FACTORS AFFECTING THE EFFICIENCY OF FOX (*VULPES VULPES*) BAITING PRACTICES ON THE CENTRAL TABLELANDS OF NEW SOUTH WALES

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A thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philsophy

School of Biological Sciences
University of Sydney
July 2005

This thesis is my own original work except where specifically acknowledged,

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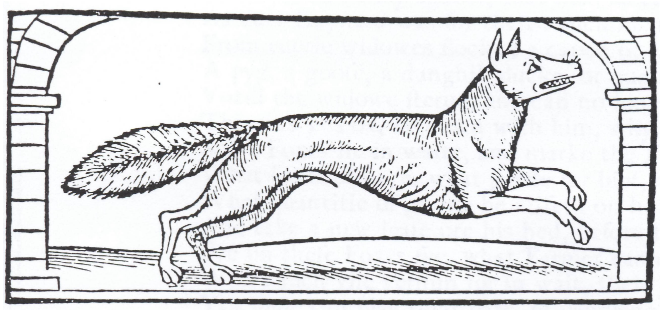
July 2005

Of the Foxe



“Raynerd the Foxe am I, a craftie childe well knowne,
Yea better known than credited, wᵗ more than is mine own:
A baftard kind of curre, mine eares declare the fame,
And yet my wit and pollicie haue purchaft me great fame.”

George Turbivile, The booke of Hunting, 1576.

ABSTRACT

The European red fox (*Vulpes vulpes* L.) is a well known predator of native species and domestic stock, and is recognised as one of Australia's most devastating vertebrate pests. Current fox management relies heavily on poisoning using baits impregnated with sodium monofluoroacetate (1080). This reliance on 1080 is likely to continue given the lack of viable alternatives for controlling foxes, so that, in the meanwhile, it is important to improve the efficiency of the current techniques. Factors affecting the susceptibility of individual foxes to bait include their ability to locate it, as well as the bait's palatability and toxicity. The economic costs associated with using different bait types, the pattern and density of their distribution will also affect the efficiency of control programs. It is essential to examine and refine all such issues to ensure efficient use of the 1080 baiting technique.

This thesis focuses generally on problems associated with management of the fox in eastern Australia. More specifically, I investigate the factors affecting the efficiency of fox baiting practices on the central tablelands of New South Wales.

The study was conducted largely on agricultural lands near the town of Molong (33^{0}10' 37"S, 148^{0}87'15"E) on the central tablelands of New South Wales. This area was chosen as it is broadly representative, in terms of land use, of a large region of eastern Australia. The highly modified, predominantly agricultural landscapes near Molong are well suited to foxes, and conflict with the predominantly pastoral community means that fox management is widely undertaken.

I determined the persistence of 1080 in two commonly used bait types, Foxoff® and chicken wingettes, under different climatic and rainfall conditions. The rate of 1080 degradation did not change significantly between the central tablelands and the relatively hotter and drier western slopes. Foxoff® baits remained lethal for longer than wingettes under all conditions, although their rate of degradation generally increased with increasing rainfall. I confirmed the presence of defluorinating micro-organisms in the

soils of eastern Australia for the first time, and suggest that, following removal from the bait, 1080 would not persist in the environment for long.

Bait should be attractive and highly palatable to ensure that the target species will find and consume it upon discovery. Caching, where discovered food is removed but not immediately consumed, may potentially reduce the efficacy and cost-effectiveness of baiting campaigns. I quantified the caching of chicken wingette, day-old chick and Foxoff® baits by inserting transmitters into bait material and assessing whether it was eaten or cached following removal. The intensity of caching did not change significantly between seasons. Type of bait had the largest influence on caching intensity, with a greater percentage of non-toxic Foxoff® baits (66.9%) being cached than either wingettes (5.7%) or day-old chicks (4.5%). The percentage of toxic (1080) baits cached was even greater, suggesting that 1080 bait may be less palatable, and detectable to foxes.

I also investigated the use of conditioned taste aversion to reduce multiple bait uptake by foxes. Levamisole, an illness-inducing chemical, was added to bait and the fate of removed bait was again monitored via radio-telemetry. Following consumption of a levamisole-treated bait, foxes avoided eating treated baits but consumed untreated baits. I concluded that a reduction in bait consumption was achieved through learned aversion to levamisole rather than via conditioned taste aversion to baits. Adding levamisole to baits, especially non-toxic bait such as rabies vaccines, could potentially be used to reduce bait monopolisation by individual foxes.

Fox density and den site preferences were assessed by investigating the distribution and density of fox natal dens on one property (9.6 km^2) over three consecutive years. A total of 9 natal dens were located in 2000 and 2001, declining to 6 in 2002. No preference was shown for den sites on the basis of habitat, slope or aspect, but more dens were located under, or adjacent to cover. Assuming that each natal den represents a breeding pair and that the population sex ratio did not differ from parity (1:1), the site contained a pre-breeding density of 1.9 foxes/km^2 in 2000 and 2001, and 1.25 foxes/km^2 in 2002. Given that the mean number of cubs is 4.0, the post-breeding density was estimated at 5.6 and

3.75 foxes/km^2 in 2000/2001 and 2002, respectively. The results demonstrated that high densities of foxes occur on agricultural lands. The success and likely accuracy of the technique to monitor fox density suggests that it may be used to calibrate more efficient abundance estimates that will be essential for the strategic management of foxes in future.

Pest animal management strategies are traditionally assessed for their effectiveness, with less consideration being given to the efficiency or cost of achieving the desired effect. I used cost-effectiveness analyses to compare between different baiting strategies based on the longevity, palatability and handling/replacement costs associated with each bait type. The results indicated that, when measured on a total cost-per-bait-consumed basis, wingettes and day-old chicks were the most cost-effective baits for campaigns of up to 4 weeks duration. This demonstrates the importance of including the longevity, and particularly the palatability of bait, when assessing cost-effectiveness. However, it is recognised that other factors, including the consistency of dosage and uptake by non-target species, may be equally or more important in deciding the appropriate baiting strategy.

The spatial and temporal application of fox baiting in the region overseen by the Molong Rural Lands Protection Board was examined between January 1998 and December 2002 as a case study to evaluate the apparent effectiveness of cooperative management practices. Most landholders (78.8%) did not bait for foxes during this period. Based on known dispersal distances, the effect of fox immigration into baited areas was determined. The results indicated that no areas baited for foxes were separated by a sufficient buffer distance (>9.58 km) from unbaited areas to be protected from fox immigration. This suggests that, at current levels of coordination, the effectiveness of most baiting operations in eastern Australia is compromised over the long term by fox immigration. However, it is recognised that short-term reductions in fox density may sometimes be all that are required to reduce predation to acceptable levels, especially for seasonally-susceptible prey. Ultimately, the cost-effectiveness of control should be evaluated in terms of the response of the prey rather than that of the predator.

