Te Kunenga
ki Pūrehuroa

The Epidemiology of the Free-Roaming Dog and Cat Population in the Wellington Region of New Zealand

A dissertation presented
in partial fulfilment of the requirements
for the degree of Master of Veterinary Studies
at Massey University

Karma Rinzin
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Abstract

We present analyses of details of dog and cat submissions to the Wellington Society for the Prevention of Cruelty to Animals shelter from July 1999 to February 2006. Our aims were to document the demographic, temporal, and spatial characteristics of the free-roaming and surrendered dog and cat population in the SPCA catchment area. The motivation for this research was to identify factors determining population growth which should in turn provide a more quantitative basis for refining strategies to control the number of free-roaming dogs and cats in this area of New Zealand.

Throughout the study period a total of 3992 dogs and 14343 cats were submitted to the Wellington shelter. On average, 11 dogs (range 1 – 41) and 40 cats (range 3 – 104) were presented to the shelter in any given week. Approximately one half (2065 of 3978, 52%) of the dogs and three quarters of the cats (10431 of 14323, 73%) were classified as free-roaming (that is, animals that were wild, stray, abandoned, or lost). The age structures of submitted dogs and cats were skewed towards younger age groups ($<$ 12 months) with little difference between sexes. A higher proportion of surrendered animals were desexed (16% dogs, cats 22%) compared with those presented as free-roaming (dogs 4%, cats 15%).

The number of free-roaming dogs and cats presented to the shelter each year steadily decreased from 1999 to 2005. A total of 333 free-roaming dogs and 1637 free-roaming cats were presented to the shelter in 2000, compared with 154 dogs and 1298 cats in 2005. A clear seasonal pattern was evident for cat submissions with large numbers presented to the shelter from October to May in any given year with a peak in December and January.

A subset of the Wellington SPCA catchment area was defined and kernel smoothing techniques used to plot the spatial distribution of the residence of members of the public who submitted animals to the shelter throughout the study period. We found a positive relationship between the number of households submitting animals to the shelter and mesh block level deprivation index.

Leslie projection matrices were used to quantify the intrinsic rate of growth of the free-roaming dog and cat population. The intrinsic rate of population growth was 0.78 (95% CI 0.56 – 0.94) for dogs and 0.98 (95% CI 0.76 – 1.16) for cats. Assuming the intensity of recruitment of animals to the shelter was constant throughout the study period these findings indicate negative growth in the free-roaming dog population and little or no growth in the free-roaming cat population. Elasticity analyses allowed us to distinguish those factors that were most influential in determining population growth. The intrinsic rate of population growth was sensitive to changes in the submission and fecundity rates of younger animals (those less than 2 years of age) with each measure being approximately equally influential in terms of the overall effect on population growth.

The studies presented in this dissertation demonstrate that submission of younger animals to the shelter (with subsequent re-homing) and/or submission and desexing (with subsequent release) are equally effective techniques for limiting the growth of the free-roaming dog and cat population in the Wellington region. Areas defined as socio-economically deprived should be targeted for intervention. June to September would be an appropriate time of the year to intensify control efforts, particularly for cats.

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Nomenclature

GIS	Geographic Information System
GnRH	Gonadotrophin releasing hormone
FAO	Food and Agriculture Organization of the United Nations
FSH	Follicle stimulating hormone
LH	Luteinising hormone
NZSPCA	New Zealand Society for the Prevention of Cruelty for Animals
OIE	Office International des Épizooties
SPCA	Society for the Prevention of Cruelty for Animals
WHO	World Health Organization
WSPA	World Society for the Protection of Animals

List of Publications

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Contents

List of Figures

List of Tables

CHAPTER 1

Introduction

Free-roaming dogs and cats (that is, animals found in public places irrespective of the level of care and level of supervision imposed upon them) impose a burden on the community in a number of ways. A diverse range of zoonotic infections, including parasitic, bacterial, viral, protozoal and fungal diseases are transmitted from dogs and cats to humans (Robertson & Thompson 2002, Acha & Szyfres 2003, WHO, FAO, and OIE 2004, Hunter & Thompson 2005, Kahn 2006). The role played by dogs in the transmission of rabies and echinococcosis has been universally recognised (WHO and WSPA 1990, Dar & Alkarmi 1997, Woldehiwet 2002, Konno et al. 2003, Bingham 2005, Hemachuda 2005, Kilic et al. 2006). The societal burden arising from dog bite injuries is also considerable (Langley 1992, Weiss et al. 1998, Overall & Love 2001, Peters et al. 2003, Feldman et al. 2004, Marsh et al. 2004, Fevre et al. 2005, Keuster et al. 2005). The impact on wildlife due to wild juveniles being preyed upon by free-roaming dogs and cats or due to the spread of fatal diseases poses a significant threat to wild life conservation (Patronek et al. 1997, Cleaveland et al. 2000, Manor & Saltz 2004).

These issues and the scarcity of literature on the ecology and population dynamics of dogs and cats in urban environments motivated this work to determine factors influencing population growth of free-roaming dogs and cats in the Wellington region. This dissertation is comprised of four main chapters. Chapter 2 reviews problems arising from an overpopulation of free-roaming dogs and cats and identifies the various techniques available to control dog and cat populations. Although a variety of methods may be used, the effectiveness of intervention strategies are generally not realised despite tremendous efforts by government and non-government humane organisations, and the community. Acknowledging this problem, modeling is proposed as a method for objectively evaluating combinations of various control methods, allowing interventions to be tailor-made for specific environments. Chapter 3 outlines some of the basic techniques for modeling population growth with special reference to dogs and cats. It also reviews techniques that have been used to estimate various parameters which are essential model inputs.

Chapter 4 provides a description of the free-roaming dog and cat population in the Wellington region in terms of place and time. Chapter 5 describes the demographic characteristics of the free-roaming dog and cat population in terms of age and fecundity. In Chapter 5 Leslie projection matrices are used to quantify the intrinsic rate of population growth allowing us to determine which of the vital rates (age-specific survival or fecundity) have the greatest influence on population growth. The analyses presented in this dissertation illustrate a range of techniques suitable for describing and explaining the temporal, spatial, and demographic aspects of humane shelter data. These techniques provide a basis for understanding factors influencing the growth of free-roaming dog and cat populations.

CHAPTER 2

A Review of Dog and Cat Ecology

2.1 Introduction

Dogs were domesticated from wolves as recently as 15000 years, ago (Morey 2006), or perhaps as early as 100000 years ago based on recent genetic fossil and DNA evidence (Savolainen et al. 2002, Lindbald-Toh 2005). Evidence suggests that dogs were first domesticated in East Asia, possibly China, and the first people to enter North America took dogs with them (Savolainen et al. 2002). While it is generally assumed that the cat was first domesticated in Egypt around 2000 BC, fossil records from Cyprus suggest that it may have occurred between 5000 and 6000 BC (Adamelli et al. 2005). The World Health Organization (WHO) and World Society for Protection of Animals (WSPA) classify dogs based on the level of dependence on human care (that is food, shelter and human companionship) and also on the level of restriction or supervision imposed by humans (WHO and WSPA 1990, Table 2.1). Throughout this dissertation I will use the term ‘free-roaming’ to describe animals found in public places irrespective of the level of care and level of supervision imposed upon them. The last three categories cited in Table 2.1 (family animals, neighbourhood animals, and feral animals) may legitimately fit into this group in one way or another.

Dogs perform a range of cultural, social, and economic functions in society. Dogs are kept as pets and companions, for hunting, as guards, draught animals, for food, or for commercial purposes. In some areas of Eurasia and North America dogs are used to carry goods and to pull sledges and carts. Large breeds in developing countries were raised to guard livestock, premises and agriculture crops. Dogs also perform some specialised tasks such as leading the blind, detection of illegal goods, tracing criminals, and as an aid to detect certain illnesses in humans (Willis et al. 2006). Dogs and cats play an important

Table 2.1: Classification of the status of dogs and cats based on the level of supervision imposed.

Classification	Description
Restricted or supervised	Fully dependent and fully restricted or supervised.
Family	Fully dependent; semi-restricted.
Neighborhood	Semi-dependent; semi-restricted.
Feral	Independent, unrestricted. Although they may survive on human waste material nobody will take responsibility for them.

role in society, enhancing the psychological and physiological well being of many people (DiSalvo et al. 2005). Recent evidence suggests that pet owners visit their doctor less frequently, use fewer medications and have lower blood pressure and cholesterol levels than those who do not own pets (Blackshaw 1996). Some studies also suggest that keeping pets is associated with a higher level of self esteem in children (Paul & Serpell 1996).

Although dogs and cats closely have cohabited with humans since early civilisation, reliable estimates of dog and cat populations are rare. American and European countries report dog to human ratios to be anywhere between 1:10 and 1:4 and cat to human ratios to be from 1:5 to 1:11 (Schneider & Vaida 1975, Nassar & Mosier 1980, Nassar & Mosier 1982, Nassar & Mosier 1984). The owned dog and cat population in New Zealand in 2005 was estimated to be approximately 650000 and 110000 (Anonymous 2006), respectively. This is equivalent to a dog and cat to human ratio of 1:6 and 1:3, respectively.

Although the free-roaming proportion of the dog and cat population is infrequently quantified evidence suggests that their numbers are increasing in many countries (Gibson et al. 2002, Levy et al. 2003, Wallace & Levy 2006). Free-roaming dog and cat population density varies with habitat, culture, and a variety of sociological conditions. Irresponsible pet ownership is thought to account for most of the surplus dog and cat problems in developed countries. A study in North America found that approximately 15% of dogs and 35% of cats were no longer in their original home after a period of 12 months (Beaver 1991). In developing countries surplus populations of owned and un-owned dogs are rampant due to a variety of reasons such as irresponsible ownership, lack of population control programmes, lack of commitment by regulatory authorities, and poor living standards (WHO and WSPA 1990). The magnitude of free-roaming cat populations in developing countries have not been quantified.

The size of free-roaming dog populations have been estimated by capture-mark-recapture methods in Spain, Nepal, the USA, and Japan. Density estimates using this method were 127 to 1304 stray dogs per km^2 in Spain (Font 1987), 231 dogs per km^2 in the USA (Beck 1975), 2930 dogs per km^2 in Nepal, and 225 dogs per km^2 in Japan (Kato et al. 2003). A study carried out in the Machakos area of Kenya found an average density of 13 dogs per km^2 (Kitala et al. 2001). A population of feral cats was monitored on New Zealand farmland over three years by means of radiotelemetry and an average density of 3.5 cats per km^2 was reported (Langham & Porter 1991).

2.2 Problems associated with free-roaming dogs and cats

Keeping and tolerating dogs and cats is not without problems. These populations are fast growing due to a high reproductive potential and this represents a hazard to the animals themselves as well to environment. Stray and feral dogs pose serious human health, socio-economic, and animal welfare problems in many countries throughout the world. A diverse range of zoonotic infections including parasitic, bacterial, viral, protozoal, and fungal diseases can be transmitted from dogs and cats to humans (Table 2.2). Dogs are involved in the epidemiology of toxocariasis, visceral larvae migrans, cutaneous larvae migrans, strongyloidiasis, diphyllobothriasis, trichinosis, dirofilariasis, stronglyloisiasis, Rocky Mountain spotted fever, giardiasis, cryptosporidiosis, and a range of other diseases (Robertson & Thompson 2002, Acha & Szyfres 2003, WHO, FAO, and OIE 2004, Hunter & Thompson 2005, Kahn 2006). Most important is the role of the dog in the maintenance and transmission of echinococcosis and rabies (WHO and WSPA 1990, Dar & Alkarmi 1997, Woldehiwet 2002, Konno et al. 2003, Hemachuda 2005, Bingham 2005, Kilic et al. 2006).

Canine rabies is widespread throughout the world and greater than 99% of all human cases are acquired from rabid dogs (WHO 1996). Some four million people annually receive post exposure treatment and greater than 30,000 deaths from rabies are reported every year. At the same time millions of animals die of rabies each year.

Although the domestication of the dogs was initiated 14,000 years ago, dogs retain many of their wild instincts, including behaviours that often lead to human attack. Epidemiological features of the occurrence of dog bites have been documented in a number of countries. The weighted estimate of the incidence of new dog bite related injuries seen in

Table 2.2: Major zoonoses acquired from dogs and cats.

Pathogen	Transmission	Human disease
Bartonella henselae	Animal bite or scratch.	Cat scratch fever.
Borrelia burgdorferi	Ixodid tick vector.	Lyme disease.
Brucellosis (dogs)	Contact with infected tissues.	Intermittent fever, malaise.
Campylobacter spp.	Faecal-oral.	Gastroenteritis.
Cryptosporidium spp.	Faecal-oral.	Abdominal pain, nausea, fever and diarrhoea.
Dermatophytosis	Direct contact.	Raised circular lesions, hyperkeratosis.
Dipylidiasis	Ingestion of flea/louse vector.	Pruritus ani.
Echinoccosis granulosus	Contaminated tissue or faecal contact.	Hydatid cyst.
Giardia spp.	Faecal-oral.	Gastroenteritis, fever.
Leptospirosis	Contact with infected secretions or tissues.	Malaise, acute nephritis, icterus, hepatitis, uveitis.
Pasteurella multocida	Animal bite.	Lymphadenopathy, leptomeningitis, subcutaneous abscesses.
Rhabdovirus	Animal bite.	Rabies.
Salmonella spp.	Faecal-oral.	Gastroenteritis.
Sarcoptes scabei	Direct contact.	Pruritic skin disease, erythema.
Toxocara canis or *T. cati*	Faecal-oral.	Visceral larvae migrans.
Toxoplasma gondii	Contact with contaminated tissue or faecal contact.	Abortions, stillbirths, encephalitis, myositis, birth defects, death.
Yersinia enterocolitica	Faecal-oral.	Gastroenteritis.

hospital emergency departments throughout the USA was estimated to be 129 per 100000 persons in 1998 (Weiss et al. 1998). In California from 1991 to 1998, the overall mean annual incidence risk of hospitalisation resulting from dog bites was 2.6 per 100000 head of population (Feldman et al. 2004). A Flemish survey reported 220 bites per 100000 children under the age of 15 years (De Keuster et al. 2005). Several studies indicate that approximately 60% to 75% of those bitten are less than 20 years of age, and most are children 5 – 9 years old (Overall & Love 2001). A study of the morbidity of dog bite injuries was carried out in New Zealand for the period 1979 to 1988 (Langley 1992). This study reported the incidence risk of hospitalisations due to dog bites to be 4.8 per 100000 head of population. Similar studies carried out by Marsh et al. (2004) for the period 1989 to 2001 reported the incidence risk of dog bite injuries at 8.1 per 100000 head of population. A field survey of dog bite injuries in Uganda estimated an incidence risk of 39.6 bites per 100000 head of population (Fevre et al. 2005).

Most of the studies that have described the incidence of dog bite injuries may be criticised because of small sample sizes, lack of consistent case definitions, and/or the populations that were studied were not representative of the source population. Moreover, most of studies underestimate the incidence of dog bite injuries because they only take into account those cases reported to the hospital. Dog bite injuries are certainly of greater importance in developing countries than is officially recognised since the rate of under reporting is expected to be much higher than in developed countries (WHO and WSPA 1990).

Free-roaming dogs and cats can affect wildlife populations by preying on juveniles or introducing and spreading diseases to other carnivores species that prey on free-roaming dogs and cats. Manor & Saltz (2004) studied the impact of free roaming dogs on the kid-mother ratio of the mountain gazelle. Their findings showed that free roaming dogs were the overwhelming factor affecting kid-mother ratio in this species. Studies conducted on free ranging domestic dogs in Zimbabwe showed that dogs were unsuccessful predators of wild animal species and that larger carnivores (for example leopards, lions, and spotted hyenas) preyed on dogs (Butler et al. 2004). Predation of larger carnivores on free-roaming dogs provides ideal circumstances for transmission of diseases which poses a threat to wildlife conservation. The role of domestic dogs in the spread of canine distemper virus infection among Serengeti wildlife has been documented (Cleaveland et al. 2000). Patronek (1998) reviewed those studies that looked at the impact of free-roaming cats on wildlife.

Although the impact of stray dogs on the tourism industry in developing countries has not been widely documented, it is likely that many tourists consider stray dogs as dangerous and a nuisance which may influence their activities when visiting tourist destinations. In addition, free-roaming dogs and cats cause many other problems by fouling public places with excreta, creating undesirable noise, causing road traffic accidents, and placing stress on road users (Robinson 1974, Dabritz et al. 2006).

2.3 Control of free-roaming dogs and cats

The overwhelming problems associated with excess numbers of free-roaming dogs and cats has come to the attention of many countries, animal welfare, and international organisations (e.g. The World Health Organization, The World Society for the Protection of Animals, and The Food and Agriculture Organization of The United Nations). The aim of this section is to review the various methods that have been applied to control dog and cat populations with special reference to free-roaming populations. Several control methods have been initiated and implemented at varying levels in various countries depending on the prevalent cultural values and the availability of resources (WHO 1987, Avanzino 1991, Jochle 1991, Arkow 1991, Olson & Johnston 1993, Mahlow & Slater 1996). In 1990 the World Health Organization and the World Society for the Protection of Animals collaborated to produce a publication titled ‘Guidelines for Dog Population Management’ (WHO and WSPA 1990). This document proposed a long term strategy for the control of free-roaming dogs and cats in a humane manner. These control methods are targeted towards factors that contribute to overpopulation which include: (1) irresponsible animal ownership (allowing owned animals to roam unsupervised and abandonment of unwanted animals); (2) uncontrolled breeding (within the owned population and subsequent abandonment of offspring); and (3) continuous availability of suitable habitats (food, water and shelter) in the environment. The main strategies to counteract an increasing number of free-roaming dogs and cats include: (1) control of survival; (2) removal of free-roaming dogs and cats from the environment (supported by habitat control and legislative backup); and (3) control of reproduction.

2.3.1 Control of survivorship

Euthanasia of newborn pups and kittens is an effective method for controlling free-roaming dog and cat populations in many countries. Killing of new-born pups is practiced in some developed countries, as well as in rural areas of developing countries where dogs have well-assigned functions (WHO and WSPA 1990). Persons under whose shelter and care dogs and cats are born have a duty to decide on the number to be kept and raised and to look for suitable homes.

In addition to the removal of young, unwanted newborn animals dogs and cats that are abandoned or unclaimed by their owners may be euthanised at humane shelters. It was estimated in 1991 that approximately 3.9 to 5.9 million dogs and 3.4 to 5.4 million cats were euthanised throughout the USA (Nassar & Fluke 1991). Destruction of free-roaming dogs and cats by shooting and poisoning has been carried out as part of routine rabies control programs in many developing countries (WHO 1987, WHO and WSPA 1990). Although widely used, these procedures tend to be culturally and socially insensitive and are not well tolerated in many societies. Experience in Latin America, Asia, and Africa have shown that removal of dogs by this method has little or no impact on population densities or the spread of rabies since losses are easily compensated-for by increased survival in the population that remains (WHO and WSPA 1990, Acha & Szyfres 2003, WHO 2004).

2.3.2 Habitat control

Dogs and cats are attracted to areas where there is adequate food and shelter. Reduction of the dog and cat carrying capacity of the environment can be achieved by improved solid waste management (community garbage collection and sanitary waste disposal), removal of shelter, clean-up of specific habitats, and education of the public. It is important to initiate these strategies concurrently with methods designed to reduce the size of the animal population. In developed countries density of feral and free-roaming dogs in urban areas has been negatively associated with socio-economic status where greater numbers of free-roaming pets are common in low-income, higher population dense areas (Beck 1975, Font 1987). A positive correlation between dog and human densities has been reported in Kenya and Zimbabwe (Butler & Bingham 2000, Kitala et al. 2001). In Asia dog abundance is associated with the availability of food, including garbage scattered on streets and the tendency of people to feed stray dogs (Kato et al. 2003).

2.3.3 Legislative measures

Legislative measures to control dog and cat populations include the registration and identification of owned animals, registration of breeding facilities and pet shops, prevention of abandonment and unsupervised roaming, and measures to prevent animal cruelty. Many countries have legislation to support the control of overpopulation of dogs and cats. In New Zealand the Dog Control Amendment Act (New Zealand Government 2003, New Zealand Government 2004) has incorporated several regulations to mitigate the free-roaming dog problem. These include requiring owners to fulfil certain legal obligations such as having a well-fenced property preventing the dog from leaving at will, the compulsory use of a leash in public places, and heavy penalties for owners of dogs found to be without a leash in public places. The law also provides initiatives for responsible dog ownership such as discount on registration fees for desexed dogs and for those owners who have passed a test covering the basic requirement of responsible dog ownership. Other supplementary provisions to control free-roaming dog populations include the compulsory desexing of impounded dogs prior to rehoming, maintenance of a dog control information database, and mandatory implantation of microchip transponders recording details of the animal's owner, veterinarian, and infringement information (if any) for those dogs registered from 30 June 2006 onwards. In 1990, San Mateo County in California USA passed legislation requiring compulsory sterilisation of of dogs unless the owner is registered as a breeder (Avanzino 1991).

Several regional councils in Australia have enacted legislation designed to minimise problems associated with free-roaming cats (see, for example, Shark Bay Shire Council 1995, Tasmanian State Government, 2005, and McMurray, 2006). These measures include: (1) imposition of restrictions on the number of cats to be kept by a single owner; (2) compulsory identification and registration of dogs and cats from 12 weeks of age; (3) reduced registration fees for desexed animals; (4) the requirement that pet shops and breeders sell desexed animals; and (5) the requirement that all dogs and cats need to be desexed and identified prior to registration.

