99	1999	4	1	100	PH18 FIV positive, 3 kittens killed by male, 1 disppeared
PH19	Left Eye	Y	16-Apr-99	April	Apr-99	1999	4	1	25	
PH19	Left Eye	N	28-Aug-99	Aug	Aug-99	1999	4	2	0	
PH19	Left Eye	N	11-Apr-00	April	Apr-00	2000	5	1	60	
PH19	Left Eye	N	9-Sep-00	Sept	Sep-00	2000	5	2	20	
PH2	Lady	N	14-Jul-99	July	Jul-99	1999	5	2	40	
PH2	Lady	N	18-May-00	May	May-00	2000	3	1	33	
PH2	Lady	N	16-Aug-00	Aug	Aug-00	2000	4	2	75	
PH2	Lady			Jan	Jan-99	1999		1	100	kittens never seen
PH22		N	8-Jun-00	June	Jun-00	2000	3	1	0	
PH22		N	8-Oct-00	Oct	Oct-00	2000	3	2	33	
PH25	Phantom	Y	30-May-00	May	May-00	2000		1	100	kittens never seen
PH29	Dooley	Y	8-Jun-00	June	Jun-00	2000	5	1	80	
PH3			13-Jul-99	July	Jul-99	1999	4	1	75	
PH3		N	13-Apr-00	April	Apr-00	2000	4	1	0	

Appendix 2, Table 1, continued.

Mother #	Mother Name	Primiparous	Birth Date	Birth Month	Birth Month/Year	Birth Year	Litter Size	Litter of Yr	6 Mo Mort %	Comments
PH3		N	8-Aug-00	Aug	Aug-00	2000	4	2	100	kittens seen once
PH31	RJ	Y	26-Apr-00	April	Apr-00	2000	3	1	66	
PH33	Runt	Y	14-May-99	May	May-99	1999	1	1	0	
PH33	Runt	N	26-Apr-00	April	Apr-00	2000		1		
PH33	Runt	N	16-Aug-00	Aug	Aug-00	2000		2	100	
PH37	Got Milk	Y	28-Apr-00	April	Apr-00	2000	1	1	100	
PH37	Got Milk	N	30-Jun-00	June	Jun-00	2000	4	2	0	
TP	Shelia	Y								died during first potential repro period
TP1	Kitty	N	18-Aug-98	Aug	Aug-98	1998	6	2	67	
TP1	Kitty	N	23-Feb-99	Feb	Feb-99	1999	3	1	100	kittens seen twice
TP1	Kitty	N	14-Apr-99	April	Apr-99	1999	2	2	100	
TP1	Kitty	N	4-May-98	May	May-98	1998	3	1	0	
TP1	Kitty	N	30-Sep-99	Sept	Sep-99	1999	3	3	100	
TP10	Midnight	N	1-May-98	May	May-98	1998	3	1	67	
TP10	Midnight	N	9-Sep-98	Sept	Sep-98	1998	4	2	100	
TP10	Midnight	N	10-Apr-99	April	Apr-99	1999	4	2	50	
TP10	Midnight	N	27-Sep-99	Sept	Sep-99	1999	4	3	100	3 disappeared, 1 found dead
TP10	Midnight	N	5-Apr-00	April	Apr-00	2000	5	1	80	
TP10	Midnight	N	28-Jul-00	July	Jul-00	2000	6	2	100	
TP10	Midnight	N		Feb	Feb-99	1999		1	100	kittens never seen
TP11	Cheerup	Y					0			never gave birth in 2 years
TP13	Pooh	Y	24-Apr-02	April	Apr-99	1999	1	1	100	TP13 disappeared, suspect dystocia
TP17	Silver	Y	20-May-99	May	May-99	1999	3	1	100	
TP17	Silver	N	7-Aug-99	Aug	Aug-99	1999	2	2	50	
TP17	Silver	N	4-Apr-00	April	Apr-00	2000		1	100	kittens never seen
TP17	Silver	N	27-Jul-00	July	Jul-00	2000		2	100	
TP2	Tiger	N	7-May-98	May	May-98	1998	2	1	0	
TP2	Tiger	N	21-Aug-98	Aug	Aug-98	1998	5	2	60	
TP2	Tiger	N	9-Aug-99	Aug	Aug-99	1999	3	2	0	all surviving
TP2	Tiger	N		Feb	Feb-99	1999		1	100	kittens never seen
TP26	Charlotte	Y	30-Jul-00	July	Jul-00	2000	3	1	100	
TP4	Tails	N	7-Jun-98	June	Jun-98	1998	3	1	100	
TP4	Tails	N	23-May-99	May	May-99	1999	2	1	0	
VR11	Smokey	Y	25-May-00	May	May-00	2000	4	1	100	kittens never seen, VR11 missing 25-27 May

Table 2. Kitten survival

Kitten #	Kitten Name	Sex	Mother #	Mother Name	Primiparous	Birth Date	Death/Censor Date	Death Cause
PH22 00 Jun 1	CJ	M	PH22		N	8-Jun-00	29/Dec/01	
BS	Charcoal	M	BS2	Gray	Y	15-May-98	13-Feb-99	trauma
BS2 May 98 2	Meatloaf	M	BS2	Gray	Y	15-May-98	8-Jun-98	unknown
BS2 May 98 3	Gray	F	BS2	Gray	Y	15-May-98	11-Jun-98	unknown
KA gray 1			KA				13-Dec-98	unknown
KA gray 2			KA				28-Dec-98	
KA gray 3			KA				5-Nov-98	HBC
KR1 99 Apr 1	Oreo	F	KR1	Baby	N	1-Apr-99	11-Mar-00	HBC
KR1 99 Apr 2	Simon	M	KR1	Baby	N	1-Apr-99	8-May-00	
KR1 99 Apr 3			KR1	Baby	N	1-Apr-99	18-Jun-99	
KR1 99 Apr 4			KR1	Baby	N	1-Apr-99	23-Jul-99	
KR2 99 Apr 1			KR2	Bashful	N	3-Apr-99	24-Jun-99	found dead
KR2 99 Apr 2			KR2	Bashful	N	3-Apr-99	31-Jul-99	
KR2 99 Apr 3			KR2	Bashful	N	3-Apr-99	31-Jul-99	
KR2 99 Apr 4			KR2	Bashful	N	3-Apr-99	31-Jul-99	
KR2 99 Sept 1	Dipstick	F	KR2	Bashful	N	24-Sep-99	26-Jan-00	
KR2 99 Sept 2	Tater Tot	F	KR2	Bashful	N	24-Sep-99	26-Jan-00	
KR2 99 Sept 3	Dopey	M	KR2	Bashful	N	24-Sep-99	19-Feb-01	
KR7 98 Jul 1	Syrup	F	KR7	Shannon	N	7-Jul-98	30-Aug-98	
KR7 98 Jul 2	Waffle	F	KR7	Shannon	N	7-Jul-98	28-Sep-98	killed by dog
KR7 98 Jul 3	Bacon	M	KR7	Shannon	N	7-Jul-98	21-Oct-98	killed by dog
KR7 98 Jul 4	Eggs	M	KR7	Shannon	N	7-Jul-98	24-Sep-98	
KR7 99 Aug 1		F	KR7	Shannon	N	8-Aug-99	24-Nov-99	killed by dog
KR7 99 Aug 2		M	KR7	Shannon	N	8-Aug-99	9-May-00	
KR7 99 Mar 1			KR7	Shannon	N	23-Mar-99	14-Aug-99	
KR7 99 Mar 2			KR7	Shannon	N	23-Mar-99	24-Sep-99	HBC
PH10 99 Nov 1			PH10			15-Nov-99	30/May/00	
PH13 98 Jul 1	Sugar		PH13			15-Jul-98	21/Sep/98	
PH13 98 Jul 2	B/W		PH13			15-Jul-98	15/Sep/98	
PH13 99 Aug 1			PH13		N	6-Aug-99	30/Sep/99	
PH13 99 Aug 2	Sherbet	F	PH13		N	6-Aug-99	1/Aug/00	
PH16	Punkin	M	PH13			15-Jul-98	26/May/99	
PH17	Groucho	M					30/Jun/99	unknown
PH18 98 Aug 1			PH18	Dipstick		15-Aug-98	20/Nov/98	
PH18 98 Aug 2			PH18	Dipstick		15-Aug-98	31/Dec/98	
PH18 99 Apr 1			PH18	Dipstick	N	9-Apr-99	27/Apr/99	infantacide
PH18 99 Apr 2			PH18	Dipstick	N	9-Apr-99	27/Apr/99	infantacide
PH18 99 Apr 3			PH18	Dipstick	N	9-Apr-99	27/Apr/99	infantacide
PH18 99 Apr 4			PH18	Dipstick	N	9-Apr-99	4/May/99	
PH19 00 Apr 1			PH19	Left Eye	N	11-Apr-00	10/Jul/00	
PH19 00 Apr 2			PH19	Left Eye	N	11-Apr-00	7/Aug/00	
PH19 00 Apr 3			PH19	Left Eye	N	11-Apr-00	8/Sep/00	killed by dog
PH19 00 Sep 1			PH19	Left Eye	N	9-Sep-00	11/Nov/00	unknown
PH19 99 Apr 2	Sad Sack		PH19	Left Eye	Y	16-Apr-99	24/Oct/99	
PH19 99 Apr 3	Smokey Jr.		PH19	Left Eye	Y	16-Apr-99	10/Apr/00	
PH19 99 Apr 4	Sassy		PH19	Left Eye	Y	16-Apr-99	8/Sep/99	killed by dog
PH19 99 Aug 1	Cinder		PH19	Left Eye	N	28-Aug-99	10/Aug/00	
PH2 00 Aug 1			PH2	Lady	N	16-Aug-00	5/Sep/00	
PH2 00 Aug 2			PH2	Lady	N	16-Aug-00	5/Sep/00	
PH2 00 Aug 3	Wild Bill	M	PH2	Lady	N	16-Aug-00	8/Dec/00	
PH2 00 May 1			PH2	Lady	N	18-May-00	4/Aug/00	
PH2 99 Jul 1			PH2	Lady	N	14-Jul-99	30/Aug/99	illness
PH2 99 Jul 2			PH2	Lady	N	14-Jul-99	22/Sep/99	unknown
PH2 99 Jul 3	Pie	F	PH2	Lady	N	14-Jul-99	2/May/00	killed by dog
PH21	Tip	M					19/Jun/99	
PH22 00 Oct 1	Tom	M	PH22		N	8-Oct-00	28/Dec/00	

Appendix 2, Table 2, continued.