This study has highlighted deficiencies in current ‘best-practice’ baiting techniques. Specific recommendations for current baiting practices, in addition to future research, are also given. In brief, these include minimising free-feed baiting, increasing the minimum distance between bait stations, and, where possible, presenting the most palatable bait. Continued research into conditioned taste aversion, aerial baiting, and techniques to reduce caching are recommended as potential techniques to improve the efficiency of baiting practices.

ACKNOWLEDGEMENTS

I would like to sincerely thank my supervisors, Glen Saunders, NSW Department of Primary Industries and Chris Dickman, University of Sydney for their friendship, guidance and support throughout this project. Many thanks also to Steve McLeod, NSW Department of Primary Industries who acted as a third 'unofficial' supervisor. All were encouraging, and their patience and enthusiasm were inspiring. I am especially indebted to Chris Dickman for his unflagging support during the write-up.

Many former and current members of Agricultural Protection and the Vertebrate Pest Research Unit helped at times either with advice and direct assistance: John Tracey, Suzy Balogh, John Druhan, Brian Lukins, Greg Jones, Sean Brown, Peter West, Peter Fleming, Lynette McLeod, Barry Kay, Eric Davis, David Croft, Heather McKenzie and Vicki Tuck-Lee. Sean Brown and Kate Wall from the University of Queensland assisted with some of the fieldwork and data entry. I'd like to sincerely thank them all for their friendship, good times and lunchtime soccer.

Many other staff at the NSW Department of Primary Industries assisted in some capacity: Rick Cother and Dorothy Noble kindly allowed me to use their laboratory and provided patient supervision and assistance in isolating and identifying soil microorganisms. Michael Priest identified the fungi species. Ron Hacker and staff from Trangie Research Station kindly allowed me access to their facilities during the bait degradation study and Jayne Jenkins and Greg Jones assisted with the setup and sampling. Richard Rodger and Peter Worsley assisted with the monumental task of matching property descriptions to landholder details – what a job it was! Remy Van de Ven and Arthur Gilmour provided very helpful statistical advice and assisted in the use of the statistical package *R*.

The Water Quality team, Orange City Council kindly allowed me to use their fluoride meter and laboratory for measuring the defluorinating ability of isolates. Laurie Twigg provided advice during the fluoroacetate laboratory work and other aspects (especially bait degradation) of the study. Bob Parker, Martin Hannan-Jones and Gina Paroz, Queensland Department of Natural Resources and Mines were contracted to undertake the fluoroacetate bait assays.

Colin Somerset, Chris Lane, Ross Trudgett, Glen Walker and other staff (especially Mary Roberson) from the Molong Rural Lands Protection Board assisted in preparing bait, locating potential study sites and matching ‘a property with a name’ during the baiting coverage case study. Who said that it couldn’t be done! They were also a friendly port of call and very forthcoming with a cuppa, especially on frosty mornings.

Jason Neville, NSW Department of Environment and Conservation and Rob Findlay State Forests, kindly supplied data on control practices on conservation lands. Molong Rural Lands Protection Board and the NSW Department of the Valuer-General kindly allowed access to their property description data. Mark Sayer (Countrywide Systems Network Inc.) provided advice on the TFS2 database download. Peter Collet and John Perfect (Land and Property Information) also provided valuable input into the matching process (many thanks chaps!).

Roger Pech and Chris Davey (CSIRO Canberra) provided some interesting discussions in the conditioned taste aversion technique. Many thanks to Giovanna Massei for her advice with the conditioned taste aversion experiments. Giovanna and Roger Quy, Julia Coats and David Cowan (Central Science Laboratory, York) were welcoming and supported my laboratory conditioned aversion experiments in the United Kingdom. The friendly staff at the Central Science Laboratory made me feel welcome during my brief stay and members of the Animal Services Team assisted in caring for the rats.

Thanks to all those who assisted in searching for dens: Brian Lukins, John Tracey, Greg Jones, Peter West, Kate Wall, Emma Hobbs and Sean Brown. Peter Worsley (NSW Department of Primary Industries) and ‘Mulga’ Daniel Huie assisted with the mapping component.

Sincere thanks to many landholders who were kind enough to allow me access to their properties for various parts of this study - especially Bill and Gina Dunlop (Nandillyan Heights), Peter and Wendy Reid (Fernleigh), Don Bruce (Myrangle), Will Lee (Claremont), Ian Atkinson (Gundabooka), Peter Welsh and family and Steve Brown (Larras Lake North). Special thanks to Peter Welsh for supplying me with comfortable accommodation during my stays on Larras Lake North.

The National Feral Animal Control Program, Bureau of Rural Sciences and NSW Department of Primary Industries funded this study. The University of Sydney and Pest Animal Control Co-operative Research Centre, Canberra (now Australasian Invasive Animal CRC) provided a postgraduate scholarship and some much appreciated travel assistance for the United Kingdom component. Many thanks to current and former members of the Pest Animal Control CRC, including Tony Peacock, Barbara Van Leewen and Anthony Szell for their support.

All animal experimentation within Australia were approved by the Orange Animal Ethics Committee (ORA 00/006; ORA 01/010); The Department of Environment, Food and Rural Affairs Animal (DEFRA) Ethics Committee at the Central Science Laboratory approved the United Kingdom experiments under Home Office licences.

I am indebted to Joe Scanlan and Dave Berman, Queensland Department of Natural Resources and Mines, for their support and encouragement during the final stages of the write-up.

Many thanks and love to my family (Mum, Dad and Penn) and friends who supported me when I needed it most – I couldn’t have done it without you. Aunty Rae always made me feel welcome during my stays in Sydney. Joe the ‘oldest cat in the world’ also gave me great company throughout – especially during the field trials - rest in peace mate. Lastly I would like to thank anyone I may have accidentally omitted who assisted during this study.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

This thesis focuses generally on problems associated with the management of an exotic pest species, the European red fox (*Vulpes vulpes*), in the Australian environment. Specifically, I investigate factors affecting the efficiency of fox baiting practices on the central tablelands of New South Wales, Australia. This chapter provides a brief review of fox impact, biology, ecology and management before introducing the issues affecting baiting efficiency.