2.3.4 Control of reproduction

Public concern has stimulated search for a suitable method of reproductive control in companion animals. Surgical, physico-chemical, pharmacological, and immunological methods exist for the reversible or irreversible control of reproductive functions in male and female dogs and cats. In this section I review methods for controlling reproduction in dogs and cats.

Surgical methods

Sterilisation of dogs and cats is the most common surgical procedure performed in veterinary practice. The benefits of surgical sterilisation in dogs and cats include prevention of diseases such as mammary neoplasia and benign prostatic hyperplasia (WHO and WSPA 1990, Howe 2006). Details of surgical methods for controlling reproductive function in male and female dogs and cats are provided in Table 2.3.

Surgical methods have the primary advantage of being permanent. Castration and ovariohysterectomy also have useful secondary benefits by altering undesirable behaviour such as aggression and the tendency to roam (in dogs) and spraying of urine (in cats) (Bloomberg 1996, Howe 2006). In the female, loss of oestrus behaviour leads to reduced roaming and calling by queen cats. Past experience has reported the beneficial effect of sterilising bitches when pregnant. The sterilisation of 398 pregnant bitches in Jaipur, India over a three month period resulted 2237 fewer pups being added to the population (Chawla and Reece, 2002).

The lateral flank approach has been suggested as an alternative to the conventional ventral midline ovariohysterectomy in dogs (Howe 2006). This method is appropriate when an animal has excessive mammary development or in situations where post-operative monitoring or examination may be limited. This approach was successfully used for neutering 16,451 bitches between November 1994 and December 2002 in Jaipur, India as a part of a rabies control program carried out by Help in Suffering, an animal welfare organisation (Reece & Chawla 2006).

Behaviour is not modified after vasectomy or destruction of the epididymis (Bloomberg 1996, Immegart 2000, Howe 2006). This may be seen as an advantage in guard dogs and for those pet owners who don't wish to alter the behavior of their animals. A variety of sclerosing agents have been injected into the epididymis including 3% solution of chlorhexidine gluconate alone or in 5% DMSO (dimethyl sulfoxide), ethyl cellulose in DMSO and formalin, zinc tannate, zinc arginine, chlorhexidine in ethyl cellulose, and acrylic hydrogel dissolved in DMSO.

To increase the effectiveness of population control measures, many humane organisations and veterinarians are promoting early age desexing (that is, desexing puppies and kittens 8 to 12 weeks of age). Several studies have evaluated the advantages and disadvantages of early age gonadectomy (Howe et al. 2001, Spain et al. 2004). The acceptance of prepubertal gonadectomy by veterinarians has been slow in the past due to concerns about anaesthesia, the potential for post-operative behavioural abnormalities, musculoskeletal disorders, urinary incontinence (in female dogs), and obesity. However, both short term and long term studies have shown that the prepubertal gonadectomy is a safe procedure and does not increase the incidence of physical or behavioural problems in dogs and cats compared with traditional age gonadectomy (Spain et al. 2004). In a survey of veterinarians in Australia, the overwhelming majority reported that early age desexing was easier as a procedure and that post anaesthesia recoveries were better compared with adult desexing (Webb 2003). This relates largely to the fact that in young animals, the ovaries and uterus are easier to find and younger animals are less obese. These characteristics help to reduce surgical time and trauma, leading to faster recovery and healing with less stress on the animal. Since 1993 the Cat Protection Society of Victoria has successfully desexed about 56000 kittens with little or no major problems (Webb 2003).

Non-surgical methods

These methods are not permanent and not to be suitable for free-roaming dogs. However, they may be still preferred by owners who are not in favour of surgical methods of birth control for their pets. Details of non-surgical methods developed for the control of reproductive function in male dogs and cats dogs are provided in Table2.4.

Non surgical methods of neutering male dogs and cats include steroid hormone suppression of reproductive function and injection of chemical sterilants into the testis (Jochle 1991, Olson & Johnston 1993, Fayrer-Hosken et al. 2000, Immegart 2000, Levy et al. 2004). Synthetic steroids with anti-androgenic or progesterone effects cause temporary sterilisation. Many may be given by injection and will reduce libido for a number of months. Those given orally may require frequent administration.

Table 2.3: Surgical methods available for the control of reproductive functions in male and female dogs and cats. Adapted from WHO and WSPA (1990).

Method	Advantages	Disadvantages
Males:		
Castration	Medium cost; 100% effective	
Vasectomy	Medium cost; 100% effective	No undesirable male behaviour modifications; androgen-dependent diseases not prevented
Sclerosis of epididymis	Low cost; 90% effective	Temporary post-operative pain
Females:		
Ovariectomy	Medium cost; 90% effective	May cause pyometra
Midline ovariohysterectomy	100% effective	Major surgery; high cost
Lateral flank ovariohysterectomy	Post operative care reduced	Limited exposure of contralateral side; difficulty in identifying previous ovariohysterectomy incision scar
Laparoscopic ovariohysterectomy	100% effective; minimally invasive surgery, less post operative pain	High cost; surgical times and complications rates higher compared with other methods
Tubal ligation	Medium cost; 100% effective	No behaviour modifications; may cause pyometra

Immunological methods to control reproduction are based on gonadotrophin releasing hormone (GnRH) agonists or antagonists (Olson & Johnston 1993, Levy & Crawford 2004). GnRH agonist and antagonists cause the down regulation of pituitary GnRH receptors and suppress the secretion of luteinising hormone (LH) and follicle stimulating hormone (FSH) which in turn suppresses cycling in females and suppresses gonadal function in males. Permanent contraception can be achieved by administration of a cytotoxin linked to GnRH which selectively destroys gonadotrophin secreting pituitary cells (Olson & Johnston 1993).

Injection of chemical sterilants into the testes, ductus deferens, or epididymis results in permanent azoospermia, alteration of the physical composition of the testis, and alterations to testosterone production (Olson & Johnston 1993, Bloomberg 1996). Injecting sterilants directly into the testis results in reduced androgen production, ameliorating androgen dependent disorders such as prostatic disease, behavioral problems, and gonadal disease.

Non-surgical methods for neutering female dogs and cats include steroid hormone suppression of reproductive functions, induction of pseudopregnancy, administration of GnRH agonists or antagonists, zona pellucida vaccines and tissue specific cytotoxins (Jochle 1991, Olson & Johnston 1993, Bloomberg 1996, Fayrer-Hosken et al. 2000,

Table 2.4: Non-surgical methods available for the control of reproductive function in dogs and cats. Adapted from WHO and WSPA (1990).

Compound	Action/indication	Dosage
Hormones:		
Proligestone	Delay and suppress oestrus	1 – 1.5 ml/5 kg
Oestradiol benzoate	Misalliance in the bitch	0.01 mg/kg at 3rd, 5th, and 7th day
	Excess libido in male	0.03 mg/kg; repeat q30d if required
Megestrol acetate	Postponement of oestrus	Bitch: 2 mg/kg SID for 8 days
		Queens: 5 mg/kg SID for 3 days
Medroxyprogesterone acetate	Prevention of oestrus	Bitch: 0.5 – 1.5 mL q6m
		Queens: 0.5 – 1.0 mL q3 – 4m
Delmadinone acetate	Interruption of oestrus cycle	1 – 1.5 mg/kg
Deslorelin acetate	Render males temporarily infertile	One implant q6m
Algepristone	Termination of pregnancy	10 mg/kg SID for 2 days
Mifipristone	Termination of pregnancy	2.5 – 5 mg/kg BID for 4.5 days
Epostane	Termination of pregnancy	2.5 – 5 mg/kg SID for 7 days
Tamoxifen citrate	Termination of pregnancy	1 mg/kg BID for 10 days
Estradiol cypionate	Termination of pregnancy	22 – 44 μg/kg on 4th day of behavioural oestrus
Prostagnandin $F_{2\alpha}$	Termination of pregnancy	125 – 250 μg/kg BID for 4 days
Prolactin inhibitors:		
Cabergoline	Termination of pregnancy	5 – 25 μg/kg SID for 5 days
Bromocriptine	Termination of pregnancy	20 – 30 μg/kg BID for 4 days
Immunisation:		
Against LH or GnRH	Suppress reproductive function	
Against zona pellucida proteins	Prevention of fertilisation	

Immegart 2000, Levy et al. 2004, Howe 2006). These agents work by number of approaches such as interrupting the oestrus cycle, suppression of oestrus or pro-oestrus, preventing pregnancy after misalliance, termination of unwanted pregnancy, and rendering bitch and queens sterile. A range of progestin products such as medroxyprogesterone acetate, chlormadinone acetate, delmadinone acetate, megestrol acetate, and proligestone are used for interruption of the oestrus cycle and oestrus suppression (Jochle 1991, Olson & Johnston 1993, Mahlow & Slater 1996). However treatments for oestrus suppression or even temporary postponement of oestrus, tend not to be favoured by clinicians because of the high level of long term complications such as pseudocyesis, glandular cystic hyperplasia, and pyometra. These side effects can be greatly reduced if treatment for interruption of oestrus are given at the correct time and at the recommended dose rate. Treatment should be initiated after the first oestrus and continued for the animal's lifetime. Benefits of the use of progestins (besides the cessation of cyclic function) are their reversibility, a reduction in the incidence of a range of dermatologic conditions, and partial or total control of epileptic seizures.

Oestrogen products have been used for more than half a century to prevent pregnancy after misalliance. Diethylstilbestrol has been the drug of choice for many decades (Jochle 1991, Olson & Johnston 1993, Mahlow & Slater 1996). Oestradiol benzoate or oestradiol valerate may also be used and have the added benefit of being less likely to induce side effects associated with disfunction of the haemopoietic tissues.

Prostaglandin $F_{2\alpha}$ and its analogues have been successfully used as abortive agents in bitches and queens (Jochle 1991, Olson & Johnston 1993, Mahlow & Slater 1996). Due to their side effects and the need for repeated administration, these drugs tend to be mostly used as in-house procedures.

CHAPTER 3

Models of Population Growth

3.1 Introduction

A population is defined as group of organisms of the same species occupying a particular space at a particular time, with the potential to breed with each other (Williams et al. 2002). Turchin (2003) defined a population as a group of individuals of the same species that live together in an area of sufficient size to permit normal dispersal and migration behaviour, and in which population changes are largely determined by birth and death processes.

Population growth is determined by four processes: reproduction, mortality, immigration, and emigration (Rockwood 2006). An increase in the size of a population can occur through reproduction and immigration while it declines as a result of mortality and emigration. Closed populations are those where there is no immigration or emigration. Methods to control dog and cat population growth are aimed at controlling reproduction and reducing survivorship. No single method will be suitable to address over population problems in any given circumstance and, as a result, population growth models have the potential to be useful tools to determine the optimum combination of methods for individual situations.

3.2 Modelling population growth

In developing a model of a population we usually begin with an existing population at time 0 and estimate the size of the population t time units into the future. Thus:

$$N_{t+1} = N_t + (B + I) - (D + E) \tag{3.1}$$

Where N_t is the population size at time t, N_{t+1} is the population size one time unit later, and B, I, D, and E are the numbers of births, immigrants, deaths, and emigrants that occur during t and $t+1$. If we assume that the numbers of immigrants and emigrants are small compared with the number of births and deaths, the terms I and E can be removed. Further, the numbers of births and deaths can be expressed as per capita rates, b and d respectively:

$$N_{t+1} = N_t + (b - d) \tag{3.2}$$

$$N_{t+1} = N_t R \tag{3.3}$$

The difference between b and d can be expressed as a single growth parameter, R, known as the net growth rate per generation or the net reproductive rate. Alternatively, the difference between b and d can be expressed as λ, the growth rate per time period.

$$N_{t+1} = N_t(b - d) = N_t R \tag{3.4}$$

If we assume that population growth is continuous a simple differential equation can be developed to quantify the instantaneous growth of the population, dN/dt (Lotka 1925).

$$\frac{dN}{dt} = rN \tag{3.5}$$

In Equation 3.5 r represents the per capita birth rate minus the per capita death rate during each time interval. If resources are unlimited and there are no competitors or predators acting on a population fertility rates will be high and death rates will be low. Under these conditions a population grows either geometrically or exponentially depending on the life history of the animal species concerned. In other words, the rate of growth is not influenced by population size. In both geometric and exponential models, the rate of growth is determined by fixed parameters (R, λ, and r) that are not modified by competition for resources.

Geometric models are applicable for those populations with discrete, non-overlapping generations (i.e. where there are no survivors from one generation to the next). Exponential models are applicable where generation intervals overlap. The basic form of the exponential model is given in Equation 3.5. By taking the integral from 0 to t of both sides of Equation 3.5 the size of a population at any given point in time can be expressed as:

$$N_t = N_0 e^{rt} \tag{3.6}$$

In Equation 3.6 r equals the instantaneous growth rate of the population. A population is said to be growing if $r > 0$, stationary if $r = 0$, and in decline if $r < 0$.

3.3 Parameters for population models

Predictive models of population growth are dependent on input parameters such as initial population size, age distribution, and fecundity. The World Health Organization have provided guidelines for estimating the different parameters required for describing dog and cat populations (WHO 1987). These guidelines were reviewed in 1990 when the WHO and WSPA produced a comprehensive set of guidelines for dog population management (WHO and WSPA 1990). Following this, dog ecology studies have been conducted in several countries such as Nepal (Kato et al. 2003), Ecuador (WHO 1988), Sri Lanka (Matter et al. 2000), Zimbabwe (Butler & Bingham 2000), Kenya (Kitala et al. 2001), Brazil (Alves et al. 2005), The Phillippines (Childs et al. 1998), and Mexico (Flores-Ibarra & Estrella-Valenzuella 2004). In this section I review the techniques for estimating parameters that may be used to inform population growth models.

3.3.1 Total population size

Dog and cat population density is related to habitat, culture, and sociological factors associated with rural and urban populations (WHO and WSPA 1990). Dog and cat population density is usually quantified using the animal to human ratio, and occasionally as the number of animals per household. In many situations it will be meaningful to quantify population density as the number of animals per unit area or in terms of area and human population (e.g. the number of dogs per household per unit area).

The numbers of owned dogs and cats in a given area may be established by questionnaire surveys and from license records in those countries which have an established system for registering companion animals. In Kenya the number of dogs per sublocation was calculated by multiplying the average number of dogs per household by the total number of households listed in a sublocation. This number was then divided by the area of each sublocation to provide an estimate of the number of dogs per km^2 (Kitala et al. 2001). The estimated dog density in Machakos District, Kenya for five rural sublocations ranged from 6 to 21 dogs per km^2. One urban sublocation had 110 dogs per km^2.

In 1971 a survey to estimate the size of the dog and cat population in Alameda and Contra Costa Counties, California was administered by mail and telephone (Schneider & Vaida 1975). Schneider & Vaida (1975) estimated the dog and cat to human ratio at 1:7 and 1:11, respectively. A study of canine population dynamics in Manhattan reported the dog to human ratio to be 1:4 (Nassar & Mosier 1980). Free-roaming animals in one year represented 12% of the total dog populations in Manhattan, of which 36% were stray and the rest were owned. A similar study to determine the size of the cat population in 1982 reported a cat to human ratio of 1:5 (Nassar & Mosier 1982). The percentage of pet owning households was 28% with, on average, 1.7 cats per cat-owning household. A study of dog and cat population dynamics in Las Vegas in 1984 reported 1 dog and 1 cat for every 4 and 8 persons, respectively (Nassar & Mosier 1984). Forty six percent of households owned dogs and 22% owned cats. On average there were 0.69 dogs and 0.35 cats per household, respectively.

A cross-sectional random-digit dial survey conducted in Indiana USA found that 76% of households owned dogs and 52% of households owned cats (Patronek et al. 1997). The average number of dogs per dog-owning household was 1.4 and the average number of cats per cat-owning household was 1.8. A survey of 954 households in Baja California, Mexico reported a dog to human ratio of 1:0.25 (Flores-Ibarra & Estrella-Valenzuella 2004). A study of canine demography in communal lands in Zimbabwe reported the number of dogs per head of population to be between 0.11 to 0.27. Canine density was positively associated with human population density and ranged between 8 to 53 dogs per km^2 (Butler & Bingham 2000).

Capture-mark-recapture techniques that have been developed for wildlife can be used to estimate the size of free-roaming dog and cat populations (Caughley 1977). These techniques are based on two assumptions: (1) that mortality, emigration and recruitment into the population are minimal throughout the study period; and (2) that all individuals within the population have an equal chance of being counted. The most widely used method to estimate the size of an animal population on the basis of capture-mark-recapture data is the Lincoln-Petersen method (Caughley 1977, McCallum 2000). A sample of n_1 individuals is captured, marked, and released back into the population. A second sample of n_2 individuals is captured and examined for marks. The idea is that the proportion of all individuals in the second sample with marks should be the same as the proportion of all individuals in the population with marks. If N is the total population size and r individuals are recaptured or re-sighted then:

$$\frac{n_1}{N} = \frac{r}{n_2} \tag{3.7}$$

The simple estimator derived from Equation 3.7

$$N = \frac{n_1 n_2}{r} \tag{3.8}$$

is biased for small values of r. A more robust estimate is

$$N_c = \frac{(n_1 + 1)(n_2 + 1)}{r + 1} - 1 \tag{3.9}$$

Despite the simplicity of the method, generating confidence intervals for a Lincoln-Petersen estimate of population size is not straightforward. Cannon & Roe (1982) provide a method for computing confidence intervals on the estimated population using a binomial methods.

The capture-mark-recapture technique was used in the Sorsogon Province of the Republic of the Philippines to estimate the size of the free-roaming dog population and to assess the effectiveness of different marking methods (Childs et al. 1998). In this study dogs were marked with either custom made plastic collars or water resistant bright yellow or pink paint at the time a rabies vaccination was applied. When the study sites were revisited after 1 to 11 days the proportion of dogs marked with paint was substantially less than those with collars. These authors concluded that collars were the preferred method for marking dogs in this area, estimating the density of dogs in this area of the Philippines to be in the order of 450 per km^2.

According to Beck (1975) it is not necessary to capture and mark animals if they are individually distinguishable. Photographing individual animals while surveying an area in the same way on two or more occasions can be used to generate data to estimate the recapture proportion. Photographic identification has many advantages over capturing since animals become neither trap prone nor trap shy.

Beck (1975) observed that dogs in similar sociological neighborhoods have similar densities, thus he was able to estimate the size of the entire Baltimore dog population by extrapolation. This method was used in an urban dog study in Spain by Font (1987) who reported free-roaming dog densities ranging from 127 to 1304 per km^2. Font also reported higher dog densities in the most economically depressed neighbourhoods, particularly those with abundant vacant lots and permanent litter accumulation. Kato et al. (2003) used this method to estimate the size of the stray dog population in Kathmandu, Nepal and in Shimotsui, Japan.

3.3.2 Sex ratio

Data on the ratio of males to females are required to parameterise models of population dynamics. The sex ratio in different age strata of a population can be quite different from the sex ratio at birth. The sex ratio of owned dogs is usually acquired by questionnaire surveys. The male to female ratio of owned dog and cats have mostly been reported to be close to 1:1 (Schneider & Vaida 1975, Nassar & Mosier 1984, Patronek et al. 1997, Scott et al. 2002, Centonze & Levy 2002, Kobelt et al. 2003). Studies of free-roaming dog populations in Spain (Font 1987) and Mexico (Flores-Ibarra & Estrella-Valenzuella 2004) reported male to female ratios of 2:1 and 1.5:1, respectively. These authors reasoned that the observed imbalances in sex ratio were due to a preference of males over females as pets or utility dogs. One study conducted in the USA reported that a higher proportion of owned cats were female (Patronek et al. 1997). Population counts and ratio of males to females reported in different studies are presented in Table 3.1.

3.3.3 Age structure

The age distribution of a population is defined as the proportions of the population belonging to various age categories at a given point in time. Data on the age structure of owned dogs and cats are usually obtained by questionnaire surveys. Although methods of age determination for various wild animal species have been developed, robust methods

Table 3.1: Estimated densities of free-roaming and owned dogs and cats, ratio of dogs and cats to humans, and proportion of the dog and cat population that were male.