Kitten #	Kitten Name	Sex	Mother #	Mother Name	Primiparous	Birth Date	Death/Censor Date	Death Cause
PH25	Phantom	F	PH10			15-Nov-99	31/Oct/00	
PH29	Dooley	F	PH19	Left Eye	N	28-Aug-99	31/Oct/00	
PH29 00 Jun 1			PH29	Dooley	Y	8-Jun-00	18/Aug/00	
PH29 00 Jun 2			PH29	Dooley	Y	8-Jun-00	18/Aug/00	
PH29 00 Jun 3			PH29	Dooley	Y	8-Jun-00	18/Aug/00	
PH29 00 Jun 4			PH29	Dooley	Y	8-Jun-00	18/Aug/00	
PH3 99 Jul 1			PH3			13-Jul-99	30/Sep/99	
PH3 99 Jul 2			PH3			13-Jul-99	30/Sep/99	
PH3 99 Jul 3			PH3			13-Jul-99	30/Oct/99	
PH3 99 Jul 4	JJ	F	PH3			13-Jul-99	13/Jun/00	
PH30	Parkay	M	PH19	Left Eye	N	28-Aug-99	18/Jan/01	
PH31	RJ	F	PH13		N	6-Aug-99	31/Oct/00	
PH31 00 Apr 1			PH31	RJ	Y	26-Apr-00	14/May/00	
PH31 00 Apr 2			PH31	RJ	Y	26-Apr-00	12/Jun/00	
PH33 00 Apr 1			PH33	Runt	N	26-Apr-00	28/Dec/00	HBC
PH34	Smudge	M	PH2	Lady	N	14-Jul-99	8/Dec/00	
PH35	Wildman	M	PH33	Runt	Y	14-May-99	20/May/01	HBC
PH36	Little Bit	F	PH31	RJ	Y	26-Apr-00	31/Oct/00	
PH37	Got Milk	F	PH2	Lady	N	14-Jul-99	18/Oct/00	unknown, ill
PH37 00 Apr 1			PH37	Got Milk	Y	28-Apr-00	5/May/00	
PH37 00 Jun 3	Larry	M	PH37	Got Milk	N	30-Jun-00	6/Feb/01	HBC
PH38	Buttercup	M	PH19	Left Eye	N	28-Aug-99	5/Mar/02	
PH39	Ferris	M	PH19	Left Eye	N	11-Apr-00	11/Apr/01	HBC
PH40	Simone	F	PH3		N	13-Apr-00	31/Oct/00	killed by dog
PH41	Van Dyke	M	PH19	Left Eye	N	11-Apr-00	2/Jun/01	
PH42	TJ	M	PH19	Left Eye	Y	16-Apr-99	15/Nov/01	
PH43	Gunsmoke	M	PH2	Lady	N	18-May-00	27/May/01	
PH46	Oleo	M	PH3		N	13-Apr-00	16/Jun/01	HBC
PH47	Onyx	F	PH3		N	13-Apr-00	31/Oct/00	
PH48	Decker	M	PH22		N	8-Jun-00	8/Dec/00	HBC
PH49	Clover	F	PH3		N	13-Apr-00	31/Oct/00	
PH50	Casper	M	PH2	Lady	N	18-May-00	31/Oct/00	
PH52	Tuffy	M	PH19	Left Eye	N	9-Sep-00	31/Oct/00	
PH53	Princess	F	PH29	Dooley	Y	8-Jun-00	21/Nov/01	trauma
PH55	Scatter	F	PH22		N	8-Oct-00	28/Apr/01	killed by dog
PH56	Mo	F	PH2	Lady	N	16-Aug-00	24/Oct/01	HBC
PH57	Fuzzy	M	PH19	Left Eye	N	9-Sep-00	31/Oct/00	
PH58	Curly	F	PH37	Got Milk	N	30-Jun-00	31/Oct/00	
PH59	Skitter	F	PH22		N	8-Oct-00	31/Oct/00	
PH60	Midnight	F	PH19	Left Eye	N	9-Sep-00	31/Oct/00	
PH61	Chopper	F	PH37	Got Milk	N	30-Jun-00	31/Oct/00	
PH62	Wally	F	PH37	Got Milk	N	30-Jun-00	31/Oct/00	
PH63	Fluffy	M	PH19	Left Eye	N	9-Sep-00	31/Oct/00	
PH64	Mouth	M	PH33	Runt	N	26-Apr-00	31/Oct/00	
TP	Piglet	F	TP2	Tiger	N	21-Aug-98	6-Mar-99	trauma
TP	Wild Thing	M	TP10	Midnight	N	1-May-98	19-Dec-98	trauma
TP	Skitty	F	TP10	Midnight	N	5-Apr-00	31-Dec-00	unknown
TP	Eyeor	M	TP2	Tiger	N	21-Aug-98	21-Jul-99	trauma
TP	Boots	F	TP1	Kitty	N	18-Aug-98	17-Aug-99	killed by dog
TP1 Apr 99 1		F	TP1	Kitty	N	14-Apr-99	15-Apr-99	unknown
TP1 Apr 99 2	Daisy Mae	F	TP1	Kitty	N	14-Apr-99	7-Jul-99	unknown
TP1 Aug 98 3		F	TP1	Kitty	N	18-Aug-98	20-Sep-98	unknown
TP1 Aug 98 4		M	TP1	Kitty	N	18-Aug-98	19-Dec-98	unknown
TP1 Aug 98 5		M	TP1	Kitty	N	18-Aug-98	11-Oct-98	unknown
TP1 Aug 98 6		F	TP1	Kitty	N	18-Aug-98	15-Oct-98	unknown
TP1 Sep 99 1			TP1	Kitty	N	30-Sep-99	30-Nov-99	unknown

Appendix 2, Table 2, continued.