1.2 Exotic pests

The spread of exotic animal species is an increasing problem throughout the world (Van Driesche and Van Driesche 2000). The spread of exotics is a form of biological invasion, which by definition, occurs when an organism increases beyond its former range (Williamson 1996). It may be caused by natural movements of the species, although most invasions are due to the interventions of humans, whether accidental or deliberate (Williamson 1996, Mack *et al.* 2000). Irrespective of the cause, newly arrived species are seen as pests when they conflict with human interests (Olsen 1998), and successful colonisation is occurring with frightening regularity (Van Driesche and Van Driesche 2000; Lowe 2001). The epidemic of vigorous exotic species overwhelming native species has been described as a 'globalisation of ecology' and, at its endpoint, may result in a one world ecosystem (Lowe 2001).

Australia is home to many exotic pest species; the majority of these were introduced deliberately and were released for reasons including food and fibre production, hunting and sport, transport, pets or as a result of acclimatisation societies (Olsen 1998). Many species have successfully established wild populations in the relatively short period since European settlement (Rolls 1969) and are recognised as significant agricultural, environmental and social pests (McLeod 2004). Mice (*Mus domesticus*) eat and damage crops and stored grain, damage building infrastructure including electrical wiring, harass intensively housed stock, spread disease, and have significant social impacts, especially during plagues (Caughley *et al.* 1998). Feral pigs (*Sus scrofa*) range over 60% of the continent, damage grain, sugar cane and banana crops, degrade sensitive wetland areas, threaten native species, and carry diseases of stock and humans (Choquenot *et al.* 1996). Common mynas (*Acridotheres tristis*) damage horticultural crops, compete with native bird species for nesting sites and defecate profusely, fouling public places (Olsen 1998). Perhaps our best recognised vertebrate pest, the European rabbit (*Oryctolagus cuniculus*) continues to flourish and degrade the environment despite the relative success of myxomatosis and rabbit haemorrhagic disease (RHD) in reducing its numbers (Coman 1999; Story *et al.* 2004). However, relatively recent and increasing knowledge of the impacts of the European red fox has seen it become recognised as one of Australia's most significant vertebrate pests (McLeod 2004). Foxes have had a devastating effect on many wildlife species and have probably contributed to numerous extinctions of native fauna (Dickman 1996). A brief review of fox impacts in Australia is given below to demonstrate the deserved status of the study animal as a pest of national significance.

1.3 Fox impact

Environmental

Native mammals, birds or reptiles can constitute a large proportion of the diet of the fox (e.g. Green and Osborne 1981; Triggs *et al.* 1984) although this does not necessarily indicate whether the impact of predation is significant on these prey populations (NSW National Parks and Wildlife Service 2001). Few studies with adequate replication have been undertaken to quantify the impact of fox predation on prey populations, although there is ample evidence to suggest widespread and massive impact, all from direct predation (Dickman 1996). Predation of young-at-foot eastern grey kangaroos (*Macropus giganteus*) has been shown to reduce recruitment in south-eastern Australia (Banks *et al.* 2000). Foxes were responsible for taking 93% of tortoise (*Emydura* spp.) eggs from a Murray River site in South Australia (Thompson 1983), and significantly reduced the recruitment of juveniles (Spencer 2000 (Spencer and Thompson 2005)). Re-introduction experiments have also shown significant losses of translocated birds and mammals due to fox predation (Priddel and Wheeler 1989; Short *et al.*

1992). Evidence from removal experiments also supports these findings; studies in Western Australia have shown substantial population increases in a variety of marsupial species including rock-wallabies (*Petrogale* spp.), bettongs (*Bettongia* spp.) and numbats (*Myrmecobius fasciatus*), following the removal of foxes (Kinnear *et al.* 1988; Friend 1990; Morris 1992). Additionally, much anecdotal information suggests that vulnerable species appear to persist only in areas where foxes are absent or found in low densities, or in habitats that offer some protection from predation (e.g. the bridled nail-tailed wallaby, *Onychogalea fraenata,* in central Queensland) (Clancy 1994; Dickman 1996; Short *et al.* 2002; King and Smith 1985). NSW National Parks and Wildlife Service (2001) concluded that the impact of fox predation on the abundance of most native fauna is unknown, but the impacts appear to be greatest for medium-sized ground-dwelling and semi-arboreal mammals, ground-nesting birds and chelid tortoises, particularly those within the 'Critical Weight Range' of 35 g to 5500 g (Burbidge and MacKenzie 1989).

Foxes are thought to have played a major part in the demise and extinction of many ground-dwelling native species in the last 130 years (Short *et al.* 2002). The impact of fox predation has been recognised as a key threatening process under schedule 3 of the Commonwealth *Endangered Species Protection Act* 1992 and also under schedule 3 of the New South Wales *Threatened Species Conservation Act* 1995.

The environmental impact of foxes each year in Australia has been coarsely estimated at $190 million dollars per annum (McLeod 2004). This figure was based solely on the number of birds consumed by foxes each year (190 million) as estimated from the number of foxes presently in Australia (~7.2 million), their food intake, the average occurrence of birds in dietary studies (1%) and a 'value' of $1 per bird. This estimate relies on many assumptions but probably significantly underestimates the true cost since it does not account for other groups (reptiles, amphibians, mammals) lost to fox predation. It also fails to consider the cost of any surplus killing (see Short *et al.* 2002 for review) since it accounts only for items that are consumed. Regardless, the figure provided by McLeod (2004) is useful to provide a conservative estimate of the impact of foxes on the Australian environment.

Agricultural

Foxes are recognised agricultural pests, especially as predators of newborn lambs (*Ovis aries*) and goat kids (*Capra hircus*). Poultry are a favoured target, but losses to commercial poultry enterprises are usually insignificant since most are well protected (Moberly *et al.* 2004). The extent of lamb and kid losses from fox predation is difficult to measure (see Greentree *et al.* 2000; Moberly *et al.* 2003; Moberly *et al.* 2004); variations in flock health and management, together with seasonal factors may affect birthing percentages and juvenile mortality (e.g. Rowley 1970; Jordan and Orr 1989). These variations mean that primary fox predation is difficult to define and resulting estimates are usually based on direct observations of a small number of flocks. Regardless, studies have shown that foxes may take, or are perceived to take up to 30% of newborn lambs (Lugton 1993a; Heydon and Reynolds 2000), although estimates usually range between 0 and 10% (Dennis 1969; Rowley 1970; Mawson and Long 1992; Greentree *et al.* 2000).

Foxes are also known to cause damage, mostly nuisance, to various other enterprises through consuming various produce, such as horticultural crops (Olsen 1998) and/or chewing infrastructure such as irrigation equipment (S. Balogh, NSW Department of Primary Industries, pers. comm. 2003).