Author and year	Animal density	Ratio [a]	Male (%)	Remarks
Dogs:				
Schneider & Vaida (1975)	–	1:7	50%	Owned, USA
Nassar & Mosier (1980)	0.43 per HH	1:4	–	Owned, USA
	1.36 per dog-owning HH			
Nassar & Mosier (1984)	0.35 per HH	1:4	45%	Owned, USA
	1.61 per dog-owning HH			
Font (1987)	127 – 1304 per km^2	–	66%	Free-roaming, Spain
Patronek et al. (1997)	–	–	48%	Owned, USA
Childs et al. (1998)	468 per km^2	–	–	Free-roaming, Philippines
WHO (1988)	60% HH owned dogs	1:6 – 1:13	50 – 89%	Owned, Sri Lanka
WHO (1988)	60% HH owned dogs	1:3	66%	Tunisia
	2.3 dogs per HH			
WHO (1988)	87% HH owned dogs	1:7	61%	Ecuador
	0.8 dogs per HH			
Butler & Bingham (2000)	1.5 per HH	1:5	56%	Zimbabwe
Matter et al. (2000)	87 per km^2	–	–	Owned, Sri Lanka
	108 per km^2	–	–	Unowned, Sri Lanka
Kitala et al. (2001)	6 – 21 per km^2	1:8	60%	Free-roaming, Kenya
	110 per km^2			
Kato et al. (2003)	2930 per km^2	1:5	–	Free-roaming, Nepal
	225 per km^2	1:5	–	Japan
Kobelt et al. (2003)	–	–	49%	Owned, Australia
Flores-Ibarra et al. (2004)	–	4:1	60%	Free-roaming, Mexico
Alves et al. (2005)	1.6 dogs per HH	1:4	–	Owned, Brazil
Cats:				
Schneider & Vaida (1975)	–	1:11	51%	Owned, USA
Nassar & Mosier (1982)	0.51 per HH	1:5	–	Owned, USA
Nassar & Mosier (1984)	1.76 per cat-owning HH	–	–	
	0.35 per HH	1:8	48%	Owned, USA
	1.61 per cat-owning HH	–	–	
Patronek et al. (1997)	–	–	32%	Owned, USA
Centonze & Levy (2002)	–	–	45%	Free-roaming, USA
Scott et al. (2002)	–	–	43%	Free-roaming, USA
Alves et al. (2005)	12.6% HH owned cats	1:16	–	Owned, Brazil
	1.8 cats per HH	–	–	

[a] Estimated ratio of animals to humans.
HH: Household.

for free-roaming dogs and cats are lacking. Age related tooth wear patterns are described for dogs and cats but they are unreliable since tooth wear is heavily dependent on nutrition and general living condition. Tooth wear is variable for owned dogs, but may be more uniform in free-roaming dogs and cats assuming living conditions are generally homogenous for this sector of the population. The age structure of dog and cat populations that have been reported in literature are presented in Table 3.2. The mean age of owned dogs in developed countries is higher compared with that in developing countries. The mean age of owned dogs in Australia was 7 years (Kobelt et al. 2003) and ranged from 2 to 4 years in Kenya, Zimbabwe, Tunisia, Ecuador, and Sri Lanka (WHO 1988, Butler & Bingham 2000, Kitala et al. 2001). The age structure of free-roaming dog and cat populations is skewed towards younger age groups ($<$ 1 year) (Nassar & Mosier 1980, Nassar & Mosier 1982, Butler & Bingham 2000, Kitala et al. 2001). In some cases the age structure of free-roaming dogs and cats is either uniform or skewed towards older age groups (Schneider & Vaida 1975, Nassar & Mosier 1984, WHO 1988, Patronek et al. 1997, New et al. 1999, Scott et al. 2002, Centonze & Levy 2002, Flores-Ibarra & Estrella-Valenzuella 2004). This may be due to various interventions undertaken to mitigate overpopulation problems such as immediate removal of litters after birth.

Table 3.2: Mean age and estimated age structure of owned and free-roaming dog and cat populations.

Author and year	Mean age	Proportion (%)			Remarks
		Puppies	Juveniles	Adult	
Dogs:					
Schneider & Vaida (1975)	–	13	0	87	Owned, USA
Nassar & Mosier (1980)	–	57	7	36	Owned, USA
Nassar & Mosier (1984)	–	0	12	88	Owned, USA
Patronek et al. (1997)	–	5	95	0	Owned, USA
WHO (1988)	3.5 yrs	24	–	–	Sri Lanka
WHO (1988)	2.5 yrs	27	–	–	Tunisia
WHO (1988)	2.5 yrs	30	–	–	Ecuador
New et al. (1999)	–	8	92		Relinquished, USA
Butler & Bingham (2000)	2.0 yrs	41	0	59	Zimbabwe
Kitala et al. (2001)	1.9 yrs	50	0	50	Free-roaming, Kenya
Kobelt et al. (2003)	6.8 yrs	–	–	–	Owned, Australia
Flores-Ibarra et al. (2004)	–	0	17	87	Free-roaming, Mexico
Cats:					
Schneider & Vaida (1975)	–	19	0	81	Owned, USA
Nassar & Mosier (1982)	–	45	16	39	Owned, USA
Nassar & Mosier (1984)	–	0	17	83	Owned, USA
Patronek et al. (1997)	–	3	97	0	Owned, USA
New et al. (1999)	–	6	94	0	Relinquished, USA
Centonze & Levy (2002)	–	18	25	57	Free-roaming, USA
Scott et al. (2002)	–	–	–	85	Free-roaming, USA

3.3.4 Survival

A life table is a means for quantifying numbers of individuals remaining in successive age classes of a population (Caughley 1977, McCallum 2000). Construction of a life table is usually the first step taken when constructing a model of population growth. There are two types of life tables: (1) cohort life tables, in which the number of individuals born at the same time are followed from birth through specified ages or age classes until the last individual dies, and (2) current life tables, which are a snapshot of the population at a particular point in time. Details of calculations for summary measures of survival in a standing population are provided in Table 3.3.

Pearl (1927) introduced the idea that biological populations routinely fit into one of three types of survivorship curves. The type I curve, known as the 'death at senescence' curve, is characterised by a high level of survival until old age, at which time the rate of death rapidly accelerates. The type II curve is linear and assumes that either a constant number or a constant proportion of the population dies in each age interval. The type III curve is characterised by a high probability of death among juveniles, low to moderate probability of death in early adulthood, then a progressively increasing probability of death with advancing age. The type III pattern applies to the vast majority of biological populations including free-roaming dogs and cats. However, this may not strictly apply to pet populations where survivorship is influenced by varying levels of veterinary intervention. Statistical models to estimate age specific survival rates are described by McCallum (2000).

Age specific survival rates for free-roaming cats have been estimated using the geometric probability distribution (Andersen et al. 2004). This method assumes that survival probabilities remain constant throughout the entire interval for which they are being estimated. Baldock et al. (2003) used a beta pert probability distribution to model the survival probability of each age-class of owned cats, with the estimate from survey data being used as the most likely value, and minimum and maximum values for the distribution being the most likely values plus or minus 5%, respectively.

Table 3.3: Structure of a single decrement life table.

Column	Definition	Calculation
x	Age which interval begins	Basic input.
K_x	Number alive at the beginning of age class x	Basic input.
D_x	Number of deaths in interval x to $x+1$	$D_x = K_{x+1} - K_x$
l_x	Fraction of initial cohort alive at beginning of interval x	$l_x = K_x/K_0$
p_x	Proportion of individuals alive at age x that survive to x to $x+1$	$p_x = l_{x+1}/l_x$
q_x	Proportion of individuals alive at age x that die in interval x to $x+1$	$q_x = 1 - p_x$
d_x	Fraction of the original cohort that dies in the interval x to $x+1$	$d_x = l_x - l_{x=1}$
L_x	Per capita fraction of age interval that lived x to $x+1$	$L_x = l_x - (d_x/2)$
T_x	Total number of time intervals lived beyond age x	$T_x = \sum_{z=x}^{\infty} L_z$
e_x	Further expectation of life at age x	$e_x = T_x/l_x$

3.3.5 Reproductive rates

Fecundity is defined as the reproductive output of an individual under ideal circumstances. Fertility is defined as the actual reproductive performance under prevailing environmental conditions. Fertility rate (mx) is, by definition, less than the fecundity rate since it is influenced by environmental conditions. Fertility rate is the average number of female offspring produced per female of a given age. Observational studies are required to determine the number of offspring born and the rearing success (providing an estimate of the number of males and females surviving to breeding age).

As per the WHO guidelines (WHO and WSPA 1990, WHO 1987), reproductive data can be collected during dog and cat desexing campaigns or elimination programmes. Typical outcome measures include summary statistics of the numbers of suckling juveniles per lactating female, the proportion of lactating females in a study population, and/or the number of foeuses present in the reproductive tract of gravid females following sterilisation. Data on the owned cat and dog population can be collected by owner survey.

Few studies have reported reproductive parameters of dogs and cats. In the few studies that have been carried out (Schneider & Vaida 1975, Nassar & Mosier 1980, Nassar & Mosier 1982, Nassar & Mosier 1984, WHO 1988, Patronek et al. 1997, New et al. 1999, Kitala et al. 2001, Butler & Bingham 2000, Centonze & Levy 2002, Scott et al. 2002, Nutter et al. 2004) the average number of litters per year ranged from 0.9 to 1.6 for cats and 0.2 to 0.6 for dogs. Average litter sizes for dogs and cats were 4.7 and 4.1, respectively. Fertility rate ranged from 0.14 to 1.4 females per year for dogs and 0.19

Table 3.4: Proportion of intact females, estimated number of litters, litter size, and fertility rate in free-roaming, relinquished, and owned dog and cat populations.

Author and year	Intact females (%)	No. litters	Litter size	Fertility rate	Remarks
Dogs:					
Schneider & Vaida (1975)	52	0.2 (all ages)	–	–	Owned, USA
Nassar & Mosier (1980)	33	–	–	0.14 (young) 0.28 (adult)	Owned, USA
Nassar & Mosier (1984)	23	–	–	–	Owned, USA
WHO (1988)	–	67% had litters	3.9	–	Tunisia
WHO (1988)	–	36% $<$ 1 yr	4.9	–	Ecuador
Patronek et al. (1997)	37	–	–	–	Owned, USA
New et al. (1999)	56	–	–	–	Relinquished, USA
Butler & Bingham (2000)	99	0.6	4.6 (1.0 – 9.0)	1.4	Free-roaming, Zimbabwe
Kitala et al. (2001)	100	54% had litters	5.2	1.3	Free-roaming, Kenya
Kobelt et al. (2003)	25	–	–	–	Owned, Australia
Cats:					
Schneider & Vaida (1975)	35	0.9 (all ages) 1.6 (1 – 3 yrs)	–	81	Owned, USA
Nassar & Mosier (1982)	41	–	–	0.49 (young) 0.26 (adult)	Owned, USA
Nassar & Mosier (1984)	14	–	–	0.09 (young) 0.19 (adult)	Owned, USA
Patronek et al. (1997)	20	–	–	–	Owned, USA
New et al. (1999)	41	–	–	–	Relinquished, USA
Centonze & Levy (2002)	30	–	–	–	Free-roaming, USA
Scott et al. (2002)	98	–	3.6 (1.0 – 8.0)	–	Free-roaming, USA
Nutter et al. (2004)	–	1.4	3.0 (1.0 – 6.0)	–	Free-roaming, USA

to 0.49 females per year for cats. Details of reproductive rates reported in the literature are provided in Table 3.4.

Although numerous studies have been carried out to quantify aspects of cat and dog reproductive efficiency, variations and inconsistencies in both the collection and analysis of data make comparisons among studies difficult. Although faults exist in the various methods adopted to quantify reproductive efficiency (e.g. difficulties associated with obtaining samples that are truly representative of the target population) we should accept the fact that perfect methodologies may not be possible in free-roaming dog and cat populations. When using parameter estimates from the literature sensitivity analyses should be conducted to provide some reassurance of the robustness of the inferences made.

3.4 Population models for dogs and cats

3.4.1 The Leslie matrix

Matrix population models are one of the primary tools used in wildlife management to estimate future population growth, explore population dynamics, and to develop management plans for endangered species. Leslie developed a matrix model that is analogous to the exponential equation (Section 3.1) used to describe change in population age structure over time (Leslie 1945, Leslie 1948). The matrix approach allows age structure and total population size over time to be estimated.

A Leslie matrix is comprised of two parts. The first is called a transition matrix which defines the survival and fertility of the population. If there are k age classes within the population the dimensions of the transition matrix is $(k + 1) \times (k + 1)$. The second part is a vector specifying the numbers of animals in each of the k classes. The length of the vector is $(k + 1)$.

The transition matrix is comprised of: (1) age-specific fertilities along the first row, m_k; (2) age-specific survival probabilities along the subdiagonal, pk; and (3) zeros everywhere else. The age-specific fertility estimates run across the top line of the matrix because they give the transition to the 0^{th} class. The age-specific survival probabilities run down the sub-diagonal one step below the principal diagonal, because there is a transition one step down the column vector at each stage. All other elements of the matrix are zero, because they refer to biologically implausible transitions. The age-specific survival probabilities (because they are probabilities) vary between 0 and 1. The age-specific fertility estimates take on values that are greater than or equal to zero and have no upper bound.

The transition matrix has $(k + 1)$ latent roots. The trace of the matrix is equal to the sum of the elements of the principal diagonal of the matrix. As m_0 (the fertility of the youngest class) will normally be zero, the sum of the roots will be zero. Provided there is at least one non-zero m in addition to m_k, no other root will be of the same modulus as the dominant, so the population will stabilise to a distribution given by the dominant latent vector. The rate of increase of the population will be given by the dominant latent root, termed λ.

Although matrix population models have been widely used in wildlife populations, their use in domestic animal populations has been limited. This method was used in dogs and cats for the first time by Nassar & Mosier (1980) and Nassar & Mosier (1982) to determine the dynamics of the dog and cat population in Kansas, USA (Nassar & Mosier 1980, Nassar & Mosier 1982). The same method was applied by the same authors to a study of dog and cat populations in the greater Las Vegas area by Nassar & Mosier (1984). Each of these studies involved discrete time model with discrete age scale and age dependent birth and survival rates.

Analysis of age specific birth and survival rates and the age distribution in the pet population of dogs and cats in Manhattan, Kansas, showed that rate of population change (λ) was 0.98 for dogs (Nassar & Mosier 1980) and 1.18 for cats (Nassar & Mosier 1982). This means that under the specified rates of birth and death the size of the dog population was estimated to be stable whereas the cat population was estimated to be increasing by approximately 18% per year. Similar studies for dog and cats population in the Las Vegas area reported λ to be close to 1 (Nassar & Mosier 1984). These authors attributed the low rate of population change to a high rate of neutering (77% for dogs and 86% for cats) and a high rate of euthanasia in those animals presented to humane shelters (Nassar & Mosier 1980, Nassar & Mosier 1982, Nassar & Mosier 1984).

3.4.2 The Lefkovitch modification of the Leslie matrix

Lefkovitch (1965) noticed that for many organisms the yearly fertility and survivorship functions remain relatively constant once adulthood was reached. Lefkovitch proposed the use of ‘stage classes’ in Leslie matrices (e.g. juvenile, young adult, and adult) instead of age classes. Lefkovitch showed that in spite of aggregating data in this way the value of λ is conserved. The stage structured model is particularly useful for free-roaming dogs or cats where accurate estimates of age may not be available.

Andersen et al. (2004) used a stage structured matrix population model to estimate the efficacy of euthanasia versus the efficacy of a trap-neuter-return program for management of free-roaming cats. Vital rates were gathered from published studies of free-roaming cats in an urban environment, with preference given to unmanipulated populations. Given the variability of the vital rate data, low and high extremes of parameter estimates and all combinations of extreme values were used in the analysis. Andersen et al. (2004) used stage-structured models with two stages: individuals less than 12 months of age (juveniles) and individuals greater than 12 months (adults). The model considered only the female population; this is appropriate if the population is not mate-limited or if the vital rates of the two sexes are identical.

Reproduction rates in cats are relatively well documented, allowing stage structured birth rates for juvenile and adult cats to be calculated. The average litter size ($\pm$ SD) is 3.6 ($\pm$ 0.2) offspring per year. The average number of litters per year ranges from 1.1 to 2.1 and sex ratio is 50:50. Average age at first conception is 212 days. Based on these estimates the fecundity of adult female cats is equal to the product of the number of kittens per litter, the number of litters per year, and the sex ratio at birth. Thus, the lower bound of a fecundity estimate for cats will be $3.6 \times 1.1 \times 0.5 = 2$ female offspring per year; and the corresponding upper bound $3.6 \times 2.1 \times 0.5 = 4$ female offspring per year. Juvenile females have a reduced mean fecundity because most are prepubertal. To account for this fecundity in juveniles is reduced by a factor of (365 - 212) / 365, yielding 1.0 – 1.6 female offspring per year.

Survivorship in dogs and cats (particularly the differences in survival among owned and free-roaming animals) has not been thoroughly documented. Survival rate estimates for adult dogs include 33% survival over a 42-month period and 67% survival over an 18-month period. The geometric probability distribution can been used to convert these data into annual survival probabilities. If P is the probability that an individual will die by time t the expression for S, the per-time-unit survival rate is:

$$S = exp(ln[1 - P]/t) \tag{3.10}$$

If the probability of survival over 42 months is 0.33, the probability of death over the same time period is 0.67. From Equation 3.10 the probability of survival per month is 0.97, equivalent to an annual survival probability of 0.73 (i.e. 0.97 raised to the 12th power). Similarly, a monthly survival probability of 0.98 results from a survival probability of 0.67 over an 18-month period (P = 0.33 and t = 18) equivalent to an annual survival probability of 0.77. Using the two estimates of adult survival, the estimated annual survival rate for adult dogs is 0.73 – 0.77.

3.4.3 Estimation of population size using demographic data

Nassar & Mosier (1991) applied a statistical model to estimate the size of the US pet population using census data. This model was based on the probability of a household owning 1 or 2 dogs according to the type of household (owned or rented) and to the number of residents (1, 2, 3, or 4 or more people per household). Two methods were used to predict the number of households in each of the 8 categories. Firstly, a quadratic regression model was fitted to the actual number of households in each category (obtained from the USA Census of Housing for the years 1950 – 1985) and this model was used to predict the number or percentage of households in each category for 1990, 1995, and 2000. For the second method a quadratic regression model was fitted to predict the average number of people per household for the years 1990, 1995, and 2000. The total projected number of households was obtained by dividing the projected population size by the average number of people per household. The projected number of households in each of the 8 categories was obtained by allocating the total projected number of households according to the percent of each category, as determined from method 1. The total number of dogs was calculated from the projected number of households in each category and the probabilities of owning 1 or 2 dogs. The projected number of cats were obtained by multiplying the projected number of households in each of four categories (those with 1, 2, 3, or 4 or more people per household) by the percentage of cat-owning households to give the total number of cat owning households. This total number was multiplied by the average number of cats per household (n = 1.97 for cats) to give the total number of cats. The projected numbers for dogs and cats for four regions were obtained by multiplying the projected number of households for a region (obtained from projected human population size for that region and the average number people per household) by the percentage of cat or dog owning households for that region to give the total number of households owning cats or dogs.

Applying this method, estimates of the size of the dog and cat population in the USA were made for the years 1990, 1995, and 2000. According to Nassar & Mosier (1991) population projections of this type are reliable due to the fact that they are based on predictor variables (household type and the number of people per household) readily available from census data.

3.4.4 Compartmental models

Nassar & Fluke (1991) developed what they term a community pet population model to evaluate programmes designed to reduce the numbers of animals presented to humane shelters for euthanasia. A community pet population was assumed to be composed of animals in the owned, free-roaming, feral, and sheltered state. These four sub-populations interacted to form a network. When reproductive status was considered (entire versus neutered) Nassar & Fluke (1991) considered the population to be a composite of eight sub-populations. Different rates may be assigned to different pathways (the transition from entire to neutered, and from one state to another). These rates were derived from data from community and shelter population studies or from survey data. Obtaining the rate for each pathway allowed changes in population size and structure over time to be predicted.

An attractive feature of this modelling approach is that it can be used to forecast population growth as well as evaluating the effect of different policies or programs within each sub-population. The major disadvantage of this approach is differentiating between free-roaming and feral animals as it will be difficult to make a clear distinction between these two sub-populations.

3.4.5 Other models

Baldock et al. (2003) developed a model based on life tables to predict the size of the Australian cat population from 1995 to 2005. The annual uptake rate of kittens into households was assumed to be constant from year to year. This rate was calculated using the number of cats less than one year of age in 1995 divided by the total population of cats estimated to be present in 1994. The number of cats less than one year old taken up by households in each subsequent year was then calculated by multiplying the constant annual uptake rate by the total number of cats in the population in the preceding year. The probability of surviving from one year to another was estimated for each age group such that result fitted the known population age structure that was measured in a survey undertaken in 1995.

Baldock et al. (2003) developed their model using a proprietary spreadsheet package. To account for uncertainty in parameter estimates Monte Carlo simulations were performed using @RISK (Palisade Corporation, Ithaca, NY) to generate a band of uncertainty in the predictions of the future population size. A beta pert probability distribution was used to model the survival probability for each age-class, with the estimate from the survey data being used as the most likely value, and minimum and maximum values for the distribution being the most likely values plus and minus 5%, respectively. For each year model output provided the mean, minimum, and maximum estimate of the predicted population size. Baldock et al. (2003) assumed that the uptake into the households of cats one year or older and the number of cats surviving greater than 20 years of age was negligible.

3.5 Conclusion

In Chapter 2 the major problems arising from an overpopulation of free-roaming dogs and cats was reviewed and different techniques that may be used to control dog and cat populations discussed. Although a variety of control methods exist, the full effectiveness of intervention strategies tend not to be realised despite tremendous efforts by government and non-government humane organisations, and the community. This occurs for several reasons including: (1) difficulties in quantifying the magnitude of the problem, and quantifying the responses to interventions; and (2) disagreement among stakeholders concerning the best way to tackle the problem. Recognising this, modeling is suggested as a method for objectively evaluating combinations of control methods, allowing intervention strategies to be more objectively compared. This chapter has outlined has outlined some of the basic techniques for modeling population growth with special reference to dogs and cats. It also reviewed different techniques that have been used to estimate various parameters which are essential model inputs.