Kitten #	Kitten Name	Sex	Mother #	Mother Name	Primiparous	Birth Date	Death/Censor Date	Death Cause
TP1 Sep 99 2			TP1	Kitty	N	30-Sep-99	30-Nov-99	unknown
TP1 Sep 99 3			TP1	Kitty	N	30-Sep-99	30-Nov-99	unknown
TP10 Apr 00 2			TP10	Midnight	N	5-Apr-00	15-May-00	unknown
TP10 Apr 00 3			TP10	Midnight	N	5-Apr-00	15-May-00	unknown
TP10 Apr 00 4			TP10	Midnight	N	5-Apr-00	2-Jun-00	unknown
TP10 Apr 00 5			TP10	Midnight	N	5-Apr-00	7-Jun-00	unknown
TP10 Apr 99 1			TP10	Midnight	N	10-Apr-99	11-Apr-99	unknown
TP10 Apr 99 2			TP10	Midnight	N	10-Apr-99	24-Jun-99	drowned
TP10 Jul 00 1	Taz	M	TP10	Midnight	N	28-Jul-00	31-Dec-00	unknown
TP10 Jul 00 2	Sassy	F	TP10	Midnight	N	28-Jul-00	20-Jan-01	unknown
TP10 Jul 00 3	Socks	F	TP10	Midnight	N	28-Jul-00	20-Jan-01	unknown
TP10 Jul 00 4		F	TP10	Midnight	N	28-Jul-00	11-Sep-00	killed by dog
TP10 Jul 00 5		M	TP10	Midnight	N	28-Jul-00	13-Sep-00	killed by dog
TP10 Jul 00 6		M	TP10	Midnight	N	28-Jul-00	13-Sep-00	killed by dog
TP10 May 98 2		M	TP10	Midnight	N	1-May-98	14-Jun-98	unknown
TP10 May 98 3		F	TP10	Midnight	N	1-May-98	24-Jun-98	unknown
TP10 Sept 98 1		F	TP10	Midnight	N	9-Sep-98	29-Sep-98	unknown
TP10 Sept 98 2	Oreo	M	TP10	Midnight	N	9-Sep-98	22-Oct-98	unknown
TP10 Sept 98 3	Plunder	M	TP10	Midnight	N	9-Sep-98	29-Dec-98	unknown
TP10 Sept 98 4		F	TP10	Midnight	N	9-Sep-98	23-Oct-98	unknown
TP10 Sept 99 1		M	TP10	Midnight	N	27-Sep-99	26-Jan-00	unknown
TP10 Sept 99 2		F	TP10	Midnight	N	27-Sep-99	30-Nov-99	
TP10 Sept 99 3		F	TP10	Midnight	N	27-Sep-99	30-Nov-99	
TP10 Sept 99 4		F	TP10	Midnight	N	27-Sep-99	30-Nov-99	
TP12	Winnie	F	TP1	Kitty	N	4-May-98	17-Aug-99	killed by dog
TP13	Pooh	F	TP2	Tiger	N	7-May-98	24-Apr-99	unknown
TP13 Apr 99 1			TP13	Pooh	Y	24-Apr-99	24-Apr-99	unknown
TP14	Skunk	M	TP1	Kitty	N	4-May-98	1-Jun-00	unknown
TP15	Shark	M	TP1	Kitty	N	18-Aug-98	24-May-99	unknown
TP16	Tigger	M	TP2	Tiger	N	7-May-98	14-Aug-00	trauma
TP17	Silver	F	TP1	Kitty	N	4-May-98	31/Oct/00	
TP17 Aug 00 1		F	TP17	Silver	N	27-Jul-00	6-Sep-00	unknown
TP17 Aug 99 2	Gray One	F	TP17	Silver	N	7-Aug-99	24-Jan-00	unknown
TP17 May 99 1			TP17	Silver	Y	20-May-99	21-May-99	killed by dog
TP17 May 99 2			TP17	Silver	Y	20-May-99	21-May-99	killed by dog
TP17 May 99 3			TP17	Silver	Y	20-May-99	24-May-99	unknown
TP19	Aaron	M	TP17	Silver	N	7-Aug-99	17-Jun-01	illness
TP2 Aug 98 3		F	TP2	Tiger	N	21-Aug-98	14-Sep-98	unknown
TP2 Aug 98 4		F	TP2	Tiger	N	21-Aug-98	8-Oct-98	unknown
TP20	Michelob	M	TP2	Tiger	N	9-Aug-99	31/Oct/00	
TP21	Pirate	M	TP2	Tiger	N	9-Aug-99	31/Oct/00	
TP22	Gremlin	M	TP2	Tiger	N	9-Aug-99	31/Oct/00	
TP26	Charlotte	F	TP10	Midnight	N	10-Apr-99	31/Oct/00	
TP26 Jul 00 1			TP26	Charlotte	Y	30-Jul-00	27-Aug-00	killed by dog
TP26 Jul 00 2	Mittens	F	TP26	Charlotte	Y	30-Jul-00	13-Jan-01	killed by dog
TP26 Jul 00 3	Muffy	F	TP26	Charlotte	Y	30-Jul-00	13-Jan-01	killed by dog
TP27	Bear	M	TP10	Midnight	N	10-Apr-99	31/Oct/00	
TP4 Apr 99 1			TP4	Tails	N	23-May-99	17-Jun-99	unknown
TP4 Apr 99 2			TP4	Tails	N	23-May-99	27-Jun-99	unknown
TP4 Jun 98 1	Oreo	M	TP4	Tails	N	7-Jun-98	28-Jul-98	unknown
TP4 Jun 98 2	Ursula	F	TP4	Tails	N	7-Jun-98	28-Jul-98	unknown
TP4 Jun 98 3	Kitten	F	TP4	Tails	N	7-Jun-98	17-Jun-98	unknown
VR12	Leo	M	VR 11	Smokey	N	6-Sep-00	31/Oct/00	
VR13	Tiger	M	VR 11	Smokey	N	6-Sep-00	31/Oct/00	
VR14	Bluie	F	VR 11	Smokey	N	6-Sep-00	31/Oct/00	
VR15	Scratchy	F	VR 11	Smokey	N	6-Sep-00	31/Oct/00	
VR16	Speedy	M	VR 11	Smokey	N	6-Sep-00	31/Oct/00	

Appendix 3. Adult cat survival data

Table 1. Adult cat survival

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Blaze	AK1	m	orig	2	censored	730	1322	uncensored	dead
Buddy	AK10	m	orig	2	censored	730	1460	censored	
Maggie	AK11	f	orig	2	censored	730	1460	censored	
Minnie	AK12	f	orig	2	uncensored	702			HBC
Burly (or/wht tom)	AK13	m	immig	2	censored	730	1258	censored	
Tippy	AK2	f	orig	2	uncensored	488			dead
Callie	AK3	f	orig	2	censored	730	1460	censored	
Alley	AK4	f	orig	2	censored	730	1460	censored	
Rusty	AK5	m	orig	2	censored	730	1460	censored	
Mollie	AK6	f	orig	2	censored	730	1460	censored	
Sissy	AK7	f	orig	2	censored	730	1090	uncensored	HBC
Tom	AK8	m	orig	2	uncensored	169			disappeared
Tiger	AK9	m	orig	2	censored	730	1460	censored	
Tweetums	BC	f	orig	2	uncensored	519			removed
Baby Two	BC	f	immig	2	censored	730	807	censored	
Magic Ashes	BC	f	immig	2	censored	730	807	censored	
Baby	BC	f	orig	2	censored	730	1460	censored	
Or tab tom	BC	m	immig	2	uncensored	6			transient
Bob	BC	m	immig	2	censored	730	1179	censored	
Homer	BC	m	immig	2	censored	469			
Shadow	BC	m	immig	2	censored	469			
Abbott	BC	m	orig	2	censored	730	1460	censored	
Hop-Along	BC1	m	orig	2	censored	730	1460	censored	
Black Male	BC10	m	orig	2	uncensored	296			dead
Calico Female	BC11	f	orig	2	censored	730	1460	censored	
Dark Tortie Female	BC12	f	orig	2	censored	730	1460	censored	
Wheelbarrow	BC13	f	orig	2	censored	730	1460	censored	
Chester	BC14	m	orig	2	censored	730	1460	censored	
Julie	BC15	f	orig	2	censored	730	1460	censored	
Or tab/wht tip female	BC16	f	orig	2	censored	730	1460	censored	
Or Tab Male "Rackroom"	BC17	m	orig	2	censored	730	1460	censored	
Black Female	BC18	f	orig	2	censored	730	1460	censored	
Black Female	BC19	f	orig	2	uncensored	0			dead
Diva	BC2	f	orig	2	censored	730	1460	censored	
Lothario	BC20	m	orig	2	censored	730	1460	censored	
Charlie	BC21	m	orig	2	censored	730	1460	censored	
Wild Kitty	BC22	f	orig	2	censored	730	1460	censored	
Frosty	BC23	f	orig	2	censored	730	1460	censored	
Pumpkin	BC24	m	orig	2	censored	730	1460	censored	
Checker	BC3	f	orig	2	censored	730	1460	censored	
B/W female	BC4	f	orig	2	censored	730	1460	censored	
Marshmallow	BC5	f	orig	2	uncensored	578			removed
Prissy	BC6	f	orig	2	uncensored	507			removed
Black Male	BC7	m	orig	2	censored	730	1460	censored	
Touche	BC8	m	orig	2	censored	730	1460	censored	
Or Tab Male	BC9	m	orig	2	censored	730	1460	censored	
Yellow Fuzzy	BN	m	immig	3	uncensored	188			disappeared
Little Mac	BN	m	orig	2	uncensored	41			HBC
Thomas	BN	m	orig	2	uncensored	69			HBC
Grace	BN1	f	orig	3	censored	730	820	uncensored	disappeared
April	BN10	f	orig	3	censored	730	1460	censored	
David	BN11	m	recruit	3	uncensored	282			HBC
Poochie	BN12	m	immig	3	uncensored	522			disappeared
Battle	BN13	m	immig	3	censored	730	1460	censored	euthanized, chronic dz
Brushy Tail	BN14	m	immig	2	uncensored	38			disappeared
Poochie Two	BN15	m	immig	2	censored	570			euthanized, chronic dz
Gabby	BN16	m	immig	2	censored	220			inside cat
Maxine	BN2	f	orig	3	censored	730	1460	censored	

Appendix 3, Table 1, continued.