Disease

Foxes are hosts and potential vectors for exotic and endemic diseases, and parasites including ticks, tapeworms and lice (Mañas *et al.* 2005; Webster and Kapel 2005). Generally, little is known of the occurrence of pathogens and parasites within and impact on Australian fox populations (Saunders *et al.* 1995), but many could potentially be transmitted to domestic and/or human hosts.

Foxes are an important end-host of the hydatid tapeworm in some parts of the world (Hofer *et al.* 2000), but it appears that the incidence of infestation is very low in rural Australia (Saunders *et al.* 1995). However, they still may confer risks to human health, especially in urban areas (Jenkins and Craig 1992). Foxes are a significant carrier of the scabies mite, *Sarcoptes scabiei*, which causes severe itching, excoriation and skin inflammation leading to hair loss and mange. In Australia, scabies can result in extensive mortality of both foxes and wombats (*Vombatus ursinus*) (Bubela 1995; Kemp *et al.* 2002) and can afflict humans; a very high incidence (up to 50%) of scabies is found in some Aboriginal communities (Kemp *et al.* 2002).

In Europe and North America, foxes are the major host of sylvatic rabies and considerable effort is made annually to reduce persistence of this disease (Wandeler 1988; MacInnes and LeBer 2000). There are potentially a large number of domestic and wild mammalian host species for rabies in Australia, but canid species, including foxes, are likely to be the major vectors (Newsome and Catling 1992; Saunders *et al.* 1995). Foxes have an extremely high rate of rabies secretion in saliva (Steck and Wandeler 1980) and the behaviour (especially dispersal) and structure of fox populations ensures that rabies is maintained and spread rapidly. As a result, Australia relies heavily on quarantine and contingencies to avoid it becoming established (Saunders *et al.* 1995).

1.4 Biology and ecology of the fox

It is essential to have a sound understanding of an animal's biology and ecology to develop effective and efficient management strategies (Olsen 1998). Knowledge of a species morphological and physiological adaptations to the environment, its diet, behaviour, habitat use, reproduction and dispersal are all essential to understand the animal and develop approaches towards management (Caughley and Sinclair 1994). Such knowledge is especially important given recent pushes towards 'Achilles heel' methods that rely on developing highly-specific control techniques based on physiological, morphological, behavioural or biochemical differences between the pest and other species (Marks 2001). The following is a summary of fox biology and ecology, derived mostly from Australian studies.

Morphology

The red fox is a member of the Family Canidae, which includes carnivores such as wolves, jackals, and coyotes (*Canis* spp.). Foxes have long, slim bodies, tall slim legs, narrow muzzles, and bushy tails (Jarman 1986). The body of an adult fox generally ranges between

570 and 740 mm in length, with a tail length of 360-450 mm. Body weight ranges between 4.5 and 8.3 kg (Coman 1983) with an average of approximately 4.5 and 5.0 kg for females and males respectively (Saunders *et al.* 2002b). Both sexes suffer from seasonal fluctuations in body weight relating to either food and/or reproductive stresses.

Reproduction

Foxes are monestrous, reproducing once per year in spring. Females are reproductively active from July to October in south-eastern Australia (McIntosh 1963a; Ryan 1976; McIlroy *et al.* 2001). The gestation period is 51-53 days, with most cubs born during August and September (McIlroy *et al.* 2001). The mean litter size is four but ranges between one and ten (Saunders *et al.* 1995). Cubs are weaned after 4 weeks and become sexually mature after 10 months. Not all females in a population breed each year; the proportion of non-breeding vixens in the population is highly variable (Englund 1970) but generally increases with population density, probably due to the social suppression of reproduction in large groups. However, studies undertaken in New South Wales suggest very few non-breeding females (Saunders *et al.* 2002b), despite relatively high population densities (2-6 foxes per km^2).

Foxes use dens as secure sites to raise their offspring. Dens are typically a burrow with single or multiple entrances, but other structures that offer protection such as logs, rock piles, shrubs and even thick grass may be used as natal sites (Berghout 2001). Vixens usually prepare multiple dens and cubs may be moved several times during the cub-rearing period. Juveniles, particularly males, disperse from four months of age to seek their own territory.

Diet

Foxes are opportunistic predators and scavengers (Doncaster *et al.* 1991; Bubela *et al.* 1998b) and, although primarily carnivorous, will consume a large variety of both plant and animal material. Foxes are mostly solitary hunters and foragers but will occasionally coordinate these activities with other individuals, especially where food sources are localised. Items consumed are mainly mammalian (McIntosh 1963b; Coman 1973; Croft and Hone 1978). Where present, rabbits can make up a large proportion of their diet (Ryan and Croft 1974; Croft and

Hone 1978 (Saunders *et al.* 2004). Other food items commonly consumed include sheep (mostly as carrion), house mice, insects, reptiles and amphibians, birds, grains, vegetable matter, and fruit and vegetable crops such as melons, grapes, apples and blackberries (Woolley *et al.* 1985; Catling 1988; Lugton 1993b; Palmer 1995). The relative frequency of food items consumed varies with season and location (Croft and Hone 1978), reflecting abundance of prey more than prey preference (Ables 1975; Molsher *et al.* 2000).

Social structure and behaviour

Foxes are crepuscular, but are also active intermittently through the night (Berghout 2001). Foxes are normally solitary, but pairs form a close association during the breeding season. In Europe, the species is reported to form family groups consisting of an adult pair and subordinate vixens from the previous year's litter although this relationship may be flexible (e.g. Macdonald 1983; Voigt and Macdonald 1984 (Henry *et al.* 2005)). Each family group establishes a territory that is defended against foxes outside their family group. The predominant family group composition throughout Australia is probably a mated pair of adult foxes with a litter of cubs (Saunders *et al.* 1995; McIlroy *et al.* 2001) although more complex social structures, including non-breeding females, may be present (Bubela 1995; Berghout 2001).

Surplus killing of prey is a common behavioural trait; this is where foxes kill excess prey not intended for immediate consumption (Kruuk 1972). It is believed that surplus killing reflects the behaviour and response of the prey to predation, animals that behave 'abnormally' are more prone to be victims of surplus killing. However, foxes are known to store, or cache food that is not immediately consumed for use at a later date (Macdonald 1976; Sklepkovych *et al.* 1996), allowing greater opportunity to control food availability spatially and temporally (Vander Wall 1990).

Home range and movements

Foxes normally occupy well-defined home ranges with non-overlapping and stable borders. Home range size is generally proportional to the amount of resources it contains with greater productivity resulting in smaller home range (Harestad and Bunnell 1979; Macdonald 1980). However, home range size in territorial solitary foragers such as the fox may be set by the dispersion of the minimum number of food patches needed to sustain a pair of foxes. The productivity of those food patches dictates how many foxes can live with the primary pair in a group territory (Macdonald 1981, 1983; Kruuk and Macdonald 1985; Moehlman 1989).