CHAPTER 4

A description of the free-roaming dog and cat population in the Wellington region

4.1 Introduction

Free-roaming dogs and cats impose a burden on public health resources through the transmission of zoonotic agents, particularly rabies (WHO and WSPA 1990, Dar & Alkarmi 1997, Robertson & Thompson 2002, Woldehiwet 2002, Acha & Szyfres 2003, Konno et al. 2003, WHO, FAO, and OIE 2004, Bingham 2005, Hemachuda 2005, Hunter & Thompson 2005, Kahn 2006, Kilic et al. 2006). In developed countries the greatest impact of free-roaming animals on public health arises from bite injuries (Langley 1992, Weiss et al. 1998, Talan et al. 1999, Overall & Love 2001, Baldock et al. 2003, Peters et al. 2003, Feldman et al. 2004, Marsh et al. 2004, Fevre et al. 2005, Keuster et al. 2005) and the incidence of bite injuries necessarily increases when unsupervised dogs and cats are numerous. The impact of free-roaming dogs and cats on wildlife due to predation and spread of infectious disease is also of concern (Patronek et al. 1997, Cleaveland et al. 2000, Butler et al. 2004, Manor & Saltz 2004). In New Zealand, cats and dogs have been implicated in the decline of populations of native skinks (Norbury 2001) and the brown and greated spotted kiwi (McLennan et al. 1996). Just as important are issues related to animal welfare as free-roaming animals are often the victim of vehicular collisions and fights between themselves and other animal species (Beck 1975, Jochle 1991, Patronek 1998, Levy et al. 2003).

Given the range of problems associated with the presence of excess numbers of free-roaming animals in urban and rural environments, it makes sense that control activities are applied to reduce both the size of existing populations and to reduce the rate of population growth. In New Zealand organisations such as the Royal New Zealand Society for the Prevention of Cruelty to Animals (RNZSPCA) fulfil this role using resources largely derived from donations from the public with smaller amounts received from charitable trusts and government grants.

Identifying temporal and spatial patterns of free-roaming dog and cat captures in a given area is a logical first step towards increasing the efficiency of control activities. Knowing when and where to look for free-roaming animals should allow provide more focus to control activities, allowing the number of animals captured to be maximised for a finite level of resource. In spite of the magnitude of the free-roaming dog and cat problem in both developed and developing countries throughout the world there are relatively few reports in the literature that quantify the association between numbers of free-roaming animals and temporal, spatial, and physical factors. Beck (1975) and Font (1987) reported higher densities of free-roaming dogs in low-income areas in Baltimore USA and in Valencia, Spain, respectively. Kato et al. (2003) compared the free-roaming dog population in Kathmandu, Nepal with the free-roaming dog population in Okayama, Japan and noted that there was a higher density of free-roaming dogs in Nepal compared with Japan. The higher density of dogs in Nepal was thought to be associated with availability of food, including the presence of street garbage and the tendency of people to feed unowned dogs. Although these studies have identified associations applicable to their respective region of study, the ability to draw the same inferences in a New Zealand setting is limited given differences in society structure, species mix (numbers of dogs relative to cats), and the prevalence of pet ownership.

In this paper we present a descriptive epidemiological analysis of data collected by the Wellington Society for the Prevention of Cruelty to Animals (SPCA) from July 1999 to February 2006. Our aims were three-fold: (1) describe the numbers of dogs and cats presented to the shelter throughout the study period; (2) describe the spatial distribution of dog and cat submissions to the shelter between 1999 and 2006; and (3) evaluate the relationship between submission density and human population density, socioeconomic deprivation, and block-level land use.

4.2 Materials and methods

The Royal New Zealand Society for the Prevention of Cruelty to Animals is a voluntary organisation which, through its district branches, encourages the humane treatment of animals and prevention of cruelty that may be inflicted upon them (RNZSPCA 2004). The Wellington SPCA is a member of the RNZSPCA and operates two animal shelters, one in Newtown (close to the Wellington central business district, Figure 4.1) and the other in Waikanae (to the north of the city, approximately 50 km from the central business district). Both shelters provide a range of services for animals and the community including provision of first aid treatment following motor vehicle (and other) accidents, investigation of complaints of abuse, re-homing of animals, and fee-for-service medical and surgical facilities for animals presented for treatment by the general public. Since July 1999 the Wellington SPCA has recorded details of dogs, cats, birds, and other animal species presented to the shelter in a relational database. Details recorded for each submission include species, breed, age (if known), reproductive status (entire or desexed), date of entry to the shelter, details of where the animal was found (street and suburb), reason for entry, and outcome (euthanased, re-homed, or returned to owner). For animals presented to the shelter by members of the public, address details of the individual making the submission are recorded.

Data from the Wellington SPCA database were screened for proper coding and missing values. The age at capture (in days) for each animal entering the shelter was derived from recorded case details or estimated on the basis of a qualitative assessment of age at the time of submission. Age for those subjects described as pups (or kittens), juveniles, adult, or aged were estimated by drawing a number from a uniform distribution with a lower and upper bound of 0 and 186, 187 and 365, 366 and 3650, and 3651 and 7302, respectively. On the basis of details provided by the person making the submission, animals were classified as either surrendered (that is, animals unwanted or presented to the shelter as a result of a complaint by a member of the public) or free-roaming (animals found in a public place irrespective of the level of care and level of supervision imposed). The free-roaming group was further classified into those animals that were owned (abandoned or lost) or un-owned (wild or stray). Counts of animals entering the shelter per month, stratified by species were plotted as a function of calendar date and the total number of submissions for each month plotted as frequency histograms. Frequency histograms of the counts of young ($\leq$ 6 months) and mature ($>$ 6 months) dogs and cats presented to the shelter each month were compared.

To describe the spatial distribution of dog and cat submissions we randomly assigned each submission an easting and northing coordinate within the boundaries of the suburb in which the animal was found. A kernel intensity surface, showing the number of dog and cat submissions per square kilometre based on a regular grid of 200 $\times$ 200 cells was calculated using the `splancs` package (Rowlingson & Diggle 2006) in R (R Development Core Team 2006). The bandwidth parameter for the kernel function (controlling the degree of smoothing of the estimated intensity surface) was fixed at 0.9 km and was calculated using the normal optimal method (Bowman & Azzalini 1997). Mesh block population counts from the 2001 New Zealand Census of Population and Dwellings (Statistics New Zealand 2001) were used to generate easting and northing coordinates for individuals within their respective mesh block. A kernel intensity surface, showing human population per square kilometre was calculated using the `splancs` package using the methodology described above. The relationship between the number of humans per square kilometre and the number of dog and cat submissions per square kilometre at the mesh block level was assessed using pairwise scatterplots.

Details of the place of residence of members of the public from the Miramar study area (Figure 4.1) who submitted animals to the shelter were geocoded by matching details in the SPCA database with address points available in the LINZ core record system (Land Information New Zealand 2007). The association between submitter intensity (expressed as the number of submitters per square kilometre calculated for each cell of a 200 $\times$ 200 regular grid) and mesh block deprivation index (as measured by the 2001 New Zealand Deprivation index, Salmond et al. 2006) was assessed. The New Zealand Deprivation index ranges from 1 to 10, with a score of 10 given to the most deprived areas. The distribution of submitter intensity estimates for each mesh block of a given deprivation score were plotted as box and whisker plots.

To investigate the hypothesis that the intensity of submitters was higher in areas adjacent to forest or recreational land we used an areal photo (Land Information New Zealand 2007) to classify each of the 258 mesh blocks that comprised the Miramar study area according to the presence or absence of forest and recreational land area. Blocks of each land area classification (forest and recreational land positive and negative) were considered in turn and the distribution of submitter intensity estimates plotted as box and whisker plots.

4.3 Results

A total of 3992 dogs and 14343 cats were processed by the Wellington SPCA from 1 July 1999 to 28 February 2006 (inclusive). Counts of dogs and cats presented to shelter as function of calendar date are shown in Figure 4.2. In addition to the distinct seasonal trend evident for cats, Figure 4.2 shows a progressive decrease in the number of dogs and cats submitted to the shelter throughout the study period. Counts of the number of dogs and cats submitted to the shelter per month (for the entire study period) are shown in Figure 4.3. Consistent with Figure 4.2, Figure 4.3 show a marked seasonal variation in cat submissions coinciding with the feline breeding season. No obvious seasonal pattern was evident for dog submissions.

Kernel smoothed intensity surfaces showing the distribution of human population density and the distribution of dog and cat submissions per square kilometre are shown in Figures 4.4a and 4.4b, respectively. Predictably, the highest densities of dog and cat submissions over the seven year study period were in the Newtown area. Density estimates are recorded at the mesh block level, using details of animals submitted to the Wellington SPCA shelter from 1 July 2001 to 30 June 2002 (inclusive) and human population counts from the 2001 New Zealand census. There was a positive relationship between human population density and dog and cat submission density for the period July 2001 to June 2002 (Figure 4.5).

A choropleth map showing mesh block level deprivation index for the Miramar study area is shown in Figure 4.6a. A choropleth map of block level land use is shown in Figure 4.6b. The corresponding intensity plot of the number of residences submitting animals to the shelter per square kilometre is shown in Figure 4.6b. The density of residences making submissions to the shelter increased with increases in mesh block deprivation score (Figure 4.7). There was no obvious relationship between block level land use and submitter density (Figure 4.8).

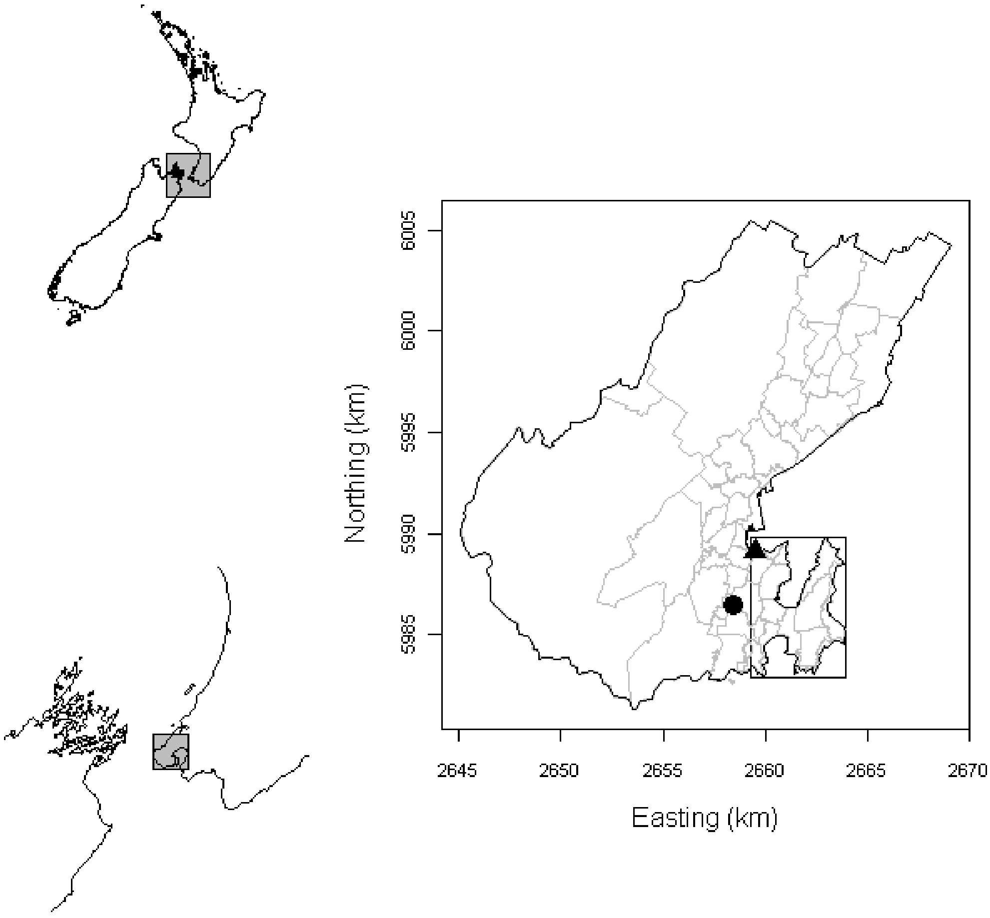


Figure 4.1: Map showing the boundaries of the suburbs that comprise the greater Wellington region, the Wellington central business district (▲), and the Wellington SPCA shelter, in Newtown (●). The boxed area in the map on the right shows the boundaries of the Miramar study area.

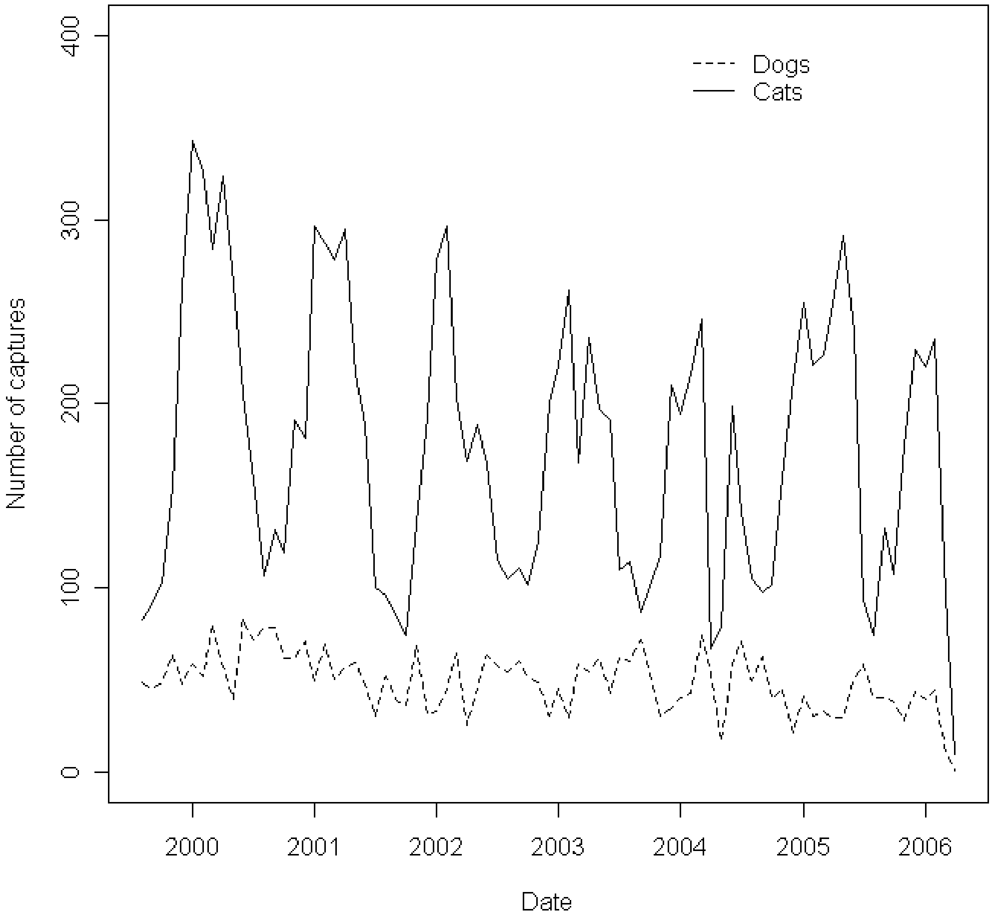
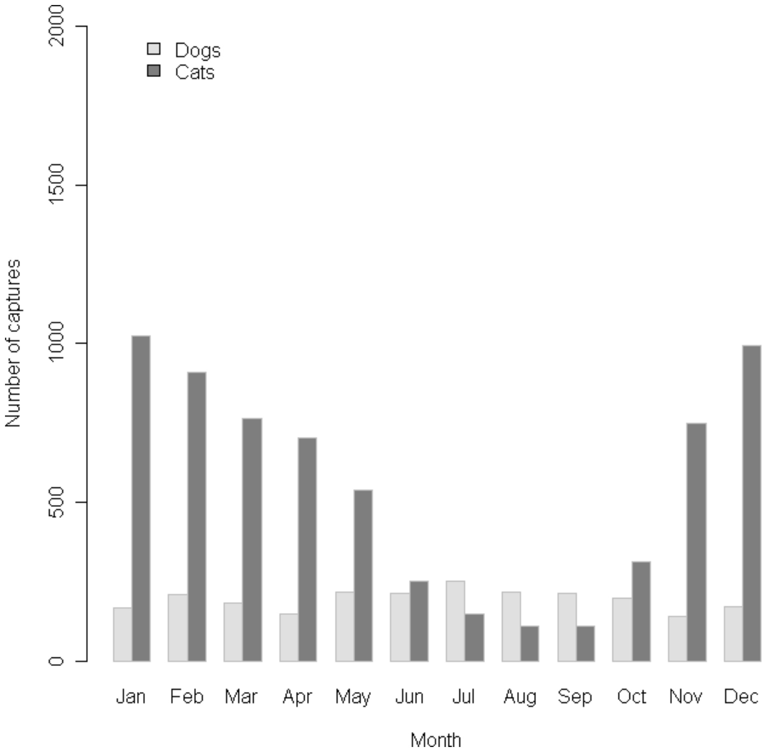
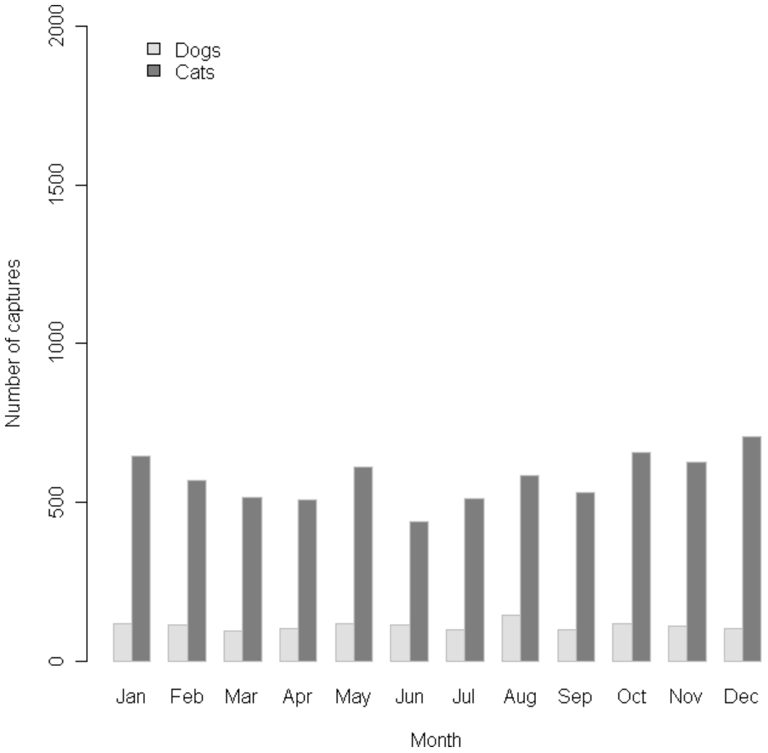


Figure 4.2: Line plot showing the number of cats and dogs presented to the SPCA shelter from July 1999 to February 2006 as a function of calendar date.



(a)



(b)

Figure 4.3: Frequency histograms showing the number of dogs and cats presented to the SPCA shelter by calendar month, July 1999 to February 2006: (a) animals ≤ 6 months of age; (b) animals > 6 months of age.

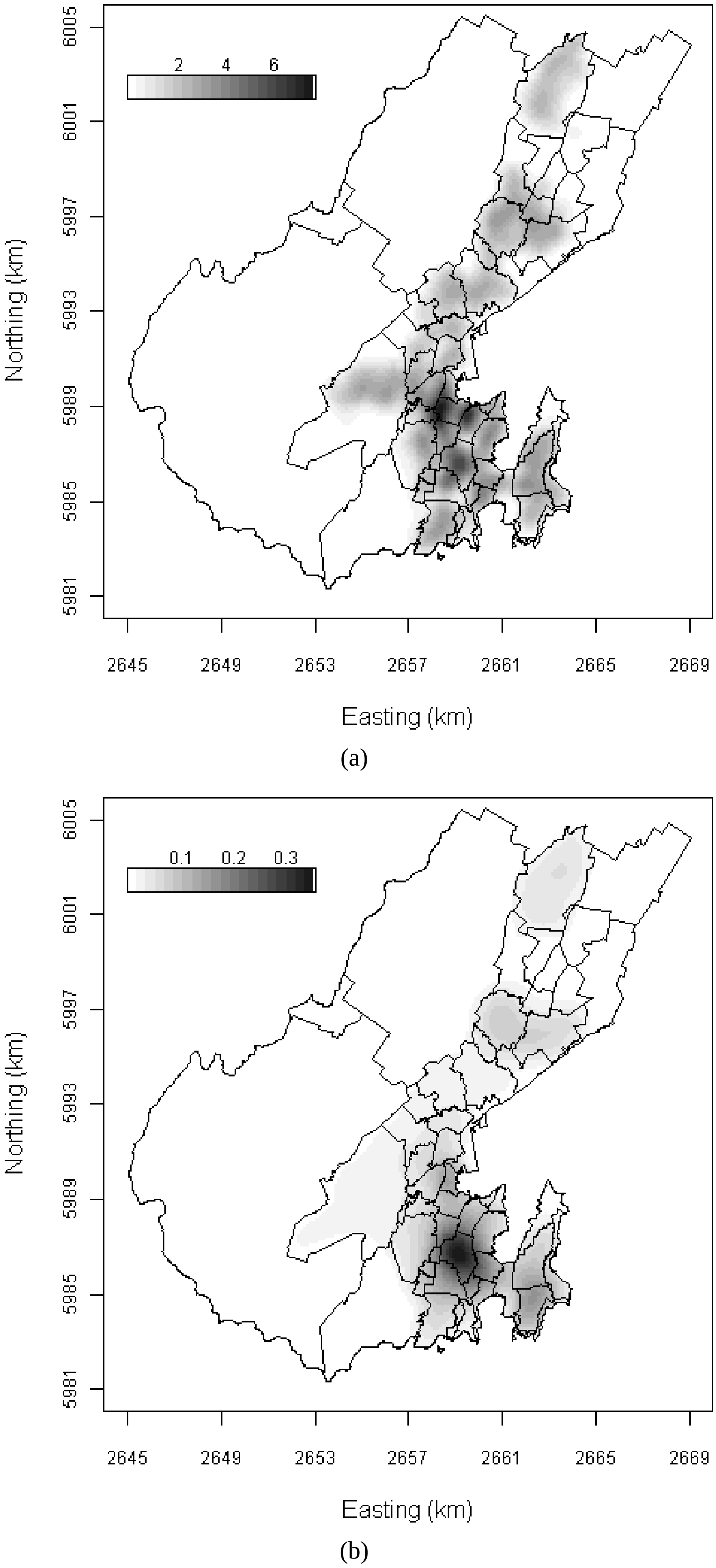


Figure 4.4: Image plots showing: (a) human population density (population per square kilometre, × 1000); and (b) the number of dog and cat submissions per square kilometre (× 1000), July 1999 to February 2006.