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Little One	BN3	f	orig	3	censored	730	1460	censored	
Purr Baby	BN4	m	orig	3	uncensored	67			HBC
Little Nut	BN5	m	orig	3	uncensored	502			dead
Anne	BN6	f	recruit	3	censored	730	1460	censored	
Old Cat	BN7	m	orig	3	uncensored	229			collar
Ava	BN8	f	orig	3	censored	730	1460	censored	
Johnathan	BN9	m	recruit	3	uncensored	29			HBC
Clint	BS1	m	orig	2	uncensored	414			HBC
Charcoal	BS10	m	orig	2	uncensored	94			killed by dogs
Big Orange	BS11	m	immig	2	censored	730	981	uncensored	disappeared
Pale Orange	BS12	m	immig	2	censored	730	802	censored	
Gray	BS2	f	orig	2	uncensored	696			disappeared
Tortie	BS3	f	orig	2	uncensored	556			disappeared
Wierdie	BS4	f	orig	2	censored	730	1460		
Black	BS5	m	orig	2	uncensored	541			disappeared
Toes	BS6	m	orig	2	uncensored	224			disappeared
Big Meatloaf	BS7	m	orig	2	uncensored	614			found dead
Renegade	BS8	m	orig	2	censored	730	991	uncensored	found dead
Nice Meatloaf	BS9	m	orig	2	censored	730	1346	uncensored	found dead
KA gray 1	KA	f	recruit	3	uncensored	32			disappeared
GreyKitten	KA	m	recruit	3	uncensored	21			HBC
KA gray 2	KA	m	recruit	3	uncensored	47			HBC
KA1	KA1	f	orig	3	uncensored	568			disappeared
KA10	KA10	f	orig	3	uncensored	485			disappeared
KA11	KA11	m	orig	3	uncensored	108			HBC
KA12	KA12	m	immig	3	uncensored	170			disappeared
KA2	KA2	f	orig	3	uncensored	478			disappeared
KA3	KA3	f	orig	3	uncensored	568			disappeared
KA4	KA4	m	orig	3	uncensored	306			HBC
KA5	KA5	m	orig	3	uncensored	416			disappeared
KA6	KA6	f	orig	3	uncensored	527			disappeared
KA7	KA7	m	orig	3	censored	730	954	uncensored	disappeared
KA8	KA8	f	orig	3	censored	730	918	uncensored	disappeared
KA9	KA9	f	orig	3	censored	730	830	uncensored	disappeared
KH May 01 6	KH	f	recruit	1	uncensored	40			disappeared
Grey/white DLH F	KH	f	recruit	1	uncensored	128			HBC
KH6 Apr 02 2	KH	f	recruit	1	censored	24			
KH5 Apr 02 1	KH	f	recruit	1	censored	21			
Casper	KH	m	recruit	1	uncensored	283			dead
Mr. Brown	KH	m	recruit	1	uncensored	304			disappeared
LJ	KH	m	recruit	1	uncensored	161			HBC
Mr. White	KH	m	recruit	1	censored	353			
Shorty	KH	m	recruit	1	censored	263			
Mr. Stripe	KH	m	recruit	1	censored	263			
KH6 Apr 02 1	KH	m	recruit	1	censored	24			
KH6 Apr 02 4	KH	m	recruit	1	censored	24			
Marilyn	KH1	f	orig	1	censored	517			
Thomas Hoover	KH10	m	orig	1	uncensored	81			disappeared
Nosy	KH2	f	orig	1	censored	517			
Fuzzy	KH3	f	orig	1	censored	517			
Carolyn	KH4	f	orig	1	censored	517			
Bandy/Bandit	KH5	f	orig	1	censored	517			
Molly	KH6	f	orig	1	censored	517			
Dommie	KH7	f	orig	1	uncensored	27			disappeared
Little Bit	KH8	f	orig	1	uncensored	25			disappeared
Pedro	KH9	m	orig	1	uncensored	58			disappeared
Missy	KR	f	recruit	1	uncensored	42			disappeared
Peace	KR	f	recruit	1	uncensored	267			emigrated

Appendix 3, Table 1, continued.

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Topanga	KR	f	recruit	1	uncensored	38			emigrated
Munchkin	KR	f	recruit	1	censored	5			emigrated
Oreo	KR	f	recruit	1	uncensored	166			HBC
Olivia	KR	f	recruit	1	uncensored	511			HBC
Diamond	KR	f	recruit	1	censored	397			
Fizzy	KR	f	recruit	1	censored	397			
Dusty	KR	f	recruit	1	censored	60			
Star	KR	f	recruit	1	censored	60			
Grey tab	KR	m	recruit	1	uncensored	23			disappeared
Simon	KR	m	recruit	1	uncensored	215			disappeared
KR7 Aug GT 2	KR	m	recruit	1	uncensored	95			disappeared
Dopey	KR	m	recruit	1	uncensored	334			disappeared
KR2 Apr Blk 1	KR	m	recruit	1	uncensored	146			disappeared
Gray Tom	KR	m	immig	1	uncensored	723			emigrated
Junior	KR	m	recruit	1	uncensored	38			emigrated
Sly	KR	m	recruit	1	uncensored	38			emigrated
Spunk	KR	m	recruit	1	uncensored	38			emigrated
Cutie Pie	KR	m	recruit	1	uncensored	93			HBC
Mr. Tim	KR	m	immig	1	censored	580			
Joy	KR	m	recruit	1	censored	267			
Mister	KR	m	recruit	1	censored	5			
Baby	KR1	f	orig	1	uncensored	482			HBC
Dark tabby	KR10	m	orig	1	uncensored	108			disappeared
Bashful	KR2	f	orig	1	censored	730	1460	censored	
PJ	KR3	m	orig	1	uncensored	508			disappeared
Taz Too	KR4	f	orig	1	uncensored	244			disappeared
Taz	KR5	f	orig	1	uncensored	195			disappeared
JP	KR6	m	orig	1	uncensored	240			drowned
Shannon	KR7	f	orig	1	uncensored	390			HBC
Sam	KR8	m	orig	1	uncensored	154			HBC
Wonder	KR9	m	orig	1	uncensored	646			killed by dogs
Pie	PH	f	recruit	1	uncensored	113			disappeared
PH10 99 Nov 1	PH	f	recruit	1	uncensored	18			disappeared
Hussy	PH	f	immig	1	censored	730	776	censored	spayed Dec 02
Andrea	PH	f	recruit	2	censored	392			
Lil Darlin	PH	f	recruit	2	censored	392			
Silver	PH	f	recruit	2	censored	392			
Poofy	PH	f	recruit	2	censored	16			
Button	PH	f	recruit	2	censored	14			
Dipper	PH	f	recruit	2	censored	14			
Spot	PH	f	recruit	2	censored	14			
Sweetie	PH	f	recruit	2	censored	14			
Sad Sack	PH	m	recruit	1	uncensored	11			disappeared
Smokey Jr.	PH	m	recruit	1	uncensored	180			disappeared
Cinder	PH	m	recruit	1	uncensored	168			disappeared
CJ	PH	m	recruit	2	uncensored	389			disappeared
Larry	PH	m	recruit	1	uncensored	41			HBC
Yellow/White Tom	PH	m	immig	2	censored	386			
Big Tom	PH	m	immig	2	censored	19			
Amber	PH	m	recruit	2	censored	392			
Cheesie	PH	m	recruit	2	censored	353			
Purcy	PH	m	recruit	2	censored	353			
Mr. T	PH	m	recruit	2	censored	14			
Nehi	PH	m	recruit	2	censored	14			
Hissy	PH1	f	immig	1	uncensored	323			disappeared
	PH10	f	orig	1	uncensored	689			disappeared
	PH11	m	orig	1	uncensored	315			disappeared

Appendix 3, Table 1, continued.

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Fuzzy Butt	PH12	m	immig	1	uncensored	325			disappeared
Calico Mom	PH13	f	orig	1	uncensored	590			disappeared
	PH14	f	orig	1	uncensored	284			disappeared
Not Tip	PH15	m	recruit	1	uncensored	230			disappeared
Punkin	PH16	m	recruit	1	uncensored	135			disappeared
Groucho/Radar	PH17	m	recruit	1	uncensored	231			dead
Dipstick	PH18	f	immig	1	uncensored	241			euthanized
Left Eye	PH19	f	recruit	1	censored	675			neutered
Left Eye	PH19	f	recruit	2	censored	730	785	censored	
Lady	PH2	f	orig	2	uncensored	616			disappeared
Lady	PH2	f	orig	1	censored	730	791		spayed
Buff Tabby	PH20	m	immig	1	uncensored	130			emigrated
Tip	PH21	m	recruit	1	uncensored	230			disappeared
Dark Tortie	PH22	f	recruit	1	censored	675			spayed
Dark Tortie	PH22	f	recruit	2	censored	730	785	censored	
Runt	PH23/33	f	recruit	1	censored	676			spayed
Runt	PH23/33	f	recruit	2	censored	730	784	censored	
Dilute Calico	PH24	f	recruit	1	uncensored	139			emigrated
Phantom	PH25	f	recruit	1	censored	289			spayed
Phantom	PH25	f	recruit	2	censored	551	611	censored	
Sherbet	PH26	m	recruit	1	uncensored	181			disappeared
JJ	PH27	m	recruit	1	uncensored	156			disappeared
Black Jack	PH28	m	immig	2	uncensored	68			disappeared
Black Jack	PH28	m	immig	1	censored	200			neutered
Dooley	PH29	f	recruit	1	censored	198			spayed
Dooley	PH29	f	recruit	2	censored	730	781		
Lower Orange	PH3	f	orig	1	censored	730	791	censored	spayed
Lower Orange	PH3	f	orig	2	censored	731	785	censored	
Parkay	PH30	m	recruit	2	uncensored	133			disappeared
Parkay	PH30	m	recruit	1	censored	195			neutered
RJ	PH31	f	recruit	1	censored	217			spayed
RJ	PH31	f	recruit	2	censored	730	784	censored	
Smudge	PH34	m	recruit	2	uncensored	93			disappeared
Smudge	PH34	m	recruit	1	censored	239			neutered
Wildman Hinshaw	PH35	m	recruit	2	uncensored	256			HBC
Wildman Hinshaw	PH35	m	recruit	1	censored	300			neutered
Little Bit	PH36	f	recruit	2	censored	730	738	censored	
Got Milk	PH37	f	recruit	2	uncensored	42			disappeared
Got Milk	PH37	f	recruit	1	censored	239			spayed
Buttercup	PH38	m	recruit	2	uncensored	545			disappeared
Buttercup	PH38	m	recruit	1	censored	194			neutered
Ferris	PH39	m	recruit	2	uncensored	185			HBC
Thomas T	PH4	m	orig	1	uncensored	349			dead
Simone	PH40	f	recruit	2	uncensored	21			killed by dogs
Van Dyke	PH41	m	recruit	2	uncensored	237			dead
TJ	PH42	m	recruit	2	uncensored	435			disappeared
TJ	PH42	m	recruit	1	censored	328			neutered
Gunsmoke	PH43	m	recruit	2	uncensored	194			disappeared
Mimi	PH45	f	recruit	2	censored	695			
Oleo	PH46	m	recruit	2	uncensored	249			HBC
Onyx	PH47	m	recruit	2	censored	730	751	censored	
Decker	PH48	m	recruit	2	uncensored	3			HBC
Clover	PH49	f	recruit	2	censored	730	751	censored	
	PH5	m	orig	1	uncensored	70			HBC
Casper	PH50	m	recruit	2	censored	716			
PH51	PH51	m	recruit	2	uncensored	65			HBC
Tuffy	PH52	f	recruit	2	censored	602			

Appendix 3, Table 1, continued.