Foxes can travel up to 10 km per day (Jarman 1986). Long distance movements are usually restricted to the dispersal phase, when juveniles disperse to find their own territory. Foxes usually disperse short distances (Coman *et al.* 1991) but quite considerable distances have been reported; Berghout (2001) recorded a straight-line distance of 285 km for one vixen on the central tablelands of New South Wales.

Distribution and abundance

The fox is a widespread species, with populations located in North America, Europe, North Africa, Asia and Australia (Long 2003). The worldwide distribution indicates that red foxes will adapt to and survive within a variety of different habitats, ranging from arctic tundra to semi-arid and arid areas (Saunders *et al.* 1995). Fox density within each environment varies greatly, with the more productive environments supporting higher densities of foxes. Studies in Australia suggest that fragmented landscapes, offering open areas for foraging and woodland areas for shelter, are highly favoured (Jarman 1986).

Fox density fluctuates considerably throughout the year, with the highest density occurring following whelping and the lowest during the mating season (Saunders and McLeod *in press*). This is because foxes breed only once per year, while mortality progressively reduces the population size until the following breeding season.

Fox populations are not static, with seasonal patterns of dispersal resulting in constant change (Trewhella 1988). The majority of dispersal occurs in juvenile males from late summer until early winter (Saunders *et al.* 1995). However adults are also known to undertake long-range movements to establish or extend territories. Such movements result in recolonisation of areas where foxes have been removed, and can occur rapidly (see Molsher 1999).

1.5 Management practices

Management strategies

There are three basic management strategies to alleviate problems caused by exotic pest species: exclusion, eradication or control (Bomford and O'Brien 1995; Courchamp *et al.* 2003). Exclusion is where the exotic species is excluded by means of a physical barrier (e.g. fence) from the area where it causes damage. This is only a local solution since its effectiveness is limited to a specific, usually small, area; it is not suitable for management of a widely distributed exotic species on a landscape scale. Regardless, exclusion may be effective and warranted, particularly to protect rare or threatened species, in situations where prey are confined to a small area, and/or for intensive enterprises where the economic benefits of exclusion exceed the costs (Long and Robley 2004).

Eradication is the complete removal of all individuals from a population, down to the last reproducing individual, or a reduction in the density to below self-replacing levels (Myers *et al.* 2000). Courchamp *et al.* (2003) suggest that eradication is the optimal response for managing the impacts of exotic species on islands. Eradication from islands is generally simplified compared to more widely distributed populations since the geographical scale is limited, and the isolation from other populations reduces the potential for reinvasion and recolonisation. As a result, there has been much successful eradication of exotic species from islands (see Courchamp *et al.* 2003 for review). For example, combinations of up to 12 mammal species (ranging from rodents to ungulates) have been removed from many New Zealand islands up to 2000 ha (Veitch and Bell 1990 in Mack *et al.* 2000). Even larger islands have been successfully eradicated; in 2000 feral pigs (*Sus scrofa*) were finally removed from Santiago Island (58,465 ha) part of the Galapagos group, after a 30-year campaign (Cruz *et al.*

2005). Critical to the success of this program was the sustained, dedicated control effort, the use of multiple control techniques (poisoning and hunting), the improved hunter access to pigs from additional trails and the intensive pig activity monitoring program (Cruz *et al.* 2005). However, even on mainland areas eradication of an exotic pest species is feasible, particularly is it is detected early and resources can be applied quickly and effectively (Simberloff 1997). One example of successful eradication from a mainland area is the removal of the coypu (*Myocastor coypus*), a large South American rodent, from marshes in south-western England after a 50 year campaign (Gosling 1989). Coypu were finally removed through undertaking an intensive, 8 year cage-trapping campaign costing £2.5 million, despite the presence of only a small population distributed over a relatively small area (Gosling 1989).

Such accomplishments demonstrate the ability to eradicate substantial populations of exotic mammals under suitable conditions. Where eradication has been successful, three key factors have contributed to the success: 1) the biology of the pest species was susceptible to the technique/s applied; 2) a sufficient level of resources was devoted for a sufficient duration; and, 3) there was widespread support from relevant agencies and the general public (Mack *et al.* 2000). For example, Cruz *et al.* (2005) reported that eradication, rather than sustained control of feral pigs on Santiago Island was favoured due to convincing biological (effective eradication techniques, potential non-target impacts), economic (limited conservation funds) and political (management pressure to reduce ecosystem degradation) arguments. If any of these criteria are not met, as is common in many circumstances faced by wildlife managers, eradication is simply not achievable (Braysher 1993; Caughley and Sinclair 1994; Bomford and O'Brien 1995). In many cases, eradication may be biologically feasible, but is limited by its high social, political and economic costs (Bomford and O'Brien 1995).

In contrast to islands, there has been no widely established population of an exotic species eradicated on any continent, despite enormous efforts (Bomford and O'Brien 1995). As a result, exotic species populations are usually controlled by means of regular population reduction rather than for the aim of eradication (Braysher 1993). Although control is usually more feasible than eradication, the gains from control are temporary. Since the reduction in density is not complete, control programs require constant or continued suppression to keep the population at low density (Courchamp *et al.* 2003). Undertaking regular population reductions of the exotic predator species rely on reducing the density of the pest species sufficiently to achieve 'acceptable' levels of impact upon the prey. Once such example is the fox baiting program developed to reduce the fox predation threat to loggerhead (*Caretta caretta*), green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) (Flakus 2002). The Australian coastline between Bundaberg and Town of 1770 is baited to coincide with the turtle nesting (October) and hatchling seasons (January/February) in addition to fox dispersal (April). At Wreck Rock, the level of fox activity has been monitored in conjunction with the level of nesting success. There have been significant increases in the hatching success of clutches laid with the reductions in fox activity resulting from fox baiting programs. Fox activity and predation has been significantly reduced; less than 1% of nests have been lost to foxes or dogs compared to up to 90% in the 1970's and 1980's (Limpus and Reimer 1994; Flakus 2002). Without the continued suppression of foxes through baiting, hatching success is likely to return to very low levels (Flakus 2002).

However, largely due to the paucity of information relating to the relationship between fox density and damage, control methods in Australia have traditionally focused on reducing fox abundance rather than specifically on reducing fox-related damage (Saunders *et al.* 1995). The control techniques commonly employed on both agricultural lands and conservation areas include poisoning, shooting, trapping, den fumigation and destruction, and exclusion fencing. Alternative management techniques, such as immunocontraception, taste aversion conditioning, and chemical deterrents are continually being researched, but none are currently in commercial use.