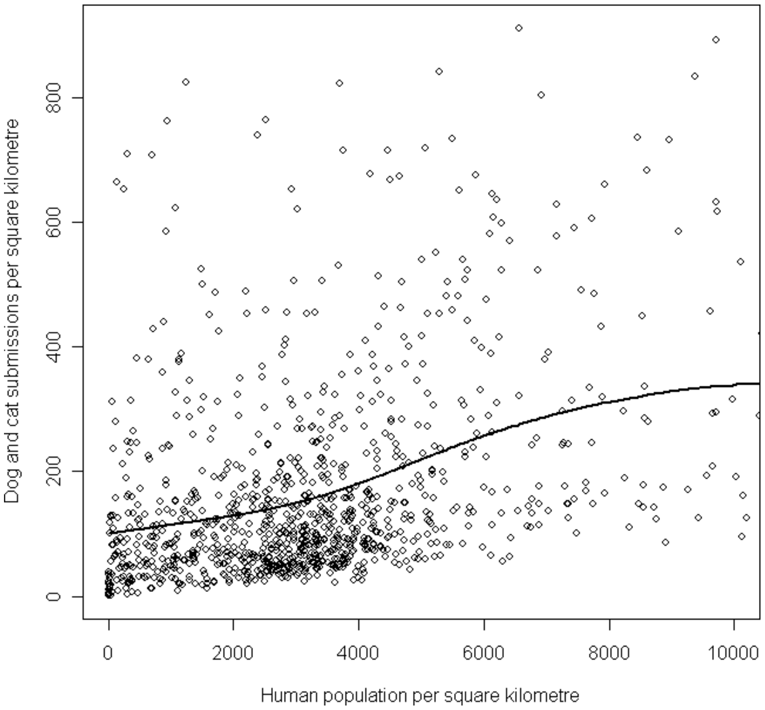
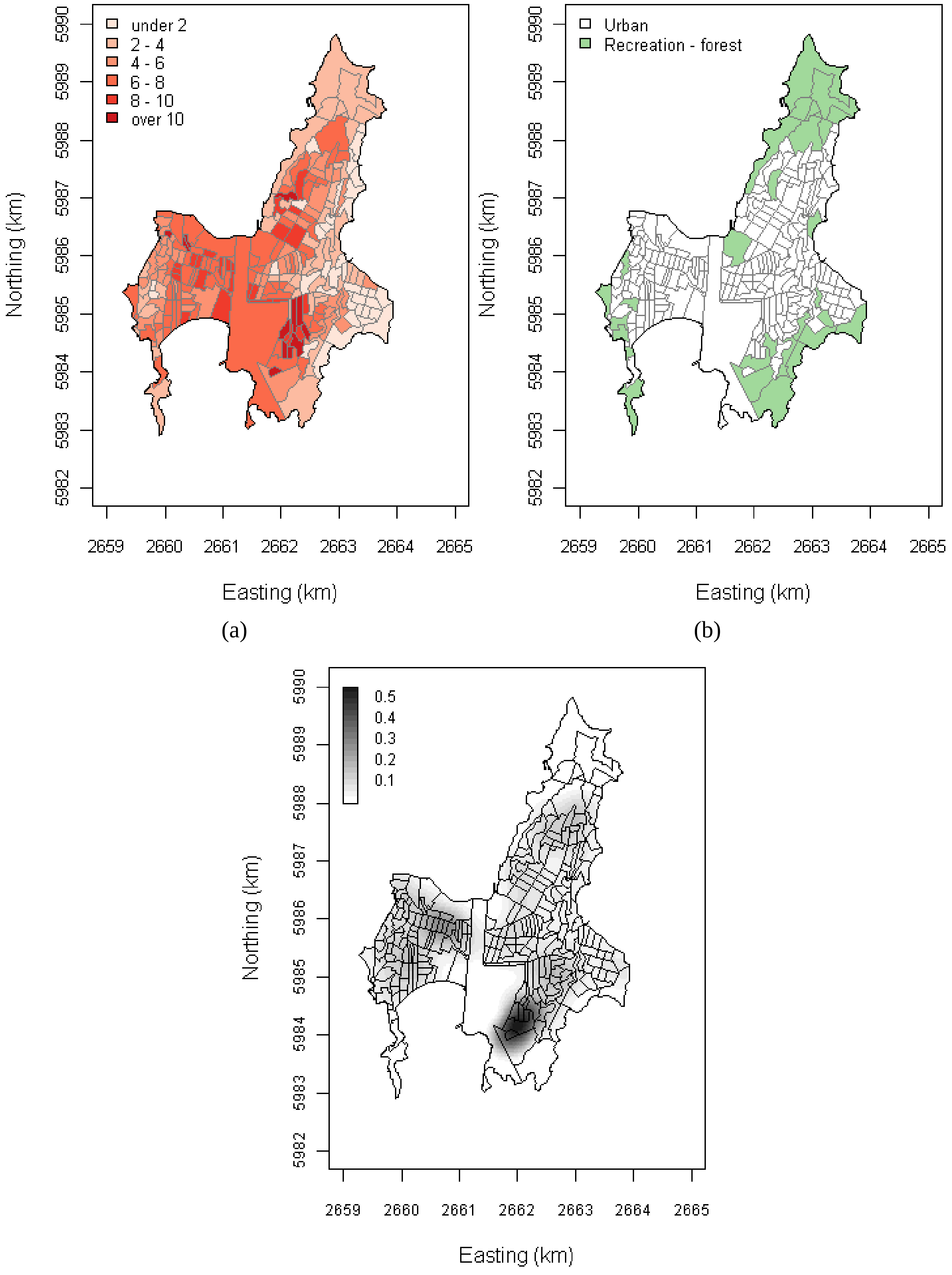


Figure 4.5: Scatterplot showing the number of dog and cat submissions per square kilometre as a function of human population density. Dog and cat density estimates are expressed at the mesh block level using details of animals submitted to the Wellington SPCA shelter from 1 July 2001 to 30 June 2002 (inclusive). Human population density estimates are derived from the 2001 New Zealand Census of Population and Dwellings. The solid line represents a smoothed spline fitted to the data.



(a)

(b)

(c)

Figure 4.6: Dog and cat submissions to the Wellington SPCA shelter from Miramar, July 1999 to February 2006: (a) choropleth map of block level deprivation index, (b) choropleth map of block level land use, and (b) image plot showing the number of residences submitting dogs and cats to the shelter per square kilometre.

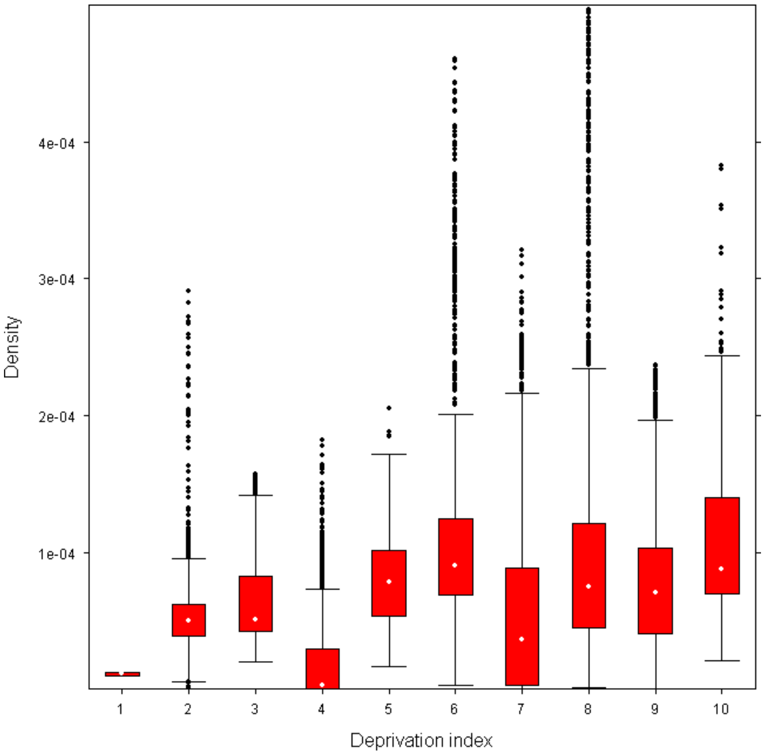


Figure 4.7: Box and whisker plot showing the number of residences submitting dogs and cats to the Wellington SPCA shelter per square kilometre as a function of mesh block deprivation index, July 1999 to February 2006.

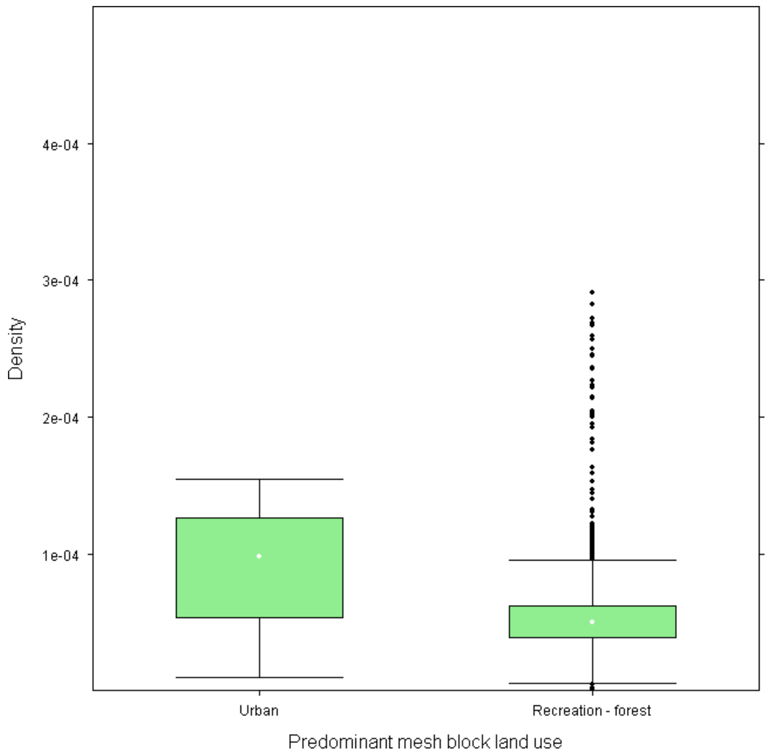


Figure 4.8: Box and whisker plot showing the number of residences submitting dogs and cats to the shelter per square kilometre as a function of mesh block land use classification, July 1999 to February 2006.

4.4 Discussion

This is a descriptive analysis of the temporal and spatial features of animals presented to the Wellington SPCA from July 1999 to February 2006. Throughout the study period a total of 3992 dogs and 14343 cats were presented to the shelter with an average of 11 dogs (range 1 – 41) and 40 cats (range 3 – 104) processed in any given week. Over time there was a progressive decrease in the number of dog and cat submissions: 1970 dogs and cats were processed by the shelter from January to December 1996 compared with 1452 for the equivalent period in 2005. In the absence of other animal welfare organisations being set up during the study period (providing an alternative collection site for unwanted animals) and assuming the intensity of recruitment of animals to the Newtown shelter remained constant throughout the study period we attribute this decrease to two factors: (1) ongoing education campaigns by the SPCA to encourage members of the public to neuter their pets (for example, the SNAP programme, RNZSPCA 2005), and (2) dog control measures implemented under the New Zealand Dog Control Amendment Act (New Zealand Government 2003, New Zealand Government 2004).

Within any given year the numbers of animals presented to the shelter varied by species with cats outnumbering dogs by a factor of four (Figure 4.2). A distinct seasonal pattern was evident for cat submissions, with greater numbers of cats (predominantly those less than 6 months of age presented to the shelter from October through to May (Figure 4.3). The greatest number of submissions per month occurred in December and January. It is not obvious from the data if the December and January peak in cat submissions was due to the natural peak of the feline breeding season or due to additional numbers of animals relinquished to the shelter as a result of the summer holiday season (or a combination of these reasons). Assuming that a holiday season effect was present, we propose that the some reduction in the number of cat submissions over this period might be achieved by targeted education programs and by encouraging proprietors of animal boarding facilities to make purchase of their services an attractive option throughout this period, particularly for cat owners.

Our spatial analyses showed that the number of animal submissions per square kilometre varied throughout the greater Wellington region with the highest numbers of submissions per square kilometre in the Newtown area (Figure 4.4b). We assume that the greatest density of submissions from Newtown was due to convenience of the shelter to members of the public in this area. Identifying other animal welfare agencies, their location, and counts of the number of animals processed per year would provide a means for more precisely estimating the total size of the Wellington free-roaming dog and cat population, and allow changes in total population size over time to be more precisely documented. Consistent with other studies (Beck 1975, Font 1987, Butler & Bingham 2000, Kitala et al. 2001) we found that numbers of free roaming animals was positively associated with increases in human population density (Figure 4.5).

To investigate the influence of deprivation on the likelihood of submission to the shelter the Miramar area was selected for detailed analysis. Miramar was thought to be suitable for this purpose because it was geographically isolated from the rest of the study area (due to the presence of Wellington airport separating the peninsular from the rest of the city) and the Wellington SPCA was the only animal welfare provider servicing this region. The kernel intensity plot of the spatial distribution of the residence of members of the public who submitted animals to the SPCA throughout the study period showed variation in submitter density with an area of relatively high submitter density in the south of the peninsular (Figure 4.6b). We identified a positive association between mesh block deprivation index and submitter density, with greater numbers of submitters per square kilometre from coming from areas classified as deprived (Figure 4.7). Assuming the place of residence of those submitting animals to the shelter provided an unbiased estimate of the spatial distribution of free-roaming animals, this finding is in agreement with those of Beck (1975) and Font (1987) who found higher densities of stray and free-roaming animals in low income areas of Baltimore, USA and Valencia, Spain, respectively. We propose that managing control activities at the mesh block level and targeting high population dense, deprived blocks should allow resources to be focussed on areas of greatest need.

We investigated the relationship between the density of submitters and mesh block land use classification on the premise that blocks that were comprised predominantly of forest or recreational land were more likely to support free-roaming animals (in terms of providing access to food), particularly cats. Most forest and recreational land area blocks were associated with a decreased submitter density although there were a number of blocks with relatively high density estimates (indicated by the outliers in the box and whisker plot on the right in Figure 4.8). A means for investigating this hypothesis further would be to record animal capture location more precisely using a global positioning devise and then to relate these locations with more detailed maps of land use. This might then distinguish if animals (particularly cats) are more likely to be caught in or adjacent to forest or areas of recreational land.

This study has provided a starting point for developing strategies to optimise the SPCA's strategy to control free-roaming dogs and cats in Wellington. Good progress has been made, evident by the decrease in the number of dog and cat submissions to the shelter per year from 1999 to 2005. On the basis of the analyses presented in this paper, the following recommendations can be made regarding control of free-roaming animals in this area: (1) cats should be the focus of controls, with intensification of activities prior to the feline breeding season (say from June to September); (2) control activities should target both deprived areas and areas of relatively high population density; and (3) to document progress and to further refine control policies, every effort should be made to record precise details of animal capture location.

CHAPTER 5

Population dynamics of the free-roaming dog and cat population in the Wellington region

5.1 Introduction

Although urban dogs and cats play an important role by providing a valued source of companionship for their owners, the transition of animals from an owned to a free-roaming state imposes a burden on society in a number of ways. A diverse range of zoonotic infections including parasitic, bacterial, viral, protozoal, and fungal diseases can be transmitted from dogs and cats to humans and the risk of transmission is likely to increase in the presence of large numbers of free-roaming animals. Studies have been conducted in a number of countries including the United States (Weiss et al. 1998, Overall & Love 2001, Peters et al. 2003, Feldman et al. 2004, Talan et al. 1999), Belgium (Keuster et al. 2005), Uganda (Fevre et al. 2005), Australia (Baldock et al. 2003), and New Zealand (Langley 1992, Marsh et al. 2004) and have identified a considerable societal burden arising from dog bite injuries to humans. What is of additional concern is that many dog bite injuries do not come to the attention of officials unless the person receiving the injury is treated by a registered medical practitioner (Weiss et al. 1998) and so the true cost of dog bite injuries to the community is much higher than the number of cases that are officially reported. As an example, the total number of officially recorded dog attacks on humans (that is, dog attacks requiring treatment by a physician or at a hospital) for 2001 – 2002 in New Zealand was 3435 (Department of Internal Affairs, New Zealand 2003) whereas the number claims relating to dog bite injuries by the Accident Compensation Corporation was 8677 throughout the same period (Department of Internal Affairs, New Zealand 2003). Free-roaming dogs and cats also pose a threat to countries with unique native flora and fauna. They impact on wildlife populations by preying on juveniles and small wild animals (Manor & Saltz 2004). The introduction of free-roaming cats into areas of New Zealand have had a devastating effect on local fauna (e.g. native skinks and kiwi) and have been implicated as one of the primary factors threatening extinction of these species (Norbury 2001, McLennan et al. 1996).

Concern about the impact of free-roaming dogs and cats on the environment, public health, and welfare has led to various efforts to reduce their numbers. In 2003 the total annual expenditure on dog control by the 54 regional councils throughout New Zealand was estimated to be in the order of NZD 20 million per year (Department of Internal Affairs, New Zealand 2003). Methods adopted by councils and welfare agencies include: (1) control of animal productivity through desexing campaigns, (2) the introduction of legislative measures to encourage responsible pet ownership; and (3) strategies to improve the capture efficiency of free-roaming animals. Given the expense of initiating and maintaining these programs it makes sense that a better understanding of the return on investment for each of these activities would allow the mix of control strategies to be optimised, with the ultimate aim of maximising return for every dollar spent.

In this paper we present an analysis of data collected by the Society for the Prevention of Cruelty to Animals (SPCA) Wellington shelter from July 1999 to February 2006. Our aims were to document: (1) demographic details, (2) reproductive status, and (3) the method of disposal for dogs and cats that entered the shelter from July 1999 to February 2006. A further aim was to use the accumulated data to quantify the change in population size throughout the study period and to determine those factors that were most influential in determining population growth. A knowledge of these features is an essential first step for designing and comparing strategies to more effectively control free-roaming animal populations.

5.2 Materials and methods

The Royal New Zealand Society for the Prevention of Cruelty to Animals (RNZSPCA) is a voluntary organisation which, through its district branches, encourages the humane treatment of animals and prevention of cruelty that may be inflicted upon them (RNZSPCA 2004). The Wellington SPCA is a member of the RNZSPCA and operates two animal shelters in the Wellington region: the first in Newtown (close to the central business district, Figure 5.1) and the other in Waikanae (to the north of the city, approximately 50 km from the central business district). Both shelters provide a range of services to the community including provision of first aid treatment to wild and domestic animals following motor vehicle (and other) accidents, investigation of complaints of abuse, re-homing of animals, and fee-for-service medical and surgical treatment for animals presented for treatment by members of the public. Since July 1999 the Wellington SPCA has recorded details of dogs, cats, birds, and other animal species presented to the shelter in a relational database. Details recorded for each submission include species, breed, age (if known), reproductive status (entire or desexed), date of entry to the shelter, details of where the animal was found, reason for entry to the shelter, and outcome (euthanased, re-homed, or returned to owner). For animals presented to the shelter by members of the public full address details of the person making the submission are recorded in addition to details of where the animal was found.

Submission details recorded in the SPCA database for dogs and cats recruited from the Wellington region were screened for proper coding, missing values, and outliers. Age (in days) was derived from details recorded in the database or estimated on the basis of a descriptor variable of age noted at the time of submission. For 6% of submissions (1114 of 17186) the following descriptor variables defined animal age: pup (or kitten), juvenile, adult, and aged. Age for those subjects described as pups (or kittens), juveniles, adult, or aged were estimated by drawing a number from a uniform distribution with a lower and upper bound of 0 and 186, 187 and 365, 366 and 3650, and 3651 and 7302, respectively. On the basis of details provided by the person making the submission, animals were classified as either surrendered (that is, animals unwanted or presented to the shelter as a result of a complaint by a member of the public) or free-roaming (animals found in a public place irrespective of the level of care and level of supervision imposed). The free-roaming group was further classified into those animals that were owned (abandoned or lost) or un-owned (wild or stray).