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Princess	PH53	f	recruit	2	uncensored	351			dead
Flash	PH54	m	immig	1	censored	131			trapped and neutered
Flash	PH54	m	immig	2	censored	611			
Scatter	PH55	f	recruit	2	uncensored	22			killed by dogs
Mo	PH56	f	recruit	2	uncensored	254			HBC
Fuzzy	PH57	m	recruit	2	censored	602			
Curly	PH58	f	recruit	2	censored	623			
Skitter	PH59	f	recruit	2	censored	571			
	PH6	f	orig	1	uncensored	169			killed by dogs
Midnight	PH60	f	recruit	2	censored	602			
Chopper	PH61	f	recruit	2	uncensored	483			disappeared
Wally	PH62	f	recruit	2	censored	623			
Fluffy	PH63	m	recruit	2	censored	602			
Mouth	PH64	m	recruit	1	censored	126			trapped and neutered
Mouth	PH64	m	recruit	2	censored	611			
Yellow Longhair	PH65	m	immig	2	censored	386			
Grey White stripe	PH66	m	immig	2	censored	384			
Blue Boy	PH7	m	orig	1	uncensored	114			HBC
Side Stripe	PH8	m	orig	1	uncensored	263			disappeared
	PH9	f	orig	1	uncensored	356			HBC
Dopey	SH	f	recruit	1	censored	279			
Rhiannon	SH	f	recruit	1	censored	279			
Sneezy	SH	f	recruit	1	censored	279			
Barry	SH	m	recruit	1	censored	288			
Larry	SH	m	recruit	1	censored	288			
Sinister	SH	m	recruit	1	censored	288			
Tweak	SH1	f	orig	1	censored	471			
Leo	SH10	m	orig	1	censored	471			
Leroy	SH11	f	orig	1	censored	471			
Serendipity	SH12	f	orig	1	censored	471			
Sylvester	SH13	f	orig	1	censored	471			
Stripe	SH14	f	orig	1	censored	471			
Little Stripe	SH15	f	orig	1	censored	471			
Lady D	SH16	f	orig	1	censored	471			
Snuffy	SH17	f	orig	1	censored	471			
Andariel	SH18	f	orig	1	censored	471			
Bear	SH19	f	orig	1	censored	471			
Tety	SH2	f	orig	1	censored	471			
Munchkin	SH20	f	orig	1	uncensored	56			dead
Squirrel	SH21	f	orig	1	uncensored	4			disappeared
Kitty	SH22	m	orig	1	uncensored	56			HBC
Little Ty	SH3	f	orig	1	censored	471			
Fluffy	SH4	f	orig	1	uncensored	45			disappeared
Turtle	SH5	f	orig	1	censored	471			
Patches	SH6	f	orig	1	censored	471			
Diablo	SH7	m	orig	1	censored	471			
Diddle	SH8	m	orig	1	censored	471			
Shadow	SH9	m	orig	1	censored	471			
Sweetie	TP	f	immig	1	uncensored	19			dead, ill
Abandoned queen	TP	f	immig	1	uncensored	3			disappeared
Skitty	TP	f	recruit	1	uncensored	90			disappeared
Boots	TP	f	recruit	1	uncensored	184			killed by dogs
Socks	TP	f	recruit	2	uncensored	234			killed by dogs
Piglet	TP	f	recruit	1	uncensored	13			stepped on by horse
Eyeor	TP	m	recruit	1	uncensored	150			ran over with tractor
Wild Thing	TP	m	recruit	1	uncensored	52			stepped on by horse
New orange tom	TP	m	immig	2	censored	144			

Appendix 3, Table 1, continued.

NAME	NUMBER	SEX	SOURCE	TREAT	2 YR CENSOR	2 YR SURVIVAL	4 YR SURVIVAL	4 YR CENSOR	CAUSE
Kitty	TP1	f	orig	1	uncensored	644			euthanized
Midnight	TP10	f	orig	1	censored	730	841	censored	spayed
Midnight	TP10	f	orig	2	censored	730	786	censored	
Cheerup	TP11	f	orig	2	uncensored	618			found dead
Cheerup	TP11	f	orig	1	censored	730	841	censored	spayed
Winnie	TP12	m	recruit	1	uncensored	286			killed by dogs
Pooh	TP13	f	recruit	1	uncensored	168			disappeared
Skunk	TP14	m	recruit	1	uncensored	575			disappeared
Shark	TP15	m	recruit	1	uncensored	99			disappeared
Tigger	TP16	m	recruit	1	uncensored	646			disappeared
Silver	TP17	f	recruit	2	uncensored	606			disappeared
Silver	TP17	f	recruit	1	censored	670			spayed
Tweetie	TP18	m	immig	2	uncensored	133			disappeared, ill
Tweetie	TP18	m	immig	1	censored	624			neutered
Aaron	TP19	m	recruit	2	uncensored	285			disappeared
Aaron	TP19	m	recruit	1	censored	214			neutered
Tiger	TP2	f	orig	2	uncensored	606			disappeared
Tiger	TP2	f	orig	1	censored	730	841	censored	spayed
Michelob	TP20	m	recruit	1	censored	212			
Michelob	TP20	m	recruit	2	censored	730	786	censored	
Pirate	TP21	m	recruit	2	uncensored	325			killed by dogs
Pirate	TP21	m	recruit	1	censored	212			neutered
Gremlin	TP22	m	recruit	2	uncensored	243			killed by dogs
Gremlin	TP22	m	recruit	1	censored	212			neutered
Thirteen	TP23	f	immig	2	uncensored	637			disappeared
Thirteen	TP23	f	immig	1	censored	224			spayed
Snowball	TP24	m	immig	1	uncensored	74			killed by dogs
Tippy	TP25	m	immig	2	uncensored	436			killed by dog
Tippy	TP25	m	immig	1	censored	224			neutered
Charlotte	TP26	f	recruit	1	censored	333			spayed
Charlotte	TP26	f	recruit	2	censored	730	786	censored	
Bear	TP27	m	recruit	2	uncensored	520			disappeared
Bear	TP27	m	recruit	1	censored	333			neutered
Whitey	TP3	m	orig	1	uncensored	59			disappeared, ill
Tails	TP4	f	orig	1	uncensored	593			disappeared
Sheila	TP5	f	orig	1	uncensored	101			dead
Grey tab	TP6	m	orig	1	uncensored	9			disappeared
Little Bit	TP7	m	orig	1	uncensored	457			killed by dogs
Icky	TP8	m	orig	1	uncensored	9			dead, ill
Spitfire	TP9	m	orig	1	uncensored	648			disappeared
Black Cat 3	VR	f	orig	3	uncensored	24			dead
Lance	VR1	m	orig	3	uncensored	265			disappeared
Smokey	VR10	f	immig	3	uncensored	585			disappeared
Black Top	VR11	m	immig	3	uncensored	589			disappeared
Leo	VR12	m	recruit	2	censored	604			
Tiger	VR13	m	recruit	2	censored	604			
Bluie	VR14	f	recruit	2	uncensored	217			disappeared
Scratchy	VR15	f	recruit	2	censored	604			
Speedy	VR16	m	recruit	2	uncensored	217			disappeared
Bear Paw	VR2	m	orig	3	censored	730	1460	censored	disappeared
Rachel	VR3	f	orig	3	censored	730	1460	censored	
Oliver	VR4	m	orig	3	censored	730	761	uncensored	disappeared, injured
Tom	VR5	m	orig	3	uncensored	681			disappeared
Chance	VR6	m	orig	3	uncensored	619			disappeared, ill
Yodie	VR7	f	orig	3	censored	730	1460	censored	
Black Cat 1	VR8	m	orig	3	uncensored	218			disappeared
Black Cat 2	VR9	m	orig	3	uncensored	122			disappeared

Appendix 4. Home range data.