Shooting

Shooting is commonly employed to reduce fox numbers at a local level, especially on pastoral properties. Shooting at night with the aid of a spotlight is favoured since foxes have a very bright, characteristic eyeshine that allows them to be easily seen at large distances. Broad-scale reductions of foxes through shooting are labour intensive, with considerable effort required to target foxes within the area, especially as density decreases. There is also evidence to suggest that shooting selectively targets juvenile foxes, with older, more wary animals escaping (Englund 1980; Coman 1988; Parker 2002). Despite the lack of thorough evaluation, shooting is unlikely to be an independently effective and efficient technique for broad-scale reduction of fox numbers or impacts given these issues.

Trapping

Trapping is not suitable for undertaking large-scale control of foxes and generally lags behind poisoning and shooting in popularity (West and Saunders 2003). Soft-jawed, cage-style, or treadle-snare traps are the most commonly used (Fleming *et al.* 1998). Trapping is a labour-intensive and highly-skilled task (Baker *et al.* 2001). Kay *et al.* (2000) reported low trapping success in central-western New South Wales, with approximately 150 trap nights required to capture one fox. Such a labour-intensive effort, together with the need to check traps daily for welfare concerns, makes it inefficient for broad-scale fox control. However, it may be very effective for localised problems where small numbers of foxes are responsible, or in closely settled or populated areas where other techniques are unable to be used (Bubela *et al.* 1998b).

Den fumigation and destruction

Fumigation and destruction of breeding dens or earths can be very effective in reducing fox numbers. In most cases these techniques are used to target cubs, but adults may also be killed. Dens are fumigated during the whelping period, generally during August/September (Saunders *et al.* 1995). Dens are primarily used from early spring to summer; during other periods in the year they are used sporadically or are inactive.

Exclusion fencing

Fences may be designed to be totally exclusive or simply to reduce crossings by foxes. Foxes are agile and capable climbers and strong diggers, so most fence designs involve barriers to restrict these activities. Other designs, such as simple electrified fences, rely on avoidance learning rather than direct exclusion (Patterson 1977). Coman and McCutchan (1994) found that most fences provide an incomplete barrier to foxes. Constant fence maintenance, monitoring and quick action to remove any foxes that breach the barrier are essential to ensure that fences remain effective. Additionally, consideration must be given towards integrating control with exclusion (Coman and McCutchan 1994) to ensure that fences remain effective.

Exclusion fences are expensive to construct and maintain. Coman and McCutchan (1994) provided examples where fox exclusion fences have cost between $18 000 and $50 000 per kilometre to construct. As a result, exclusion fencing is usually restricted to protecting rare or threatened species, situations where prey are confined to a small area, and/or intensive enterprises where the economic benefits of fences exceed construction and maintenance costs (Long and Robley 2004).

Guard animals

Livestock guard dogs have been used for thousands of years to protect stock from predators (De la Cruz 1995; Rigg 2001). Other animals, including alpacas (*Lama pacos*), llamas (*Lama glama*) and donkeys (*Equus asinus*) are aggressive towards canids (Andelt 2004) and are becoming increasingly popular in Australia to protect stock from fox predation (Jenkins 2003).

Overseas studies have reported that livestock guard animals substantially reduce predation on sheep or goats by a range of predators, including foxes (Jenkins 2003). The level of effectiveness depends on a number of flock management and environmental factors, such as:

- prey species and response to predation
- the density of guard animals to prey
- the protective response of the guard animals
- the size, habitat and topography of the paddock where prey are located
- the number and density of the prey
- predator density

Factors that reduce the ability of a guard to observe or defend the flock will ultimately reduce its effectiveness. The physical constraints of guarding large areas and the need for a high ratio of guard to prey effectively limits the application of the technique for most situations (Andelt 2004). Despite this, there are many anecdotes about the effectiveness of guard animals. However, replicated studies need to be undertaken to assess the effectiveness of guards under Australian conditions (Jenkins 2003).

Fertility control

Limiting recruitment through fertility control may be a humane and cost-effective alternative to lethal control for reducing long-term fox impacts (McIlroy *et al.* 2001). It may be undertaken through use of a chemical abortifacient to induce miscarriage or abortion (Marks *et al.* 1996) or potentially via immunocontraception, which utilises the animals own immune system to block reproduction. Generally, modelling indicates that immunocontraception will be effective in reducing the rate of increase of fox populations (Hone 1992; Pech *et al.* 1997), but, as for chemical abortifacients, it is likely that animals would have to be re-treated again during their fertile lifetimes (G. Reubel, Pest Animal Control Cooperative Research Centre, pers. comm. 2003). This would make it less cost-efficient compared to lethal baiting programs at reducing either recruitment or fox-associated damage.

Although initial work has been undertaken to manufacture a self-disseminating virus to induce immunocontraception (Seamark 2001), the final form of the contraceptive is likely to be a bait-delivered vaccine (Bradley *et al.* 1997). Continuing research by the Pest Animal Control Cooperative Research Centre (now Australasian Invasive Animal Cooperative Research Centre) may see its development in the future.

Poisoning

The management of foxes on agricultural and conservation lands in Australia relies most heavily on poison baiting. In New South Wales, the use of 1080 for fox control has increased rapidly during the last 20 years; less than 50,000 baits were laid each year in the mid 1980's, but this increased to over one million in the late 1990's (Thompson *et al.* 1991; Saunders *et al.* 1995; West and Saunders 2003). In the current decade usage across the state remains high but overall growth has reached an asymptote (H. McKenzie, NSW Department of Primary Industries, pers. comm. 2002). However, several areas of the state, including parts of the central tablelands, have experienced increases in overall effort for controlling foxes (West and Saunders 2003), indicating recognition of the fox problem and the need to undertake fox management. A survey of Rural Lands Protection Boards (RLPBs) in New South Wales indicated that baiting amounted to 74% of control effort for foxes in 2002 (West and Saunders 2003), further demonstrating our critical dependence on poisoning with 1080 for fox control.

Poisoning is undertaken by distributing poison bait across the landscape. Bait in New South Wales must be buried (5-10 cm depth) (Environment Protection Authority 2002) as a measure to prevent uptake by non-target species (Allen *et al.* 1989), although aerial baiting is permitted in some western areas under restricted circumstances e.g. Yathong Nature Reserve for protection of malleefowl (*Leipoa ocellata*). Current directions indicate that fox baits shoul be laid at no closer than 100 m intervals (recommended 200-500 m) (Environment Protection Authority 2002) in prominent positions close to roads, fencelines and along other distinct habitat ecotones to maximise the chance of uptake (Korn and Lugton 1990). Additional directions for use include: checking and replacing baits at regular intervals, retrieving and destroying (by deep burial or burning) any untaken baits at the end of the campaign, and destroying baits within 4 weeks of purchase (see Appendix 1).