We used Leslie projection matrices (Leslie 1945, Leslie 1948, Lefkovitch 1965) to estimate the intrinsic rate of growth of the free-roaming dog and cat population serviced by the Wellington SPCA. In the usual situation the Leslie matrix uses summary estimates of age-specific vital statistics (statistics quantifying the rate of reproduction and survival) to project future population growth. Using this approach changes in population structure are given by $n_{t+1} = M \times n_t$, where n_t and n_{t+1} represent the numbers of animals in each age class at times t and $t + 1$, and M is a transition matrix defining the age-specific reproductive rates and survival probabilities acting on the population throughout the study period. A key point is that in this study we express survival in terms of the likelihood of an animal being submitted to the shelter (as distinct from the usual usage of the term, the likelihood of death). One of the outputs from these analyses is an estimate of the intrinsic rate of population growth (λ) derived from the eigenvalues of the population projection matrix. When λ is less than 1 the population is decreasing in size; when λ is greater than 1 the population is increasing, and when λ is equal to 1 the population is static.

The observed data relating to free-roaming dogs and cats were used to derive estimates of the age-specific submission probabilities for each species. Assuming the age structure of the free-roaming dog and cat population was stable we fitted a non-parametric (Kaplan-Meier) survival function to the observed data and plotted the instantaneous hazard of submission as a function of age (in years). For the Leslie projection matrices we applied a beta pert distribution to each of the point estimates of age-specific submission probability to account for uncertainty in our submission estimates. Using the beta pert distribution the most likely value was set to equal the observed submission probability estimate, the minimum value at the observed estimate less 0.10, and the maximum value at the observed estimate plus 0.10.

Age dependent birth rates were estimated as the product of the number of offspring born per litter, the number of litters per animal per year, and the sex ratio at birth. The mean number of offspring per litter was estimated to vary between 3.9 and 4.9 for dogs (WHO 1988, Butler & Bingham 2000, Kitala et al. 2001) and 3.0 and 4.1 for cats (Scott et al. 2002, Andersen et al. 2004, Nutter et al. 2004, Wallace & Levy 2006). Sex ratios were assumed to be consistently 50:50. We assumed at least one litter per female per year for dogs and 1.5 litters per female per year for cats. Age at first conception for both species was 180 days. Based on these values, the fecundity of dogs was estimated as 4.5 $\times$ 1 $\times$ 0.5 = 2.25 female offspring per year and the fecundity of cats was 3.6 $\times$ 1.5 $\times$ 0.5 = 2.7 female offspring per year. Juvenile females have reduced fecundity because most are prepubertal. This reduction is equal to (365 - 180) / 365, which yielded 1.1 and 1.3 female offspring per year for dogs and cats, respectively. Each species were assigned their estimated fecundity rate for 0 to 5 years of age, thereafter fecundity was assumed to be close to zero.

The initial number of animals in each age category in year zero was estimated by dividing the total number of free-roaming animals presented to the Wellington shelter in 2000 by the proportion of animals in each age group (using data derived from the entire study period). The estimated fecundity and submission rates for animals 0 to 10 years of age were used to construct a 10×10 transition matrix. These details were combined with the number of animals in each age class in year zero to provide an estimate of the number of female dogs (or cats) present during each year of a 5 year prediction period. These predictions were compared with the actual counts of animals presented to the shelter from 2001 to 2005. One thousand Monte Carlo simulations were conducted using the spreadsheet add-in @RISK (Palisade Corporation, Ithaca, NY). For each simulation a random draw was taken from the specified beta pert distributions and the estimated population size calculated on each occasion. We report the predictions of population size as point estimates and 95% confidence intervals, computed on the basis of the 1000 Monte Carlo simulations.

To determine which of the vital rates (submission probability or fecundity) had the greatest impact on population growth, elasticity analyses were conducted on the dog and cat population models. Elasticities measure the response of λ to changes in a single vital rate, with the magnitude of the change scaled to the mean of that vital rate. In this context the elasticity provides an estimate of the impact on λ that would be obtained by changing each vital rate by a fixed proportion of its current mean, holding all other vital rates constant (Caswell 2001).

5.3 Results

A total of 3992 dogs and 14343 cats were processed by the Wellington SPCA from 1 July 1999 to 28 February 2006 (inclusive). Population pyramids, showing the age and sex distribution of free-roaming dogs and cats are shown in Figure 5.2. The age distribution of the population was highly skewed towards animals in young age groups: 68% of dogs and 55% of cats were less than 12 months at the time of presentation to the shelter. Compared with dogs, greater proportions of free-roaming cats were from older age groups. The median age at presentation for dogs was 10 weeks (range 1 day to 22 years) and 7 months for cats (range 1 day to 22 years) years for cats. Figure 5.3 shows the instantaneous hazard of submission as a function of age for dogs and cats. The (observed) instantaneous hazard of submission for 0 – 1 year old dogs and cats was 0.85 and 0.81, respectively.

There was an almost equal distribution of males and females in all age classes with an overall sex ratio (male:female) of 0.97:1 for dogs and 0.98:1 for cats (Table 5.1). A greater proportion of animals classified as free-roaming animals were male (1.27:1 for dogs and 1.13:1 for cats, Tables 5.2 and 5.3). The proportions of dogs that were classified as surrendered and free-roaming was similar. In contrast, most of the cats that entered the shelter were free-roaming (10431 of 14343, 73%). Among the free-roaming animals, 99% of dogs (2049 of 2065) and 53% cats (5539 of 10431) were classified as owned. Approximately equal proportions of dogs and cats that entered the shelter were euthanased or re-homed.

Tables 5.2 and 5.3 provide details of the reproductive status of free-roaming dogs and cats greater than 3 months of age. Greater proportions of adults (those greater than 12 months of age) were desexed, compared with juveniles (3 to 12 months of age) for both dogs and cats (dogs χ^2 10.48; df 1; P < 0.01, cats χ^2 288; df 1; P < 0.01). Greater proportions of males were desexed, compared with females (dogs χ^2 12.3; df 1; P < 0.01, cats χ^2 679; df 1; P < 0.01). A greater proportion of cats that were owned were desexed compared with those that classified as free-roaming (χ^2 332; df 1; P < 0.01).

Tables 5.4 and 5.5 provide the age-specific vital statistics for the free-roaming dog and cat populations. The gross reproductive rates (the average number of offspring produced by an individual that lives to senescence) was 10.2 for dogs and 12.2 for cats. The net reproductive rate, R_0 (the average number of female offspring produced by an individual in its lifetime, accounting for removal of animals from the population via submission to the SPCA shelter) was 1.5 and 2.1 for dogs and cats, respectively.

Figure 5.4 shows the actual numbers of free-roaming dog and cats in the Wellington region for the period January 2000 to December 2005 (inclusive). Superimposed on this plot are the total numbers of free-roaming dogs and cats predicted by the Leslie matrix models. The intrinsic rate of population growth (λ) was 0.78 (95% CI 0.56 – 0.94) for dogs and 0.98 (95% CI 0.76 – 1.16) for cats. Assuming the intensity of recruitment of animals to the shelter was constant throughout the study period these findings indicate negative growth in the free-roaming dog population and little or no growth in the free-roaming cat population. Elasticity analyses showed that the intrinsic rate of population growth (λ) was most sensitive to changes in the submission and fecundity rates of younger animals (0 – 2 years) for both dogs and cats (Figure 5.5).

Table 5.1: Dog and cat submissions to the Wellington SPCA shelter, July 1999 to February 2006. Population demographic characteristics.

Characteristic	Dogs (%)	Cats (%)	Total (%)
Age:			
0 – 6 months	2332 (58)	6616 (46)	8948 (49)
6 months – 1 year	392 (10)	1414 (10)	1806 (10)
1 year – 10 years	804 (20)	4543 (32)	5347 (29)
$>$ 10 years	132 (3)	953 (7)	1085 (6)
Unknown	332 (8)	817 (6)	1149 (6)
Total	3992 (100)	14343 (100)	18335 (100)
Sex:			
Male	1907 (48)	6835 (48)	8742 (48)
Female	1961 (49)	6969 (49)	8930 (49)
Unknown	124 (3)	539 (4)	663 (4)
Total	3992 (100)	14343 (100)	18335 (100)
Source:			
Free-roaming owned [a]	2049 (51)	5539 (39)	7588 (41)
Free-roaming un-owned [b]	16 (0.5)	4892 (34)	4908 (27)
Surrendered	1913 (48)	3892 (27)	5805 (32)
Unknown	14 (0.5)	20 (0)	34 (0)
Total	3992 (100)	14343 (100)	18335 (100)
Outcome:			
Died	61 (2)	429 (3)	490 (3)
Euthanised	1738 (44)	7133 (50)	8871 (48)
Reclaimed	373 (9)	871 (6)	1244 (7)
Re-homed	1503 (38)	5860 (41)	7363 (40)
Other	316 (8)	48 (0)	364 (2)
Total	3992 (100)	14343 (100)	18335 (100)

[a] Includes animals lost, abandoned, or submitted to the shelter as a result of a complaint.
[b] Includes strays and wild animals.

Table 5.2: Dog submissions to the Wellington SPCA shelter, July 1999 to February 2006. Reproductive status of free-roaming dogs greater than 3 months of age.

Variable	Desexed (%)	Entire (%)	Total (%)	χ^2	*df*	P
Age:						
Juvenile [a]	8 (3)	245 (97)	253 (100)	10.48	1	< 0.01
Adult [b]	58 (10)	519 (90)	577 (100)			
Total	66 (8)	764 (92)	830 (100)			
Gender:						
Male	51 (11)	413 (89)	464 (100)	12.3	1	< 0.01
Female	15 (4)	351 (96)	366 (100)			
Total	66 (8)	764 (92)	830 (100)			
Source:						
Owned [c]	65 (8)	762 (92)	827 (100)	0.31	1	0.57
Un-owned [d]	1 (33)	2 (67)	3 (100)			
Total	66 (8)	764 (92)	830 (100)			

[a] Dogs 3 – 12 months of age.
[b] Dogs $>$ 12 months of age.
[c] Includes animals lost, abandoned, or submitted to the shelter as a result of a complaint.
[d] Includes strays and wild animals.

Table 5.3: Cat submissions to the Wellington SPCA shelter, July 1999 to February 2006. Reproductive status of free-roaming cats greater than 3 months of age.

Variable	Desexed (%)	Entire (%)	Total (%)	χ^2	*df*	P
Age:						
Juvenile [a]	91 (7)	1237 (93)	1328 (100)	288	1	< 0.01
Adult [b]	1390 (30)	3303 (70)	4693 (100)			
Total	1481 (25)	4540 (75)	6021 (100)			
Gender:						
Male	1221 (38)	1974 (62)	3195 (100)	679	1	< 0.01
Female	260 (9)	2566 (91)	2826 (100)			
Total	1481 (25)	4540 (75)	6021 (100)			
Source:						
Owned [c]	1212 (33)	2511 (67)	3723 (100)	332	1	< 0.01
Un-owned [d]	269 (12)	2029 (88)	2298 (100)			
Total	1481 (25)	4540 (75)	6021 (100)			

[a] Cats 3 – 12 months of age.
[b] Cats $>$ 12 months of age.
[c] Includes animals lost, abandoned, or submitted to the shelter as a result of a complaint.
[d] Includes strays and wild animals.

Table 5.4: Dog submissions to the Wellington SPCA shelter, July 1999 to February 2006. Age-specific vital statistics for free-roaming dogs.

Age (years)	n	l_x	s_x	m_x	$l_x m_x$
0 – 1	2862	1.00	0.07	1.10	1.10
1 – 2	188	0.07	0.70	2.25	0.15
2 – 3	132	0.05	0.57	2.25	0.10
3 – 4	75	0.03	0.91	2.25	0.06
4 – 5	68	0.02	0.82	2.25	0.05
5 – 6	56	0.02	0.89	0.01	0.00
6 – 7	50	0.02	0.90	0.01	0.00
7 – 8	45	0.02	0.56	0.01	0.00
8 – 9	25	0.01	0.72	0.01	0.00
9 – 10	18	0.01	-	0.01	-

n: Number of dogs in age class.
l_x: Proportion of population present at 0 – 1 year of age present at start of interval.
s_x: Proportion of individuals present at age x that are present at age $x+1$.
m_x: Half the number of offspring born to a parent of age x.

Gross reproductive rate: 10.2.
Net reproductive rate (R_0): 1.5.

Table 5.5: Cat submissions to the Wellington SPCA shelter, July 1999 to February 2006. Age-specific vital statistics for free-roaming cats.

Age (years)	n	l_x	s_x	m_x	$l_x m_x$
0 – 1	8831	1.00	0.10	1.30	1.30
1 – 2	905	0.10	0.74	2.70	0.28
2 – 3	671	0.08	0.74	2.70	0.21
3 – 4	499	0.06	0.80	2.70	0.15
4 – 5	400	0.05	0.79	2.70	0.12
5 – 6	317	0.04	0.79	0.01	0.00
6 – 7	249	0.03	0.72	0.01	0.00
7 – 8	180	0.02	0.65	0.01	0.00
8 – 9	117	0.01	0.64	0.01	0.00
9 – 10	75	0.01	-	0.01	-

n: Number of cats in age class.
l_x: Proportion of population present at 0 – 1 year of age present at start of interval.
s_x: Proportion of individuals present at age x that are present at age $x+1$.
m_x: Half the number of offspring born to a parent of age x.

Gross reproductive rate: 12.2.
Net reproductive rate (R_0): 2.1.

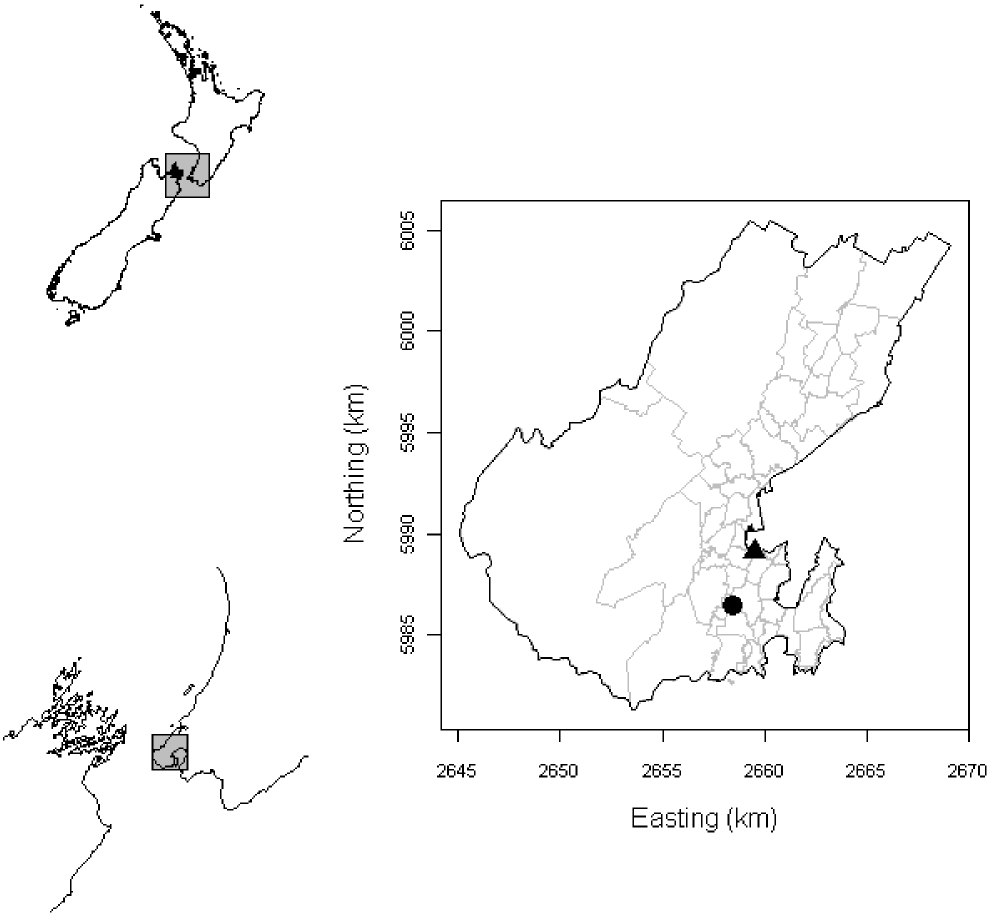
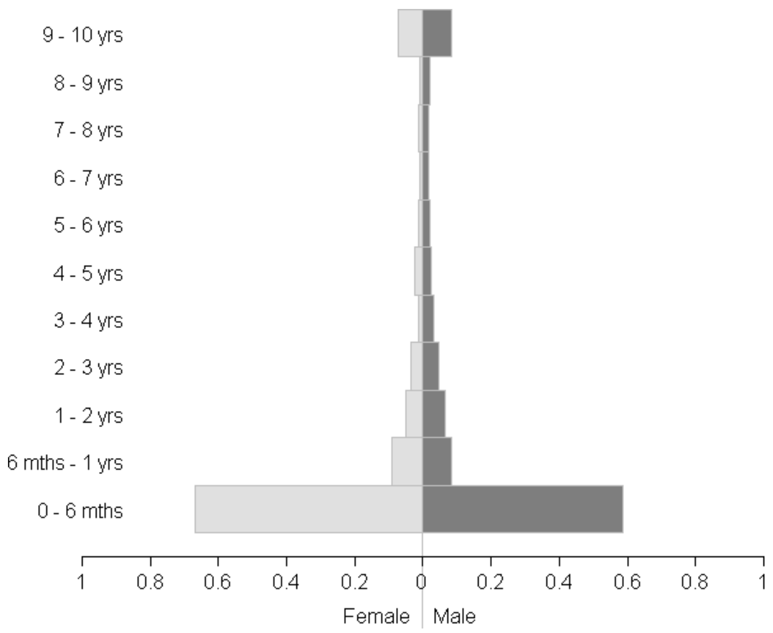
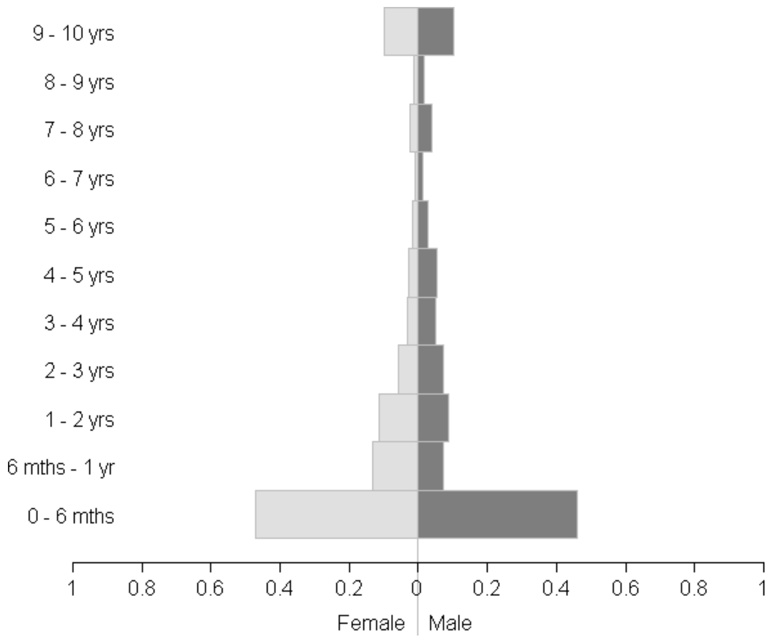


Figure 5.1: Map showing the boundaries of the suburbs that comprise the greater Wellington region, the Wellington central business district (▲), and the Wellington SPCA shelter (●).