Table 1. Individual cat MCP 100 and MCP 95

Cat ID	Treatment	Sex	Sample Size	Total Visits	%Obs	100% MCP (ha)	95%MCP (ha)
AK10M	2	M	51	66	0.77	1.054	0.447
AK11F	2	F	26	66	0.39	0.431	0.351
AK12F	2	F	31	66	0.47	0.447	0.417
AK1M	2	M	56	66	0.85	1.776	0.527
AK2F	2	F	26	45	0.58	0.028	0.020
AK3F	2	F	35	66	0.53	0.113	0.094
AK4F	2	F	35	66	0.53	0.050	0.039
AK5F	2	F	33	66	0.50	0.147	0.059
AK6F	2	F	34	66	0.52	0.175	0.102
AK7F	2	F	52	66	0.79	0.464	0.384
AK9M	2	M	32	66	0.48	0.427	0.382
BC BABY F	2	F	23	77	0.30	0.158	0.087
BC11F	2	F	26	77	0.34	0.069	0.062
BC12F	2	F	20	77	0.26	0.060	0.048
BC14M	2	M	61	77	0.79	0.200	0.101
BC15F	2	F	51	77	0.66	0.051	0.034
BC16F	2	F	29	77	0.38	0.128	0.096
BC17M	2	M	21	77	0.27	0.092	0.062
BC1M	2	M	42	77	0.55	0.191	0.145
BC20M	2	M	55	77	0.71	0.141	0.100
BC21M	2	M	70	77	0.91	0.301	0.135
BC23F	2	F	25	77	0.32	0.108	0.080
BC24M	2	M	26	77	0.34	0.157	0.098
BC2F	2	F	44	77	0.57	0.177	0.116
BC3F	2	F	46	77	0.60	0.175	0.150
BC4F	2	F	35	77	0.45	0.079	0.078
BC7M	2	M	23	77	0.30	0.071	0.063
BC8M	2	M	58	77	0.75	0.086	0.053
BC9M	2	M	39	77	0.51	0.142	0.112
BN10F	3	F	62	79	0.78	0.637	0.604
BN11M	3	M	41	56	0.73	0.777	0.597
BN12M	3	M	24	65	0.37	1.989	1.438
BN13M	3	M	32	58	0.55	0.408	0.396
BN1F	3	F	50	79	0.63	0.460	0.444
BN2F	3	F	23	72	0.32	0.331	0.323
BN3F	3	F	44	79	0.56	0.497	0.421
BN5M	3	M	42	58	0.72	0.593	0.346
BN6F	3	F	53	60	0.88	0.622	0.527
BN8F	3	F	63	79	0.80	0.580	0.547
BS1M	2	M	33	47	0.70	0.176	0.151
BS2F	2	F	45	68	0.66	0.197	0.153
BS3F	2	F	35	58	0.60	0.116	0.109
BS4F	2	F	56	76	0.74	0.225	0.172
BS5M	2	M	35	58	0.60	0.209	0.172
BS7M	2	M	35	63	0.56	0.102	0.097
BS8M	2	M	64	76	0.84	0.143	0.078
BS9M	2	M	48	76	0.63	0.144	0.109

Appendix 4, Table 1, continued.

Cat ID	Treatment	Sex	Sample Size	Total Visits	%Obs	100% MCP (ha)	95%MCP (ha)
KA3F	3	F	33	66	0.50	0.352	0.208
KA4M	3	M	26	45	0.58	3.947	3.230
KA5M	3	M	21	52	0.40	1.978	1.586
KA7M	3	M	29	84	0.35	2.318	1.769
KA8F	3	F	33	84	0.39	0.844	0.754
KR1F	1	F	28	48	0.58	0.117	0.076
KR2F	1	F	59	67	0.88	0.238	0.144
KR3M	1	M	36	50	0.72	0.103	0.098
KR6M	1	M	22	26	0.85	0.056	0.033
KR7F	1	F	31	40	0.78	0.034	0.032
KR9M	1	M	37	58	0.64	0.092	0.068
PH10F	1	F	36	87	0.41	0.098	0.076
PH12M	1	M	34	55	0.62	0.187	0.128
PH13F	1	F	25	68	0.37	0.130	0.083
PH17M	1	M	26	28	0.93	0.525	0.399
PH18F	1	F	42	42	1.00	0.181	0.124
PH19F	1	F	58	65	0.89	0.093	0.056
PH21M	1	M	21	28	0.75	0.185	0.149
PH23F	1	F	54	67	0.81	0.233	0.198
PH2F	1	F	68	97	0.70	0.275	0.176
PH35M	1	M	21	23	0.91	0.044	0.041
PH3F	1	F	40	97	0.41	0.172	0.140
PH4M	1	M	39	57	0.68	0.182	0.117
PH9F	1	F	22	59	0.37	0.116	0.071
TP10F	1	F	44	68	0.65	0.452	0.113
TP11F	1	F	54	76	0.71	0.308	0.262
TP12M	1	M	25	25	1.00	0.035	0.027
TP14M	1	M	33	46	0.72	0.061	0.060
TP16M	1	M	38	49	0.78	0.122	0.081
TP17F	1	F	45	53	0.85	0.264	0.216
TP18M	1	M	42	48	0.88	0.313	0.214
TP1F	1	F	56	63	0.89	0.258	0.125
TP2F	1	F	59	76	0.78	2.486	0.398
TP4F	1	F	51	58	0.88	0.227	0.142
TP7M	1	M	43	47	0.91	0.226	0.133
TP9M	1	M	65	69	0.94	1.239	0.331
VR1M	3	M	26	37	0.70	0.184	0.167
VR2M	3	M	72	75	0.96	0.509	0.308
VR3F	3	F	65	75	0.87	0.212	0.153
VR4M	3	M	54	75	0.72	0.342	0.245
VR5M	3	M	64	69	0.93	0.337	0.253
VR6M	3	M	40	65	0.62	0.185	0.160
VR7F	3	F	60	75	0.80	0.093	0.062
VR8M	3	M	24	34	0.71	0.876	0.422

Table 2. Individual cat KE 95 and KE 50 estimates

Cat ID	Treatment	Sample Size	Percent	Orig KE (ha)	Orig Smooth	Revised Smooth	Revised KE	KE Used (ha)
AK10M	2	51	50	0.045	31.50	73	0.197	0.197
AK10M	2	51	95	0.305	31.50	73	0.944	0.944
AK11F	2	26	50	0.069	41.23	75	0.229	0.229
AK11F	2	26	95	0.573	41.23	75	1.309	1.309
AK12F	2	31	50	0.133	39.99	60	0.258	0.258
AK12F	2	31	95	0.716	39.99	60	1.243	1.243
AK1M	2	56	50	0.032	26.38	35	0.052	0.052
AK1M	2	56	95	0.162	26.38	35	0.233	0.233
AK2F	2	26	50	0.002	6.67	13	0.009	0.009
AK2F	2	26	95	0.028	6.67	13	0.052	0.052
AK3F	2	35	50	0.013	16.08	n/a	n/a	0.013
AK3F	2	35	95	0.076	16.08	n/a	n/a	0.076
AK4F	2	35	50	0.003	7.42	14	0.009	0.009
AK4F	2	35	95	0.033	7.42	14	0.052	0.052
AK5F	2	33	50	0.009	13.62	19	0.016	0.016
AK5F	2	33	95	0.067	13.62	19	0.079	0.079
AK6F	2	34	50	0.009	12.12	21	0.020	0.020
AK6F	2	34	95	0.079	12.12	21	0.109	0.109
AK7F	2	52	50	0.033	29.87	56	0.122	0.122
AK7F	2	52	95	0.355	29.87	56	0.906	0.906
AK9M	2	32	50	0.086	35.81	55	0.203	0.203
AK9M	2	32	95	0.536	35.81	55	0.959	0.959
BC BABY	2	23	50	0.036	18.99	24	0.059	0.059
BC BABY	2	23	95	0.193	18.99	24	0.213	0.213
BC11F	2	26	50	0.014	11.88	n/a	n/a	0.014
BC11F	2	26	95	0.106	11.88	n/a	n/a	0.106
BC12F	2	20	50	0.012	11.39	19	0.025	0.025
BC12F	2	20	95	0.076	11.39	19	0.123	0.123
BC14M	2	61	50	0.019	13.11	21	0.034	0.034
BC14M	2	61	95	0.146	13.11	21	0.178	0.178
BC15F	2	51	50	0.003	7.32	11	0.006	0.006
BC15F	2	51	95	0.037	7.32	11	0.048	0.048
BC16F	2	29	50	0.016	12.56	14	0.016	0.016
BC16F	2	29	95	0.158	12.56	14	0.146	0.146
BC17M	2	21	50	0.014	15.22	33	0.048	0.048
BC17M	2	21	95	0.119	15.22	33	0.246	0.246
BC1M	2	42	50	0.010	14.48	28	0.045	0.045
BC1M	2	42	95	0.141	14.48	28	0.244	0.244
BC20M	2	55	50	0.012	10.08	15	0.014	0.014
BC20M	2	55	95	0.105	10.08	15	0.117	0.117
BC21M	2	70	50	0.020	11.47	16	0.029	0.029
BC21M	2	70	95	0.158	11.47	16	0.168	0.168
BC23F	2	25	50	0.033	13.93	22	0.045	0.045
BC23F	2	25	95	0.152	13.93	22	0.217	0.217
BC24M	2	26	50	0.042	13.80	15	0.041	0.041
BC24M	2	26	95	0.180	13.80	15	0.164	0.164
BC2F	2	44	50	0.022	16.30	26	0.045	0.045
BC2F	2	44	95	0.176	16.30	26	0.270	0.270
BC3F	2	46	50	0.010	13.78	31	0.041	0.041
BC3F	2	46	95	0.110	13.78	31	0.254	0.254
BC4F	2	35	50	0.004	9.85	25	0.024	0.024
BC4F	2	35	95	0.010	9.85	25	0.126	0.126
BC7M	2	23	50	0.015	12.52	16	0.019	0.019
BC7M	2	23	95	0.106	12.52	16	0.135	0.135
BC8M	2	58	50	0.007	8.44	14	0.014	0.014
BC8M	2	58	95	0.063	8.44	14	0.076	0.076
BC9M	2	39	50	0.024	12.47	25	0.037	0.037
BC9M	2	39	95	0.117	12.47	25	0.146	0.146
BN10F	3	63	50	0.094	33.34	39	0.100	0.100
BN10F	3	62	95	0.703	33.34	39	0.756	0.756