A variety of bait types has been used to target foxes, but in New South Wales bait types are limited to fowl heads, fowl eggs, chicken wingettes, boneless red meat, offal (i.e. tongue, liver or kidney) and manufactured bait (Environment Protection Authority 2002). Choice of bait type is largely a result of personal preferences of the practitioner and availability of the substrate from the RLPB. The commercially manufactured Foxoff® bait is the most commonly used, comprising over 48% of baits distributed to landholders in 2001 (West and Saunders 2003). Chicken heads were popular, but concerns regarding leakage of 1080 solution following preparation means that their continued use is discouraged (D. Croft, NSW Department of Primary Industries, pers. comm. 2000). Chicken wingettes are becoming favoured and are perceived to be highly palatable (D. Bate, NSW Department of Primary Industries, pers. comm. 2000, and T. Abblett, Wentworth Rural Lands Protection Board, pers. comm. 2001). Their use is increasing; ten percent of RLPBs used wingettes in 2001 despite being introduced only in 1998 (West and Saunders 2003).

Sodium monofluoroacetate (1080) is the only toxin registered in New South Wales to target foxes and is favoured throughout Australia for its cost-efficiency (Saunders *et al.* 1997a), relative target selectivity (e.g. McIlroy 1986), and low environmental persistence (Twigg and Socha 2001). Canids are particularly susceptible to fluoroacetate; the LD_{50} for foxes is generally accepted as 0.013 mg kg^{-1} (McIlroy and King 1990). Despite this sensitivity, fluoroacetate poisoning is characterised by a latent period, with symptoms generally appearing between 30 minutes and 4 hours after consumption (Chenowith and Gilman 1946; Egekeze and Oehme 1979; Sheehan 1984; Staples *et al.* 1995) and mean time to death in foxes occurring after 4 hours (Marks *et al.* 2000).

A variety of techniques is utilised on both agricultural and conservation lands for fox control in Australia but, despite pushes towards development of new lethal and non-lethal control measures, we are still critically reliant upon the use of 1080 poison. Given the lack of alternatives, this dependence is likely to continue into the future, especially in areas where overall control effort appears to be increasing (e.g. central tablelands) (West and Saunders 2003). However, many issues pertinent to its use remain equivocal and/or contested. It continues to be plagued by ethical concerns about its humaneness (Rammell and Fleming 1978; Marks *et al.* 2000; RSPCA 2003) and (see Sharp and Saunders *in press* for review). There is some evidence that animal populations exposed to 1080 over long periods can develop forms of genetic resistance (Twigg 2001), potentially reducing the efficacy or effectiveness of control operations. There are also concerns with non-target species uptake and consumption, particularly where the susceptible spotted-tailed quoll (*Dasyurus maculatus*) is present (NSW National Parks and Wildlife Service 2001); and there are questions about its cost-effectiveness (Saunders and McLeod *in press*). Therefore, it is essential to look for viable alternatives to 1080. Meanwhile, improvements to the current techniques are required to ensure that it is undertaken in an efficient and effective manner.

The following section will identify and introduce some of the factors that influence baiting efficiency.

1.6 Factors influencing the efficiency of baiting campaigns

The efficiency of baiting programs will be influenced by complex interactions between behavioural and logistical factors (Saunders and McLeod *in press*). Factors affecting the susceptibility of an individual to a bait, including bait palatability and toxicity, may be affected by other issues such as attraction to bait, density, presentation, and campaign timing, as well as distribution and replacement strategies. Additionally, the efficiency of programs will be affected by economic costs associated with the above factors. A broad overview of pertinent issues is presented here, but each will be covered in more detail throughout the thesis.

Bait degradation

Bait must retain its lethal dose of 1080 for a sufficient period to allow the target animal to find and consume the bait (McIlroy *et al.* 1986), but it must also degrade so long-term hazards to non-target species and environmental persistence are reduced (Twigg *et al.* 2000).

The 1080 in bait can be lost through the contribution of one or more of the following - defluorination by bacteria, fungi and other microbes, leaching by rainfall, consumption by sarcophagous insects or conversion to inorganic fluoride compounds (Korn and Livanos 1986; McIlroy *et al.* 1986; Kramer *et al.* 1987; McIlroy and Gifford 1988; Fleming and Parker 1991; Parfitt *et al.* 1994; Saunders *et al.* 2000; Twigg *et al.* 2000; Twigg and Socha 2001; Twigg *et al.* 2001). If 1080 is leached from the bait, the presence of defluorinating micro-organisms will ensure that 1080 will not persist in the environment (Twigg *et al.* 2000). However, given that degradation is not consistent for each bait substrate (e.g. Wong *et al.* 1991; Saunders *et al.* 2000; Twigg *et al.* 2000; Twigg *et al.* 2001), the longevity of each bait type needs to be assessed with these considerations in mind. These considerations are the focus of Chapter 2.

Bait palatability and caching

Bait should be attractive and highly palatable to ensure that the target species will find and consume the bait upon discovery (Allen *et al.* 1989). However, several studies have shown that significant proportions of baits removed by foxes may not be consumed but stored, instead (Saunders *et al.* 1999; Thomson and Kok 2002); this caching may therefore entail a 'waste' of bait, and potentially reduce the efficacy and cost-effectiveness of baiting programs (Van Polanen Petel *et al.* 2001). Additionally, there may be concerns for the safety of non-target species where baits are cached, and hence are unable to be retrieved.

Caching is related to the palatability of the food, food availability and nutritional status of the predator (Scott 1943; Macdonald 1976; Van Polanen Petel *et al.* 2001); it is likely therefore that the intensity of caching will fluctuate seasonally with food availability and the annual reproductive cycle. It is important to assess the rate of bait caching for bait types across different seasons, and this issue is explored further in Chapter 3.

Bait aversion

All mammals can develop aversion to particular food materials (Prakash 1988). Bait aversion, or an acquired aversion to poison bait, is known to occur in many 'pest' mammal populations including rodents, possums (*Trichosurus vulpecula*) and coyotes (Sterner and Shumake 1978; Reidinger and Mason 1987; Prakash 1988; Hickling 1994) and usually results from the target animal ingesting a sub-lethal dose and becoming sick. This problem could potentially affect the efficiency of fox baiting programs, and is investigated in taste aversion trials in Chapter 4.