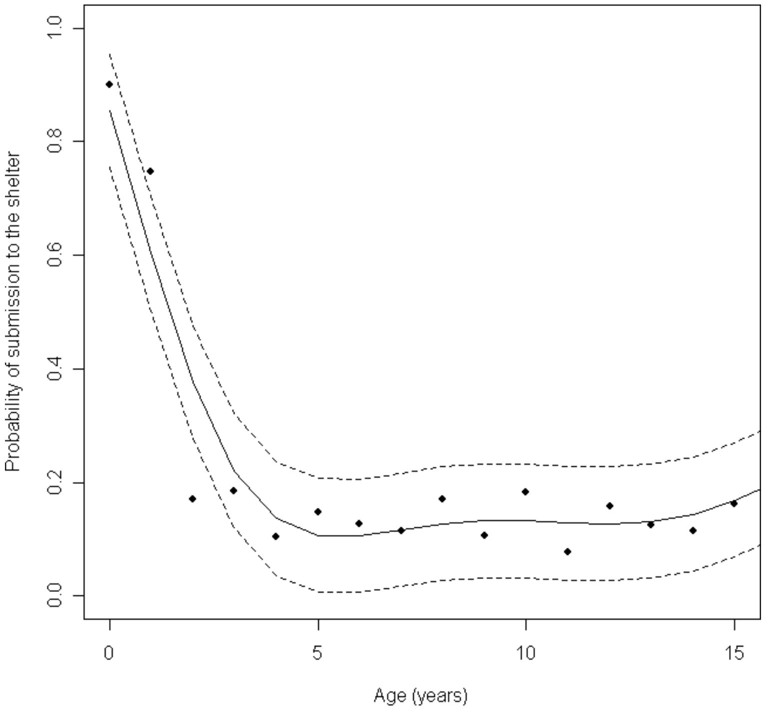


(a) Dogs

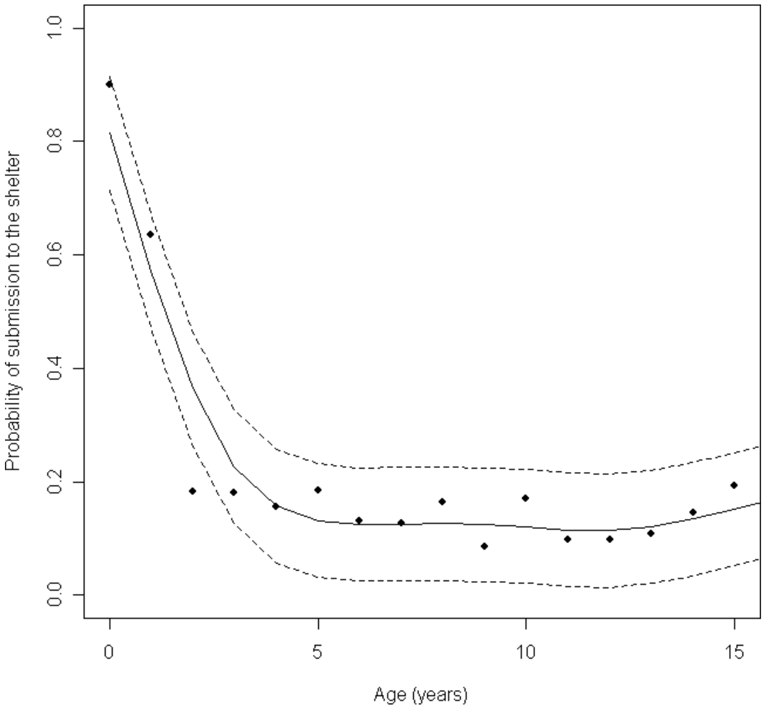


(b) Cats

Figure 5.2: Population pyramids showing the age and sex distribution of free-roaming (a) dogs and (b) cats submitted to the Wellington SPCA shelter, July 1999 to February 2006.

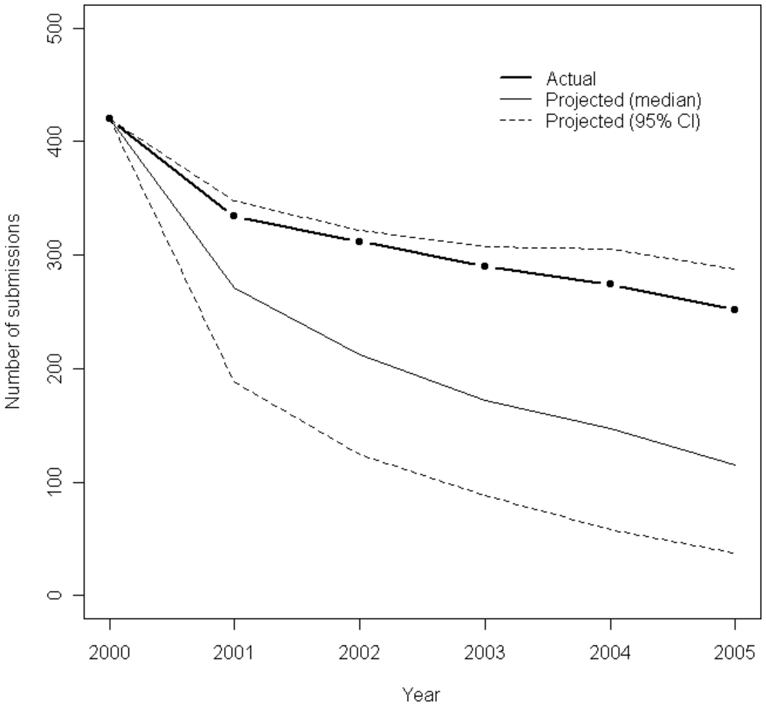


(a) Dogs

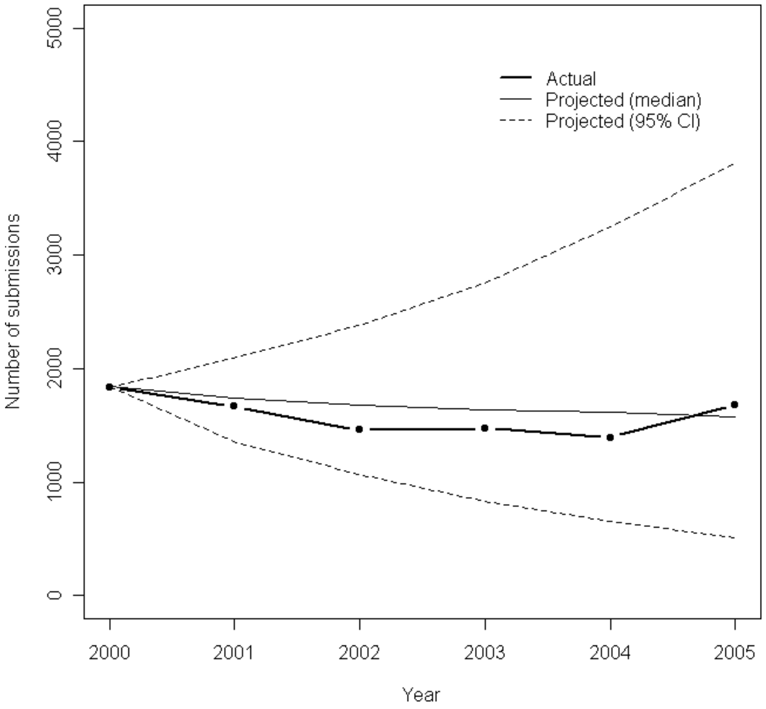


(b) Cats

Figure 5.3: Instantaneous hazard of submission for: (a) free-roaming dogs, and (b) free-roaming cats submitted to the Wellington SPCA, July 1999 to February 2006. In the above plots the solid line represents a smoothed spline fitted to the point estimates of submission hazard (•). The lower and upper dashed lines represent the minimum and maximum estimates of submission hazard, used in the beta pert distributions described in the text.

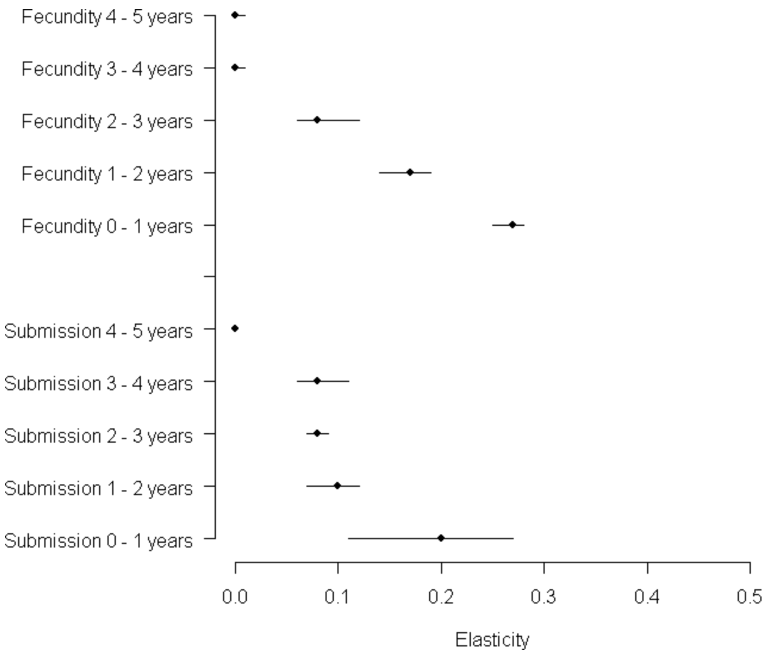


(a) Dogs

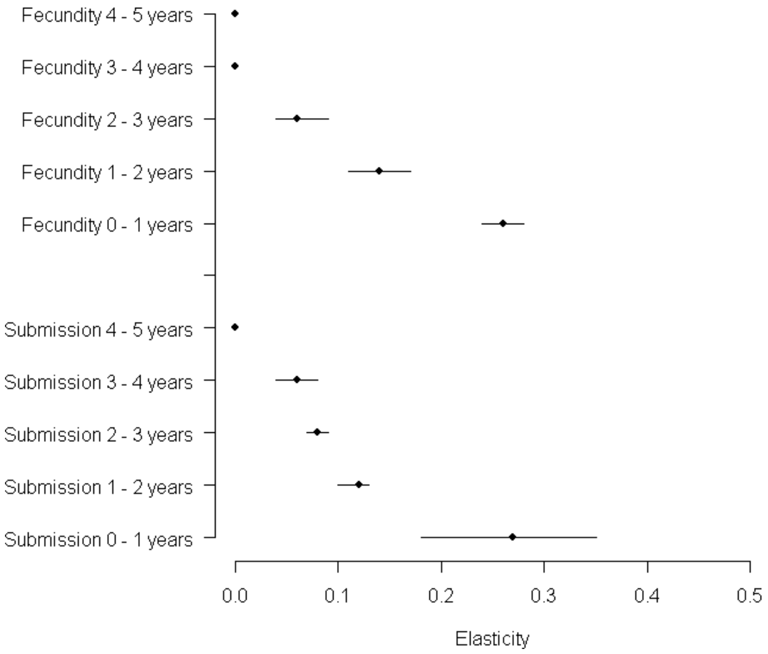


(b) Cats

Figure 5.4: Dog and cat submissions to the Wellington SPCA shelter, July 1999 to February 2006. Line plots showing the actual and projected numbers of: (a) free-roaming dogs, and (b) free-roaming cats. The dashed lines indicate the 95% confidence intervals of the population projections.



(a) Dogs



(b) Cats

Figure 5.5: Dog and cat submissions to the Wellington SPCA shelter, July 1999 to February 2006. Error bar plots showing the point estimate (and 95% confidence intervals) of the elasticity of the intrinsic rate of population increase in response to changes in age-specific submission and fecundity rates for: (a) dogs, and (b) cats.

5.4 Discussion

The classification of animals as either surrendered or free-roaming in this study was based on whether a submission was made by a member of the public (for surrendered animals) or SPCA staff (in the case of free-roaming animals). It is likely that some animals that were classified as surrendered were, in fact, free-roaming. Given the magnitude of the difference in the size of the free-roaming and surrendered groups, the misclassification of animal origin — if it was present — must have been strong to distort the inferences drawn from these data.

Of the free-roaming population, almost all dogs were classified as owned whereas equal proportions of cats were classified as owned or un-owned (Table 5.1). Two explanations account for these findings. Firstly, dogs are more likely to be collared than cats, with the presence of a collar providing definitive physical evidence of ownership. Secondly, legislation to control dogs was imposed in the Wellington region during the study period (New Zealand Government 2003, New Zealand Government 2004) and the effect of the measures applied increased the likelihood of identifying the owner of dogs presented to the shelter as free-roaming. The small number of dogs presented to the shelter (relative to cats) and the high proportion of free-roaming dogs classified as owned provide indirect support for legislative controls to be applied to cats, as already done so by a number of regional councils throughout the world (see, for example legislation enacted by The Shark Bay Shire Council 1995, The Tasmanian State Government 2005, and a commentary provided by Arkow 1991).

The age structures of both dog and cat populations submitted to the shelter were highly skewed towards younger age groups (< 12 months) with little or no difference between sexes. Median age at the time of submission was greater for cats than for dogs (7 months versus 10 weeks for cats and dogs, respectively). These findings reflect either the ease with which these age groups can be captured and/or targeted application of control efforts towards this sector of the population. In addition, the relatively young age of animals entering the shelter contributed to what we believe to be a high degree of success in rehoming animals (Table 5.1). The higher median age of cats at the time of submission is indicative of a higher proportion of older animals in this population (Figure 5.2). This reflects the greater propensity for cats to evade capture and to survive in an urban environment with little or no direct human support. The increased likelihood of breeding in this sexually mature group facilitates growth in this sector of the free-roaming population. As outlined above, legislative measures to control owned cats would be a logical means for reducing the rate of growth of this sector of the free-roaming animal population.

Of those animals presented to the shelter as free-roaming, males were more likely to be desexed than females (Tables 5.2 and 5.3). A total of 11% of free-roaming male dogs were desexed compared with 4% of females. We attribute this difference to the relative ease and lower cost of the desexing procedure for males, compared with females. There are few reports of the reproductive status of free-roaming dog populations in developed countries. The little work that has been done have considered owned dog populations (see, for example Schneider & Vaida 1975, Nassar & Mosier 1980, Nassar & Mosier 1984, and Patronek et al. 1997) and are therefore not directly comparable with the results reported here. The difference in the proportion of males and females that were desexed was greater for cats. Thirty eight percent of male cats were desexed compared with 9% of females. Surveys of free-roaming cat populations in urban centres in North America reported desexing rates in females to be vary between 53% and 70% (Patronek et al. 1997, New et al. 1999, Centonze & Levy 2002, Scott et al. 2002, Wallace & Levy 2006). We note that each of these surveys had been conducted after population control campaigns (which included desexing as an intervention) and are, as a result, not directly comparable with the results reported here.

Higher proportions of surrendered animals were desexed (dogs 16%, cats 22%) compared with those presented as free-roaming (dogs 4%, cats 15%). Schneider & Vaida (1975) found that 48% of female dogs and 65% of female cats were desexed in a cross-sectional study based on a self administered questionnaire sent to 27076 households in California, USA. Nassar & Mosier (1980) found that 66% of female dogs were desexed in study of 600 households in Kansas, USA. In a later study in the same area Nassar & Mosier (1982) found that 59% of female cats were desexed. Patronek et al. (1997) found that 63% of female dogs and 80% of female cats were desexed in a random digit dial telephone survey of 1272 households in Indiana, USA. We propose that a cross-sectional survey of the owned dog and cat population would allow desexing rates in the Wellington region to be compared with those reported in the literature and would provide some indication of the scope available to increase desexing rates in the owned animal population. Increasing desexing rates in the owned animal population would be a logical means for reducing the potential for population growth in the free-roaming sector, given that sexually mature animals entering the free-roaming population are predominantly derived from animals that are owned (Nassar & Mosier 1980, Nassar & Mosier 1982).

Our analyses show that submission of free-roaming, younger animals to the shelter (with subsequent re-homing) and/or submission and desexing (with subsequent release) are equally effective techniques for limiting the growth of the free-roaming dog and cat population in the Wellington region (Figure 5.5). Early age desexing of puppies and kittens (at 8 – 12 weeks of age) has been advocated as an alternative to neutering animals as juveniles or adults (Webb 2003) and both short term and long term studies have shown that the prepubertal gonadectomy is a safe procedure that does not increase the incidence of physical or behavioural problems in dogs and cats compared with traditional age gonadectomy (Howe et al. 2001, Spain et al. 2004). Our findings provide further support for this strategy: not only is early age desexing safe, limiting reproduction in young animals provides benefit in terms of reducing the potential for population growth.

CHAPTER 6

General discussion

Descriptions of the distribution of free-roaming dogs and cats in terms of time and space (Chapter 4) has allowed us to determine the time of year when animals were most likely to enter the Wellington SPCA shelter and from where they were likely to originate. Our analyses show that greater numbers of submissions occur in the spring and early summer (particularly for cats) and from deprived socio-economic areas. We found an inconsistent relationship between the number of submissions and proximity to recreational and forest areas.

The age structure of animals entering the shelter was highly skewed towards animals 0 – 1 year of age (Chapter 5). The proportion of desexed animals was much higher for owned animals, compared with those classified as unowned. The intrinsic rate of population growth, estimated by the Leslie projection matrices developed in Chapter 5, was 0.78 (95% CI 0.56 – 0.94) for dogs and 0.98 (95% CI 0.76 – 1.16) for cats. Assuming the intensity of recruitment of animals to the shelter was constant throughout the study period these findings indicate negative growth in the free-roaming dog population and little or no growth in the free-roaming cat population.

Elasticity analyses of the Leslie matrix allowed us to distinguish those factors (submission or fecundity rates) which were most influential in determining growth of the free-roaming dog and cat population. We showed that the intrinsic rate of population growth was equally sensitive to changes in both submission and fecundity rates of young dogs and cats (0 – 2 years of age). We conclude that both submission of young free-roaming animals to the shelter (with subsequent re-homing) and submission and desexing (with subsequent release) provide the most effective means for reducing the size of the free-roaming dog and cat population in the Wellington region.

6.1 The SPCA data

The SPCA data provided us with a a rare opportunity to quantify aspects of free-roaming dog and cat population dynamics in a New Zealand setting. Although the accumulated data was of high quality, animal submission details made either by members of the public or by SPCA staff provided an unavoidably biased cross section of the free-roaming dog and cat population. The first bias relates to the age distribution of submitted animals, where large numbers of animals from younger age groups were presented relative to older animals (Figure 5.2). The second source of bias in these data is associated with the spatial distribution of submitted animals, where more animals were submitted from the Newtown area, relative to other areas of Wellington (Figure 4.4).

The bias in age distribution of submitted animals was dealt with by expressing 'survival' in the Leslie matrix models in terms of the likelihood of an animal being submitted to the shelter, as distinct from the usual usage of the term — the likelihood of death. Population growth was therefore expressed in terms of fecundity and the probability of submission to the shelter, with the implication being that once an animal was delivered to the SPCA it was permanently removed from the free-roaming population by either being re-homed or euthanased. Our spatial analyses at the regional level were carried out by randomising the point location of animal capture within the recorded suburb of origin (e.g. Figure 4.4). This approach did not account for the first order spatial trend in the data (i.e. the high concentration of submissions from the Newtown area) but did allow the actual distribution of submissions to be described at a greater level of resolution than (say) choropleth maps of submission counts per suburb. For inference we took a subset of the data and geocoded the residential address of members of the public who submitted animals to the shelter (rather than using the exact location of where the animal was found). This approach, we believe, allowed the spatial distribution of submitted animals to be documented without systematic bias but would have increased the imprecision of the associations that were observed (e.g. the association between deprivation and animal submission density, Figure 4.7).

Acknowledging these issues that were encountered using data for a purpose other than for which it was collected, the following recommendations can be made to the SPCA regarding the future collection of animal submission details:

1. To estimate reproductive rates and age-specific survival probabilities with better accuracy and precision, prospective observational studies should be carried out during the conduct of desexing campaigns. This would involve recording details of age and sex of animals encountered when house-to-house visits are made to recruit animals to be desexed.

2. The coordinates of animal capture location should be recorded using either hand held global positioning devices (carried by SPCA field staff) and by linking the practice database with a simple Geographic Information System (GIS). At the time of presentation of animals to the shelter, SPCA staff could clarify the location of animal capture with clients using the desktop GIS. Easting and northing coordinates (in New Zealand National Grid format) might then be transferred from the GIS to the practice database.

3. Every effort should be made to correctly record details of age, sex, and reproductive status of animals at the time they are presented to the shelter. Simple methodologies for estimating animal age should be investigated and all staff trained in their use. At the very least, animals should be correctly classified as puppies or kittens, juveniles, adult, or aged at the time of submission.

6.2 Control in developing countries

On the basis of the studies described in this thesis, I would now like to discuss the implications of stray dog population control in developing countries. The burden to the society by tolerating excess number of free-roaming dogs is certainly of greater importance in developing countries than is officially recognised. Control methods that might be adopted have been reviewed in Chapter 2. The effectiveness and suitability of control measures in individual countries depends on dog ecology, population biology, and social and cultural contexts.

Emphasis on the reduction of the carrying capacity of the environment by improved solid waste management, removal of shelters, clean-up of specific habitats, and education of the public to reduce sources of food for scavenging dogs would complement dog population management programs. As demonstrated in Chapter 4 the application of spatial analytical techniques to identify associations between environmental factors (e.g. habitat and sources of food) and free-roaming animal density holds potential for optimising control programs in developing countries.

Methods for controlling reproduction in dogs and cats have been reviewed in Chapter 2. Surgical, physico-chemical, pharmacological, and immunological methods exist for the reversible or irreversible control of reproductive function in both male and female dogs. To date, only surgical methods of reproduction control have been adopted by most of developing countries. Most campaigns carried out have been *ad hoc* and desexing campaigns have not appeared to target any particular sex. The lateral flank approach has been suggested as an alternative to the conventional midline ovariohysterectomy in dogs when proper post-operative care is not possible (Howe 2006). This approach was successfully used to neuter 16451 bitches in Jaipur, India as part of a rabies control program (Reece & Chawla 2006). The advantage of early age desexing of puppies and kittens from 8 – 12 weeks of age (instead of desexing at the conventional 6 months of age) has been reported (Howe et al. 2001, Webb 2003, Spain et al. 2004) and the suitability of this approach in developing countries should be investigated.

Quantifying the size of free-roaming animal populations is indispensable for proper planning and evaluation of control measures. Techniques which could be employed for collection of information to estimate population size and other vital rates were reviewed in Chapter 3. Capture-mark-recapture methods (primarily used in studies of wildlife) can be used to estimate the size of free-roaming animal populations. Estimating the size of free-roaming animal populations would provide an objective means for establishing the effectiveness of control programs.