Appendix 4, Table 2, continued

Cat ID	Treatment	Sample Size	Percent	Orig KE (ha)	Orig Smooth	Revised Smooth	Revised KE	KE Used (ha)
BN11M	3	41	50	0.211	41.99	61	0.353	0.353
BN11M	3	41	95	1.189	41.99	61	1.650	1.650
BN12M	3	25	50	0.363	72.62	n/a	n/a	0.363
BN12M	3	24	95	3.849	72.62	n/a	n/a	3.849
BN13M	3	32	50	0.055	31.32	50	0.106	0.106
BN13M	3	32	95	0.455	31.32	50	0.720	0.720
BN1F	3	50	50	0.050	27.33	n/a	n/a	0.050
BN1F	3	50	95	0.689	27.33	n/a	n/a	0.689
BN2F	3	23	50	0.269	50.95	n/a	n/a	0.269
BN2F	3	23	95	1.064	50.95	n/a	n/a	1.064
BN3F	3	44	50	0.031	26.07	33	0.047	0.047
BN3F	3	44	95	0.356	26.07	33	0.447	0.447
BN5M	3	42	50	0.033	27.43	37	0.083	0.083
BN5M	3	42	95	0.474	27.43	37	0.607	0.607
BN6F	3	53	50	0.103	36.28	n/a	n/a	0.103
BN6F	3	53	95	0.909	36.28	n/a	n/a	0.909
BN8F	3	63	50	0.197	31.32	41	0.228	0.228
BN8F	3	63	95	0.765	31.32	41	0.941	0.941
BS1M	2	33	50	0.013	14.30	26	0.028	0.028
BS1M	2	33	95	0.088	14.30	26	0.132	0.132
BS2F	2	45	50	0.017	14.77	38	0.058	0.058
BS2F	2	45	95	0.128	14.77	38	0.282	0.282
BS3F	2	35	50	0.015	15.02	n/a	n/a	0.015
BS3F	2	35	95	0.155	15.02	n/a	n/a	0.155
BS4F	2	56	50	0.010	14.32	23	0.022	0.022
BS4F	2	56	95	0.117	14.32	23	0.192	0.192
BS5M	2	35	50	0.017	17.65	29	0.041	0.041
BS5M	2	35	95	0.221	17.65	29	0.339	0.339
BS7M	2	35	50	0.015	12.54	16	0.022	0.022
BS7M	2	35	95	0.121	12.54	16	0.153	0.153
BS8M	2	64	50	0.008	11.03	n/a	n/a	0.008
BS8M	2	64	95	0.069	11.03	n/a	n/a	0.069
BS9M	2	48	50	0.012	11.26	20	0.019	0.019
BS9M	2	48	95	0.097	11.26	20	0.129	0.129
KA3F	3	33	50	0.028	25.35	40	0.059	0.059
KA3F	3	33	95	0.241	25.35	40	0.446	0.446
KA4M	3	26	50	0.284	75.73	145	1.076	1.076
KA4M	3	26	95	2.875	75.73	145	5.389	5.389
KA5M	3	21	50	0.169	58.83	100	0.433	0.433
KA5M	3	21	95	1.595	58.83	100	2.205	2.205
KA7M	3	29	50	0.386	73.40	126	0.817	0.817
KA7M	3	29	95	2.834	73.40	126	5.372	5.372
KA8F	3	33	50	0.037	32.60	43	0.069	0.069
KA8F	3	33	95	0.256	32.60	43	0.414	0.414
KR1F	1	28	50	0.010	12.58	30	0.037	0.037
KR1F	1	28	95	0.080	12.58	30	0.166	0.166
KR2F	1	59	50	0.010	11.80	n/a	n/a	0.010
KR2F	1	59	95	0.050	11.80	n/a	n/a	0.050
KR3M	1	36	50	0.010	11.07	25	0.032	0.032
KR3M	1	36	95	0.073	11.07	25	0.161	0.161
KR6M	1	22	50	0.015	11.38	25	0.035	0.035
KR6M	1	22	95	0.071	11.38	25	0.153	0.153
KR7F	1	31	50	0.004	7.71	13	0.015	0.015
KR7F	1	31	95	0.038	7.71	13	0.067	0.067
KR9M	1	37	50	0.014	11.12	26	0.045	0.045
KR9M	1	37	95	0.094	11.12	26	0.171	0.171
PH10F	1	36	50	0.004	10.72	23	0.019	0.019
PH10F	1	36	95	0.018	10.72	23	0.102	0.102
PH12M	1	34	50	0.009	14.35	29	0.038	0.038
PH12M	1	34	95	0.111	14.35	29	0.219	0.219

Appendix 4, Table 2, continued

Cat ID	Treatment	Sample Size	Percent	Orig KE (ha)	Orig Smooth	Revised Smooth	Revised KE	KE Used (ha)
PH13F	1	25	50	0.008	14.11	30	0.046	0.046
PH13F	1	25	95	0.098	14.11	30	0.235	0.235
PH17M	1	26	50	0.107	31.01	44	0.165	0.165
PH17M	1	26	95	0.665	31.01	44	0.925	0.925
PH18F	1	42	50	0.010	14.69	26	0.033	0.033
PH18F	1	42	95	0.133	14.69	26	0.227	0.227
PH19F	1	58	50	0.002	17.15	n/a	n/a	0.002
PH19F	1	58	95	0.008	17.15	n/a	n/a	0.008
PH21M	1	21	50	0.016	20.34	25	0.030	0.030
PH21M	1	21	95	0.213	20.34	25	0.281	0.281
PH23F	1	54	50	0.010	16.38	23	0.019	0.019
PH23F	1	54	95	0.081	16.38	23	0.160	0.160
PH2F	1	68	50	0.007	13.49	25	0.024	0.024
PH2F	1	68	95	0.076	13.49	25	0.205	0.205
PH35M	1	21	50	0.004	10.89	25	0.022	0.022
PH35M	1	21	95	0.022	10.89	25	0.114	0.114
PH3F	1	40	50	0.008	13.55	24	0.024	0.024
PH3F	1	40	95	0.104	13.55	24	0.212	0.212
PH4M	1	39	50	0.008	13.60	25	0.025	0.025
PH4M	1	39	95	0.069	13.60	25	0.150	0.150
PH9F	1	22	50	0.007	13.42	22	0.018	0.018
PH9F	1	22	95	0.060	13.42	22	0.108	0.108
TP10F	1	44	50	0.050	20.44	35	0.095	0.095
TP10F	1	44	95	0.224	20.44	35	0.300	0.300
TP11F	1	54	50	0.015	19.05	65	0.152	0.152
TP11F	1	54	95	0.107	19.05	65	0.628	0.628
TP12M	1	25	50	0.005	9.94	15	0.010	0.010
TP12M	1	25	95	0.056	9.94	15	0.080	0.080
TP14M	1	33	50	0.006	11.15	17	0.012	0.012
TP14M	1	33	95	0.060	11.15	17	0.091	0.091
TP16M	1	38	50	0.008	11.84	15	0.010	0.010
TP16M	1	38	95	0.061	11.84	15	0.067	0.067
TP17F	1	45	50	0.017	20.07	42	0.076	0.076
TP17F	1	45	95	0.168	20.07	42	0.450	0.450
TP18M	1	42	50	0.020	20.67	27	0.034	0.034
TP18M	1	42	95	0.179	20.67	27	0.218	0.218
TP1F	1	56	50	0.013	11.23	n/a	n/a	0.013
TP1F	1	56	95	0.095	11.23	n/a	n/a	0.095
TP2F	1	59	50	0.119	44.24	n/a	n/a	0.119
TP2F	1	59	95	0.708	44.24	n/a	n/a	0.708
TP4F	1	51	50	0.013	12.93	n/a	n/a	0.013
TP4F	1	51	95	0.092	12.93	n/a	n/a	0.092
TP7M	1	43	50	0.011	15.16	60	0.131	0.131
TP7M	1	43	95	0.072	15.16	60	0.469	0.469
TP9M	1	65	50	0.033	17.08	n/a	n/a	0.033
TP9M	1	65	95	0.227	17.08	n/a	n/a	0.227
VR1M	3	26	50	0.020	17.27	25	0.033	0.033
VR1M	3	26	95	0.194	17.27	25	0.257	0.257
VR2M	3	72	50	0.024	17.62	40	0.070	0.070
VR2M	3	72	95	0.160	17.62	40	0.345	0.345
VR3F	3	65	50	0.019	12.53	27	0.036	0.036
VR3F	3	65	95	0.126	12.53	27	0.205	0.205
VR4M	3	54	50	0.045	18.09	35	0.070	0.070
VR4M	3	54	95	0.289	18.09	35	0.373	0.373
VR5M	3	64	50	0.012	15.40	24	0.025	0.025
VR5M	3	64	95	0.130	15.40	24	0.235	0.235
VR6M	3	40	50	0.009	14.52	26	0.027	0.027
VR6M	3	40	95	0.090	14.52	26	0.221	0.221
VR7F	3	60	50	0.008	10.22	17	0.015	0.015
VR7F	3	60	95	0.067	10.22	17	0.094	0.094
VR8M	3	24	50	0.093	38.85	85	0.279	0.279
VR8M	3	24	95	0.545	38.85	85	0.983	0.983

Appendix 5. Data from Community Meetings

Table 1. Likert questionnaire scores from Orange County meeting, pre and post.