Although the methods described in this thesis provide a useful methodological approach for estimating age-specific vital rates from passively collected data, it should be stressed that there is no substitute for properly planned prospective observational studies. Epidemiology plays a key role here, particularly with respect to providing advise regarding study design and appropriate study size. Slater (2001) provides a useful discussion of the various roles of the veterinary epidemiologist in the study of free-roaming dogs and cats. Once age-specific vital rates are available, we have demonstrated how Leslie projection matrices can be used to quantify population growth and to evaluate the key factors influencing it. Although these provide a starting point for refining control programs, questions arise concerning more detailed aspects of interventions such as the relative effectiveness of desexing males (in preference to females) and when control measures are carried out (particularly for seasonal breeders such as cats). State transition models (Isham 1993) provide a starting point to answer such questions. For these to provide robust conclusions however emphasis must be paid to the quality of the data used to inform such models. The recommendations made in this thesis regarding data collection provide a useful starting point to achieve these objectives.

Bibliography

Acha, P. & Szyfres, B. (2003), *Zoonosis and communicable diseases common to man and animals; Chlamydioses, Rickettsioses and viruses*, PAHO, WHO, Washington DC, USA.

Adamelli, S., Marinelli, L., Normando, S. & Bono, G. (2005), ‘Owner and cat features influence the qualiity of life of the cat’, *Applied Animal Behaviour Science* **94**, 89–98.

Alves, M., Matos, M., Reichmann, M. & Dominguez, M. (2005), ‘Estimation of dog and cat population in the state of Sau Paulo’, *Revista de Saude Publica* **39**(6), 1–7.

Andersen, M., Martin, B. & Roemer, G. (2004), ‘Use of matrix population models to estimate the efficasy of euthanasia versus trap-neuter-return for management of free-roaming cats’, *Journal of the American Veterinary Medical Association* **225**(12), 1871–1876.

Anonymous (2006), Pet food and pet care products in New Zealand, Technical report, Global Market Information Database. URL: www.gmid.euromonitor.com/Reports.aspx.

Arkow, P. (1991), ‘Animal control laws and enforcement’, *Journal of the American Veterinary Medical Association* **198**, 1164–1172.

Avanzino, R. (1991), ‘Pet overpopulation and humane education in schools and communities’, *Journal of the American Veterinary Medical Association* **198**(7), 1237–1242.

Baldock, F., Alexander, L. & More, S. (2003), ‘Estimated and predicted changes in the cat population of Australian households from 1979 to 2005’, *Australian Veterinary Journal* **81**(5), 289–292.

Beaver, B. (1991), ‘The role of veterinary colleges in adressing the surplus dog and cat problem’, *Journal of the American Veterinary Medical Association* **198**(7), 1241–1243.

Beck, A., ed. (1975), *The ecology of feral and free roving dogs in Baltimore*, Vol. 1 of *The Wild Canids: Their Systematics, Behavioral Ecology and Evolution*, Van Nostrand Reinhold Company.

Bingham, J. (2005), ‘Canine rabies ecology in Southern Africa’, *Emerging Infectious Diseases* **11**(9), 1337–1342.

Blackshaw, J. (1996), ‘Developments in the study of human-animal relationships’, *Applied Animal Behaviour Science* **47**, 1–6.

Bloomberg, M. (1996), ‘Surgical neutering and non-surgical alternatives’, *Journal of the American Medical Association* **208**(4).

Bowman, A. & Azzalini, A. (1997), *Applied Smoothing Techniques for Data Analysis: The Kernel Approach with S-PLUS Illustrations*, Oxford University Press, London.

Butler, J. & Bingham, J. (2000), ‘Demography and dog-human relationships of dog population in Zimbabwean communal lands’, *The Veterinary Record* **147**, 442–446.

Butler, J., du Toit, J. & Bingham, J. (2004), ‘Free-ranging domestic dogs (*Canis familiaris*) as predators and prey in rural Zimbabwe: Threats of competition and disease to large wild carnivores’, *Biological Conservation* **115**, 369–378.

Cannon, R. & Roe, R. (1982), *Livestock Disease Surveys: A Field Manual for Veterinarians*, Australian Government Publishing Service, Canberra.

Caswell, H., ed. (2001), *Matrix Population Models: Construction, Analysis and Interpretation*, Sinauer, Sunderland, MA.

Caughley, G. (1977), *Analysis of Vertebrate Populations*, John Wiley and Sons.

Centonze, L. & Levy, J. (2002), ‘Characteristics of free-roaming cats and their care takers’, *Journal of the American Veteinary Medical Association* **220**(11), 1627–1633.

Childs, J., Robinson, L., Sadek, R., Madden, A., Miranda, M. & Miranda, M. (1998), ‘Density estimates of rural dog populations and an assessment of marking methods during a rabies vaccination campaign in the Philippines’, *Preventive Veterinary Medicine* **33**, 207–218.

Cleaveland, S., Appel, M., Chalmers, W., Chillingworth, C., Kaare, M. & Dye, C. (2000), ‘Serological and demographic evidence for domestic dogs as a source of canine distemper virus infection for Serengeti wildlife’, *Veterinary Microbiology* **72**, 217–227.

Dabritz, H., Atwill, E., Gardner, I., Miller, M. & Conrad, P. (2006), ‘Outdoor faecal deposition by free-roaming cats and attitudes of cat owners and non owners towards stray pets, wildlife, and water pollution’, *Journal of the American Veterinary Medical Association* **229**(1), 74–81.

Dar, F. & Alkarmi, T. (1997), ‘Public health aspects of cystic echinococcosis in the Arab countries’, *Acta Tropica* **67**, 125–132.

De Keuster, T., Lamoureux, J. & Kahn, A. (2005), ‘Epidemiology of dog bites: A belgian experience of canine behaviour and public health concerns’, *The Veterinary Journal* **172**(3), 482 – 487.

Department of Internal Affairs, New Zealand (2003), ‘Survey of Territorial Authorities on Dog Control Issues — Final Report’.

DiSalvo, H., Haiduven, D., Johnson, N., Reyes, V., Hnch, C., Shaw, R. & Stevens, D. (2005), ‘Who lets the dogs out? Infection control did: Utility of dogs in health care settings and infection control aspects’, *American Journal of Infection Control* **34**(5), 301–307.

Fayrer-Hosken, R., Dookwah, H. & Brandon, C. (2000), ‘Immunocontrol in dogs’, *Animal Reproduction Science* **60-61**, 365–373.

Feldman, K., Trent, R. & Jay, M. (2004), ‘Epidemiology of hospitalizations resulting from dog bites in California, 1991-1998’, *American Journal of Public Health* **94**(11), 1940–1941.

Fevre, E., Kaboyo, R., Persson, V., Edelsten, M., Coleman, P. & Cleaveland, S. (2005), 'The epidemiology of animal bite injuries in Uganda and projections of the burden of rabies', *Tropical Medicine and International Health* **10**(8), 790–798.

Flores-Ibarra, M. & Estrella-Valenzuella, G. (2004), 'Canine ecology and socioeconomic factors associated with dogs unvaccinated against rabies in a Mexican city across the US – Mexico border', *Preventive Veterinary Medicine* **62**, 79–87.

Font, E. (1987), 'Spacing and social organization: Urban Stray dogs revisited', *Applied Animal Behaviour Science* **17**, 319–328.

Gibson, K., Keizer, K. & Golding, C. (2002), 'A trap, neuter, and release program for feral cats on Prince Edward Island', *Canadian Veterinary Journal* **43**, 695–698.

Hemachuda, T. (2005), 'Rabies and dog population control in Thailand: Success or failure?', *Journal of the Medical Association of Thailand* **88**, 120–123.

Howe, L. (2006), 'Surgical methods of contraception and sterilization', *Theriogenology* **66**, 500–509.

Howe, L., Slater, M., Boothe, H., Hobson, H., Holcom, J. & Spann, A. (2001), 'Long-term outcome of gonadectomy performed at an early age or traditional age in dogs', *Journal of the American Veterinary Medical Association* **218**(2), 217–221.

Hunter, P. & Thompson, R. (2005), 'The zoonotic transmission of Giardia and Cryptosporidium', *International Journal of Parasitology* **35**, 1181–1190.

Immegart, H. (2000), 'Evaluation of intratesticular injection of glycerol for nonsurgical sterilization of dogs', *American Journal of Veterinary Research* **61**(5), 544–549.

Isham, V. (1993), 'Stochastic models for epidemics with special reference to aids', *Annals of Applied Probability* **3**, 1 – 27.

Jochle, W. (1991), 'Pet population control in Europe', *Journal of the American Veterinary Medical Association* **198**(7), 1225–1230.

Kahn, L. (2006), 'Confronting zoonoses, linking human and veterinary medicine', *Emerging Infectious Diseases* **12**(4), 556–561.

Kato, M., Yamamoto, H., Inukai, Y. & Kira, S. (2003), ‘Survey of the stray dog population and the health education program on the prevention of dog bites and dog-acquired infections: A compative study in Nepal and Okayama Prefecture, Japan’, *Acta Medica Okayama* **57**(5), 261–266.

Keuster, T., Lamoureux, J. & Kahn, A. (2005), ‘Epidemiology of dog bites: A Belgian experience of canine behaviour and public health concerns’, *The Veterinary Journal* **172**, 482–487.

Kilic, B., Unal, B., Semin, S. & Konakci, S. (2006), ‘An important public health problem: Rabies suspected bites and post-exposure prophylaxis in a health district in Turkey’, *International Journal of Infectious Diseases* **10**, 248–254.

Kitala, P., McDermott, J., Kyule, M., Gathuma, J., Perry, B. & Wandeler, A. (2001), ‘Dog ecology and demography information to support the planning of rabies control in Machakos District, Kenya’, *Acta Tropica* **78**, 217–230.

Kobelt, A., Hemsworth, P., Barnett, J. & Coleman, G. (2003), ‘A survey of dog ownership in suburban Australia conditions and behaviour problems’, *Applied Animal Behaviour Science* **82**, 137–148.

Konno, K., Oku, Y. & Tamashiro, H. (2003), ‘Prevention of alveolar echinococcosis — ecosystem and risk management perspectives in Japan’, *Acta Tropica* **89**, 33–40.

Land Information New Zealand (2007), *Land Information New Zealand*. Private Box 5501, Wellington New Zealand.

Langham, N. & Porter, R. (1991), ‘Feral cats (*Felis catus L.*) on New Zealand Farmland. I. Home range’, *Wildlife Research* **18**, 741–760.

Langley, J. (1992), ‘The incidence of dog bites in New Zealand’, *New Zealand Medical Journal* **105**, 33–35.

Lefkovitch, L. (1965), ‘The study of population growth in organisms grouped by stages’, *Biometrics* **21**(1), 1–18.

Leslie, P. (1945), ‘On the use of matrices in certain population mathematics’, *Biometrika* **33**, 183–212.

Leslie, P. (1948), ‘Some further notes on the use of matrices in population mathematics’, *Biometrika* **35**, 213–245.

Levy, J. & Crawford, P. (2004), ‘Humane strategies for controlling feral cat populations’, *Journal of the American Veterinary Medical Association* **225**(9), 1354–1360.

Levy, J., DGale, D. & Gale, L. (2003), ‘Evaluation of the effect of a long term trap-neuter-return and adoption program on free-roaming cat populations’, *Journal of the American Veterinary Medical Association* **222**(1), 42–46.

Levy, J., Miller, L., Crawford, P., Ritchey, J., Ross, M. & Fagerstone, K. (2004), ‘GnRH immunocontraception of male cats’, *Theriogenology* **62**, 1116–1130.

Lindbald-Toh, K. (2005), ‘Genome sequence, comparative analysis and halotype structure of the domestic dogs’, *Nature* **438**(7069), 803–819.

Lotka, A. (1925), *Elements of Physical Biology*, Williams and Wilkins Company, Dover, New York, USA.

Mahlow, J. & Slater, M. (1996), ‘Current issues in the control of stray and feral cats’, *Journal of the American Veterinary Medical Association* **209**(12), 2016–2020.

Manor, R. & Saltz, D. (2004), ‘The impact of free-roaming dogs on gazelle kid/female ratio in a fragmented area’, *Biological Conservation* **119**, 231–236.

Marsh, L., Langley, J. & Gauld, R. (2004), ‘Dog bite injuries’, *New Zealand Medical Journal* **117**(1201), 1–6.

Matter, H., Wandeler, A., Neuenschwander, B., Harischandra, L. & Meslin, F. (2000), ‘Study of the dog population and the rabies control activities in the Mirigama area of Sri Lanka’, *Acta Tropica* **75**, 95–108.

McCallum, H. (2000), *Population Parameters: Estimation for Ecological Models*, Methods in Ecology, Blackwell Science Ltd.

McLennan, J., Potter, M., Robertson, H., Wake, G., Colbourne, R., Dew, L., Joyce, L., McCann, A., Miles, J., Miller, P. & Reid, J. (1996), ‘Role of predation in the decline of kiwi, *Apteryx spp*, in New Zealand’, *New Zealand Journal of Ecology* **20**(1), 27 – 35.

McMurray, R. (2006), Victorian domestic animal management legislation and population control, *in* ‘National Summit to End Pet Overpopulation’, Melbourne, Australia, pp. 19–26.

Morey, D. (2006), ‘Burying key evidence: The social bond between dogs and people’, *Journal of Archaeological Science* **33**, 158–175.

Nassar, R. & Fluke, J. (1991), ‘Pet population dynamics and community planning for animal welfare and animal control’, *Journal of the American Veterinary Medical Association* **198**(7), 1160–1164.

Nassar, R. & Mosier, J. (1980), ‘Canine population dynamics: A study of Manhattan, Kansas, canine population’, *American Journal of Veterinary Research* **41**(11), 1798–1803.

Nassar, R. & Mosier, J. (1982), ‘Feline population dynamics: A study of the Manhattan, Kansas, feline population’, *American Journal of Veterinary Research* **43**(10), 167–170.

Nassar, R. & Mosier, J. (1984), ‘Study of feline and canine populations in the Greater Las Vegas area’, *American Journal of Veterinary Research* **45**, 282–287.

Nassar, R. & Mosier, J. (1991), ‘Projections of pet populations from census demographic data’, *Journal of the American Veterinary Medical Association* **198**(7), 1157–1159.

New, J., Salman, M. D., Scarlett, J., Kass, P., Vaughn, J., Schrr, S. & Kelch, W. (1999), ‘Moving: Characteristics of dogs and cats and those relinquishing them to 12 US animal shelters’, *Journal of Applied Animal Welfare Science* **2**(2), 83–96.

New Zealand Government (2003), Dog Control Amendment Act, Technical Report 119, New Zealand Government, Wellington, New Zealand.

New Zealand Government (2004), Dog Control Amendment Act, Technical Report 61, New Zealand Government, Wellington, New Zealand.

Norbury, G. (2001), ‘Conserving dryland lizards by reducing predator-mediated apparent competition and direct competition with introduced rabbits’, *Journal of Applied Ecology* **38**, 1350 – 1361.

Nutter, F., Levine, J. & Stoskopf, M. (2004), ‘Reproductive capacity of free-roaming domestic cats and kittens survival rate’, *Journal of the American Veterinary Medical Association* **225**(9), 1399–1402.

Olson, P. & Johnston, S. (1993), ‘New developments in small animal population-control’, *Journal of the American Veterinary Medical Association* **202**(6), 904–.

Overall, K. & Love, M. (2001), ‘Dog bites to humans — demography, epidemiology, injury, and risk’, *Journal of the American Veterinary Medical Association* **218**(12), 1923–1934.

Patronek, G. (1998), ‘Free-roaming and feral cats — their impact on wildlife and human beings’, *Journal of the American Veterinary Medical Association* **212**(2), 218–226.

Patronek, G., Beck, A. & Glickman, L. (1997), ‘Dynamics of dog and cat population in a community’, *Journal of the American Veterinary Medical Association* **210**(5).

Paul, E. & Serpell, J. (1996), ‘Obtaining a new pet dog: Effects on middle childhood children and their families’, *Applied Animal Behaviour Science* **47**, 17–29.

Pearl, R. (1927), ‘The growth of populations’, *The Quarterly Review of Biology* **2**(4), 532–548.

Peters, V., Sottiaux, M., Appelboom, J. & Kahn, A. (2003), ‘Post traumatic stress disorder afer dog bites in children’, *Journal of Pediatrics* **144**, 121–122.

R Development Core Team (2006), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Reece, J. & Chawla, S. (2006), ‘Control of rabies in Jaipur, India, by the sterilisation and vaccination of neighbourhood dogs’, *The Veterinary Record* **159**, 379–383.

RNZSPCA (2004), Animal Welfare Policy — Companion Animals, Technical report, Royal New Zealand Society for the Prevention Cruelty to Animals.

RNZSPCA (2005), Annual Report to Members 2005 – 2006, Technical report, Royal New Zealand Society for the Prevention of Cruelty to Animals.

Robertson, I. & Thompson, R. (2002), ‘Enteric parasitic zoonoses of domesticated dogs and cats’, *Microbes and Infection* **4**, 867–873.

Robinson, D. (1974), ‘Dog nuisance versus dog control’, *Journal of the American Veterinary Medical Association* **165**.

Rockwood, L. (2006), *Introduction to Population Ecology*, Blackwell Publishing, Victoria, Australia.

Rowlingson, B. & Diggle, P. (2006), *splancs: Spatial and Space-Time Point Pattern Analysis*. R package version 2.01-19.

Salmond, C., Crampton, P., King, P. & Waldegrave, C. (2006), ‘Nzidep: A new zealand index of socioeconomic deprivation for individuals’, *Social Science and Medicine* **62**(6), 1474 – 1485. salmond$_crampton : 2002.$

Savolainen, P., Zang, Y., Luo, J., Lundeberg, J. & Leitner, T. (2002), ‘Genetic evidence for an East Asian origin of domestic dogs’, *Science* **298**(5598), 1610–1613.

Schneider, R. & Vaida, M. (1975), ‘Survey of canine and feline populations: Alameda and Contra Costa counties, California, 1970’, *Journal of the American Veterinary Medical Association* **166**(5), 481–486.

Scott, K., Levy, J. & Crawford, C. (2002), ‘Characteristics of free-roaming cats evaluated in a trap-neuter-return program’, *Journal of the American Veterinary Medical Association* **221**(8), 1136–1138.

Shark Bay Shire Council (1995), Local Government Act, Technical report, Shark Bay Shire Council, Denham, Western Australia.

Slater, M. (2001), ‘The role of veterinary epidemiology in the study of free-roaming dogs and cats’, *Preventive Veterinary Medicine* **48**, 273–286.

Spain, C., Scarlett, J. & Houpt, K. (2004), ‘Long-term risks and benefits of early age gonadodectomy in dogs’, *Journal of the American Veterinary Medical Association* **224**(3), 380–387.

Statistics New Zealand (2001), *New Zealand Census of Population and Dwellings – 2001*. PO Box 2922, Wellington New Zealand.

Talan, D., Citron, D., Abrahamian, F., Moran, G. & Goldstein, E. (1999), ‘Bacteriologic analysis of infected dog and cat bites’, *New England Journal of Medicine* **340**(2), 85–92.

Tasmanian State Government (2005), Cat Control Bill, Technical report, Tasmanian State Government, Hobart, Tasmania.

Turchin, P. (2003), *Complex Population Dynamics: A Theoretical Empirical Synthesis*, Princeton University Press, Princeton, New Jersey, USA.

Wallace, J. & Levy, J. (2006), ‘Population characteristics of feral cats admitted to seven trap-neuter-return prgrams in the United States’, *Journal of Feline Medicine and Surgery* **8**, 279–284.

Webb, C. (2003), Why promote paediatric desexing?, *in* ‘Seminar held by the Australian Veterinary Association and the Minister of Agriculture’s Animal Welfare Advisory Committee on Early Age Desexing of Puppies and Kittens’, Victoria, Australia, pp. 6–14.

Weiss, H., Friedman, D. & Coben, J. (1998), ‘Incidence of dog bites injuries treated in emergency departments’, *Journal of the American Medical Association* **279**(1), 51–53.

WHO (1987), Guidelines for dog rabies control, Technical Report VPH/83.43 Review 1, World Health Organization.

WHO (1988), Report of WHO consultation on dog ecology studies related to rabies control, Technical Report WHO/Rab.Res/88.25, World Health Organization.

WHO (1996), Report on third international symposium of rabies in Asia, Technical Report WHO/EMC/ZOO/96.8, World Health Organization.

WHO (2004), WHO Expert Consultation on Rabies, Technical Report Series 931, World Health Organization.

WHO and WSPA (1990), Guidelines for dog population management, Technical Report WHO/ZOO/90.166, World Health Organization and The World Society for the Protection of Animals.

WHO, FAO, and OIE (2004), Report of the WHO/FAO/OIE Joint Consultation on Emerging Zoonotic Diseases, Technical Report WHO/CDS/CPE/ZFK/2004.9, World Health Organization, Food and Agriculture Organization of the United Nations, and Office International des Épizooties.

Williams, B., Nichols, J. & Conroy, M. (2002), *Analysis and Management of Animal Populations*, Academic Press, Florida, USA.

Willis, C., Church, S., Guest, C., Cook, W., McCarthy, N., Bransbury, A., Church, M. & John, C. (2006), ‘Olfactory detection of human bladder cancer by dogs: Proof of principle study’, *British Medical Journal* **329**, 711–714.

Woldehiwet, Z. (2002), ‘Rabies: Recent developments’, *Research in Veterinary Science* **73**, 17–25.