Orange Pre	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Feral cat 1	1	10	1	3	5	5	5	3	3	5	5	5
Feral cat 2	4	9	3	1	10	9	1	2	3	9	1	3
Feral cat 3	1	10	1	3	10	2	7	5	1	5	1	1
Feral cat 4	1	10	1	10	10	10	10	10	1	5	1	10
Feral cat 5	4	9	2	1	5	5	4	4	2	5	4	3
Feral cat 6	1	9	2	5	9	3	5	4	5	3	3	5
Feral cat 7	2	10	2	2	5	5	7	5	3	5	5	3
Feral cat 8	1	10	1	1	6	5	5	3	2	5	2	5
Feral cat 9	4	9	4	1	4	8	3	4	3	5	2	2
Feral cat 10	1	10	1	5	10	5	3	5	1	5	1	5
Regulatory 1	1	8	2	1	3	6	4	1	1	8	1	1
Regulatory 2	3	8	3	3	6	5	4	6	5	4	4	4

Orange Post	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Feral cat 2	1	9	1	1	9	7	1	2	2	8	1	2
Feral cat 3	1	10	1	4	10	5	5	5	1	5	1	4
Feral cat 4	1	10	1	8	9	1	5	5	1	2	1	7
Feral cat 6	1	7	2	8	10	3	5	8	3	3	3	5
Feral cat 8	1	9	4	3	3	6	6	3	1	7	5	1
Feral cat 10	1	10	1	5	10	6	6	6	1	6	1	9
Regulatory 1	1	10	1	1	5	5	1	1	1	9	1	1
Regulatory 2	2	8	4	4	6	7	1	8	5	4	5	3

Orange Pre	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23
Feral cat 1	5	5	4	1	5	4	5	3	1	7	1
Feral cat 2	2	4	7	1	4	1	4	7	3	7	1
Feral cat 3	5	1	10	1	1	5	1	7	1	6	5
Feral cat 4	10	1	10	1	1	10	1	10	1	10	10
Feral cat 5	7	5	5	1	2	3	5	5	2	3	3
Feral cat 6	4	2	8	3	2	7	5	5	3	8	5
Feral cat 7	3	4	6	3	3	5	5	5	5	7	5
Feral cat 8	1	5	5	1	1	5	5	8	1	7	5
Feral cat 9	3	5	3	4	2	4	3	7	5	4	5
Feral cat 10	5	1	10	1	1	5	1	4	1	5	4
Regulatory 1	2	8	4	3	5	2	7	7	2	1	1
Regulatory 2	7	4	7	1	4	4	3	6	2	10	4

Orange Post	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23
Feral cat 2	2	2	2	1	2	1	2	9	2	9	1
Feral cat 3	7	1	5	1	1	5	5	10	1	6	1
Feral cat 4	8	1	10	1	1	9	1	5	1	8	1
Feral cat 6	5	3	3	3	3	7	3	9	3	9	5
Feral cat 8	4	8	2	1	8	3	9	6	1	9	7
Feral cat 10	5	1	10	1	1	6	1	6	1	8	6
Regulatory 1	1	4	4	1	2	2	3	2	1	1	1
Regulatory 2	6	2	9	1	3	4	2	6	1	8	1

Appendix 5, Table 1 continued.

Orange Pre	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32
Feral cat 1	2	4	8	4	5	8	1	8	3
Feral cat 2	1	2	7	6	3	7	2	4	5
Feral cat 3	1	1	1	6	1	6	10	10	1
Feral cat 4	1	10	1	5	1	10	2	10	1
Feral cat 5	3	3	9	6	3	8	4	5	3
Feral cat 6	4	5	3	3	4	8	3	5	5
Feral cat 7	3	5	5	5	5	5	2	5	7
Feral cat 8	3	3	5	5	5	5	2	3	2
Feral cat 9	2	3	7	4	6	7	4	4	7
Feral cat 10	1	5	1	8	1	10	5	6	3
Regulatory 1	4	1	10	7	2	10	4	1	3
Regulatory 2	3	6	5	5	4	5	2	5	4

Orange Post	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32
Feral cat 2	1	2	3	9	2	9	2	4	4
Feral cat 3	1	3	1	5	1	10	5	10	1
Feral cat 4	1	2	2	5	1	9	1	8	1
Feral cat 6	5	8	3	5	3	8	3	9	5
Feral cat 8	3	3	9	3	7	10	1	8	8
Feral cat 10	1	6	1	8	1	10	6	8	1
Regulatory 1	1	1	10	5	5	5	4	1	6
Regulatory 2	3	6	5	3	3	3	2	3	1

Table 2. Likert questionnaire scores from Wake County meeting, pre and post.

Wake Pre	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**
Feral Cat 1	1	10	1	10	10	7	2	7	9	7	1	4
Feral Cat 2	1	10	1	10	10	4	5	8	1	5	1	5
Feral Cat 3	1	9	1	5	5	4	3	3	3	7	4	2
Regulatory 1	1	10	2	7	8	7	7	7	2	8	6	6
Regulatory 2	3	10	1	3	3	6	3	3	1	8	4	3
Feral Cat 4	1	10	2	5	10	2	5	5	1	5	2	8
Feral Cat 5	1	9	2	7	10	3	1	8	8	5	1	4
Feral Cat 6	1	10	1	6	10	9	4	10	1	8	1	10
Feral Cat 7	1	10	1	10	10	1	8	1	1	1	10	8
Feral Cat 8	1	10	1	8	10	1	3	4	1	3	3	4
Regulatory 3	1	10	2	4	9	4	4	3	4	4	5	2
Feral Cat 9	1	10	1	10	10	1	5	2	1	5	1	10
Regulatory 4	1	10	1	1	1	8	1	1	1	10	10	1

Wake Post	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**
Feral Cat 1	1	10	1	9	10	6	9	9	1	6	1	2
Feral Cat 2	1	10	1	7	10	5	7	10	1	5	1	4
Feral Cat 3	1	10	3	7	8	6	7	5	2	7	3	3
Regulatory 2	3	10	3	2	3	6	6	3	1	7	7	2
Feral Cat 7	1	10	1	8	10	2	9	9	1	6	1	10
Feral Cat 8	1	10	1	8	10	4	9	4	1	4	8	3
Regulatory 3	1	10	1	5	9	5	5	3	5	5	5	2
Feral Cat 9	1	10	1	10	10	1	5	10	1	1	5	10
Regulatory 4	1	10	1	1	1	10	1	1	1	10	10	1

Wake Pre	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**	**Q21**	**Q22**	**Q23**
Feral Cat 1	9	1	10	1	1	10	1	10	1	10	1
Feral Cat 2	5	1	10	1	1	9	1	9	1	10	5
Feral Cat 3	4	3	5	1	3	5	6	3	2	7	1
Regulatory 1	7	2	7	1	2	5	3	10	3	10	1
Regulatory 2	1	8		3	8	4		3	2	3	4
Feral Cat 4	4	1	1	1	1	5	1	3	1	6	4
Feral Cat 5	4	1	8	1	1	8	2	9	2	10	3
Feral Cat 6	2	1	10	1	1	10	1	6	1	9	1
Feral Cat 7	3	1	10	1	1	10	1	10	1	10	1
Feral Cat 8	8	1	10	1	1	10	6	10	1	10	1
Regulatory 3	4	4	8	1	5	4	5	4	1	9	1
Feral Cat 9	5	1	10	1	1	10	1	10	1	10	5
Regulatory 4	3	10	1	1	10	6	10		1	6	8

Wake Post	**Q13**	**Q14**	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	**Q20**	**Q21**	**Q22**	**Q23**
Feral Cat 1	9	1	10	1	1	10	1	10	1	10	1
Feral Cat 2	10	1	10	1	1	9	1	9	1	8	5
Feral Cat 3	4	4	6	1	4	7	4	9	2	8	1
Regulatory 2	1	8	2	8	8	3	8	4	1	3	7
Feral Cat 7	10	1	10	1	1	9	1	8	1	8	1
Feral Cat 8	4	4	10	1	1	10	2	10	1	10	1
Regulatory 3	5	3	7	1	3	5	3	5	3	10	2
Feral Cat 9	10	1	10	1	1	10	1	10	1	10	5
Regulatory 4	1	10	3	1	3	4	10	7	1	3	1

Appendix 5, Table 2, continued.

Wake Pre	**Q24**	**Q25**	**Q26**	**Q27**	**Q28**	**Q29**	**Q30**	**Q31**	**Q32**
Feral Cat 1	1	2	2	10	1	10	2	1	1
Feral Cat 2	1	6	1	4	1	10	2	10	1
Feral Cat 3	1	3	6	3	4	9	3	4	5
Regulatory 1	10	6	7	9	3	8	8	3	4
Regulatory 2	4	2	7	4	7	7	9	4	9
Feral Cat 4	1	3	3	7	1	9	1	8	1
Feral Cat 5	5	2	6	8	2	9	1	7	3
Feral Cat 6	1	1	3	9	1	10	1	10	1
Feral Cat 7	1	3	1	10	1	10	3	1	1
Feral Cat 8	1	3	8	4	1	10	10	10	1
Regulatory 3	1	1	5	5	5	5	1	3	5
Feral Cat 9	1	4	1	10	1	10	1	5	1
Regulatory 4	1	1	10	8	8	8	2	5	10

Wake Post	**Q24**	**Q25**	**Q26**	**Q27**	**Q28**	**Q29**	**Q30**	**Q31**	**Q32**
Feral Cat 1	1	1	2	6	1	3	2	2	1
Feral Cat 2	3	8	1	3	1	10	1	10	3
Feral Cat 3	1	5	8	4	2	8	3	7	2
Regulatory 2	7	3	7	4	5	4	8	4	10
Feral Cat 7	1	3	1	10	2	10	3	10	4
Feral Cat 8	1	8	8	3	1	10	10	10	1
Regulatory 3	1	2	9	5	2	7	1	4	1
Feral Cat 9	1	10	1	10	1	10	10	10	1
Regulatory 4	3	1	10	10	6	5	2	1	10