Baiting coverage

The long-term effectiveness of control programs is frequently hampered by the immigration of foxes back into areas from which they were removed (e.g. Molsher 1999). One strategy to counter this problem is to undertake control over relatively large areas, increasing the 'area to edge' ratio of the control area. This effectively isolates 'core' areas from most yearly immigrants by distance (Thomson *et al.* 2000). This strategy requires coordination between neighbouring landholders, especially where property sizes (or land management units) are relatively small. However, there have been few assessments to determine if this strategy is efficient, nor if it is being undertaken in an effective manner. I explore this issue using a case study in Chapter 5.

Pest abundance estimates

It is difficult to determine the efficacy of conventional poisoning programs since carcasses are rarely found, and typically used measures of abundance (e.g. spotlight counts) are inherently biased, or usually too variable to accurately detect changes in the abundance of the pest (Saunders and McLeod *in press*). This is especially true for the fox, where density seldom exceeds $4/km^2$ and individuals are often cryptic. Better techniques are needed to allow for meaningful monitoring of abundance, and hence improved monitoring of management programs. I investigate the utility of one alternative method, counting breeding dens, in Chapter 6.

1.7 Study aims

In consideration of the factors influencing baiting efficiency of the fox, the aims of this study are specifically:

1. To determine the longevity of commonly used bait types in the central tablelands environment;
2. To confirm the presence of defluorinating micro-organisms in soil in eastern Australia;
3. To investigate the seasonal caching of commonly used bait types by foxes;
4. To investigate the potential of conditioned taste aversion (CTA) to reduce multiple bait uptake by individuals;
5. To investigate the effectiveness of current fox control strategies on a landscape scale;

6. To investigate fox density in the central tablelands to assist in developing/refining monitoring techniques; and
7. To investigate the cost-effectiveness of identified baiting strategies

1.8 Study area

The study was conducted on agricultural lands near the town of Molong ($33^0$10’37”S, $148^0$87’15”E; Figure 1.1) on the central tablelands of New South Wales. Several properties in this district were used for different aspects of this study. Each will be explained in greater detail in subsequent chapters, where relevant.

The central tablelands is representative of the agricultural lands of south-eastern Australia, being highly disturbed and modified by land use associated with human settlement and development (Allan 1999). Most suitable farming and grazing country has been cleared (50% of natural vegetation has been lost: NSW National Parks and Wildlife Service (2002), resulting in a highly fragmented landscape consisting of remnant patches of natural vegetation surrounded by agricultural lands (Goldney 1987).

The Molong district is typically temperate with cool to cold winters and warm to hot summers (Sturman and Tapper 1996). The mean daily temperatures in July range between -0.1 – 12.9^0C while in January the mean ranges between 13.3 and 31.0^0C (Figure 1.2). The annual mean rainfall is 707 mm and mean monthly rainfall is reasonably consistent and is neither summer nor winter dominant (Gentilli 1972 in Sturman and Tapper 1996; Bureau of Meteorology 2003). Monthly rainfall varied considerably during the study period (Figure 1.3), and annual rainfall ranged between a high of 777 mm in 2000 to below 420 mm in 2002. The relationship between mean monthly rainfall and observed rainfall, presented as a cumulative deficiency plot, is presented in Figure 3.1.

The majority of the district is gently undulating, but topography ranges from river flats to rolling and steep hills. Rock intrusions (mainly Ordovician, Tertiary, or Devonian associated) in the form of knolls and ridges are common (Packham 1969). Soil groups include krasnozems, red earths and red podzolic soils to the east and south of the town, grading to less fertile solodic soils to the west and north (Dwyer 1978; Murphy and Eldridge 2001).

Figure 1.1: Location of the central tablelands area (shaded black) in New South Wales (main) and Australia (inset).

Plant communities in non-cropping areas typically consist of open pasture interspersed with remnant trees such as white box (*Eucalyptus albens*), apple box (*Eucalyptus bridgesiana*), yellow box (*Eucalyptus melliodora*), blakelys red gum (*Eucalyptus blakelyi*) and mugga ironbark (*Eucalyptus sideroxylon*), although some patches of woodland remain. River red gum (*Eucalyptus camaldulensis*), river oak (*Casuarina cunninghamiana*) and weeping willow (*Salix babylonica*) are found along the banks of streams (Dwyer 1978). Further west, grey box (*Eucalyptus woollsiana*), narrow-leaved ironbark (*Eucalyptus crebra*) and cypress pine (*Callitrus glauca*) replace *E. bridgesiana* and *E. sideroxylon* (Dwyer 1978).

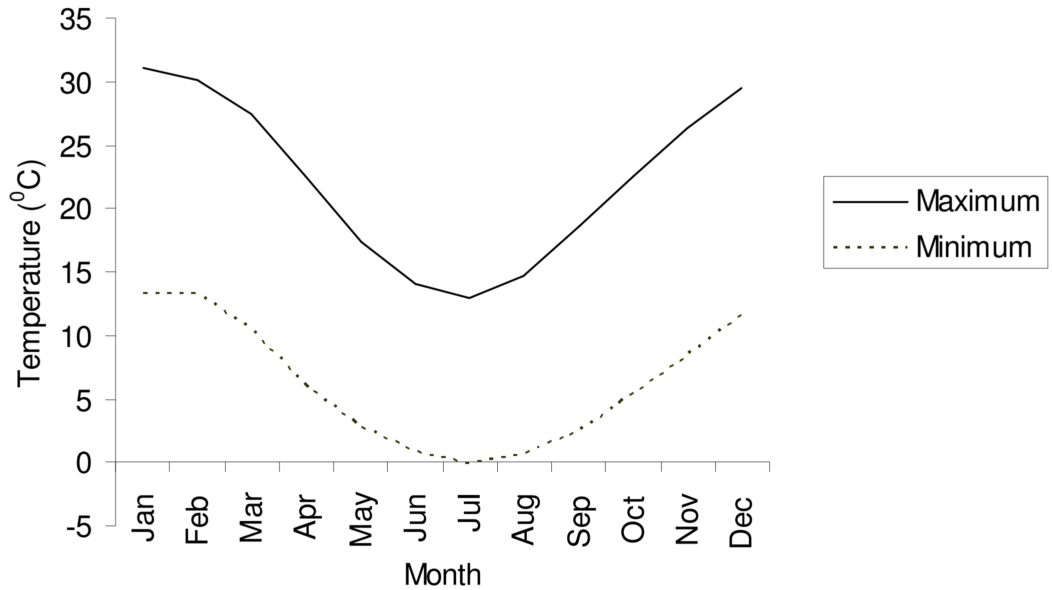

Figure 1.2: Mean daily minimum and maximum temperatures (^{0}C) for Molong from Bureau of Meteorology records (1884-2001).

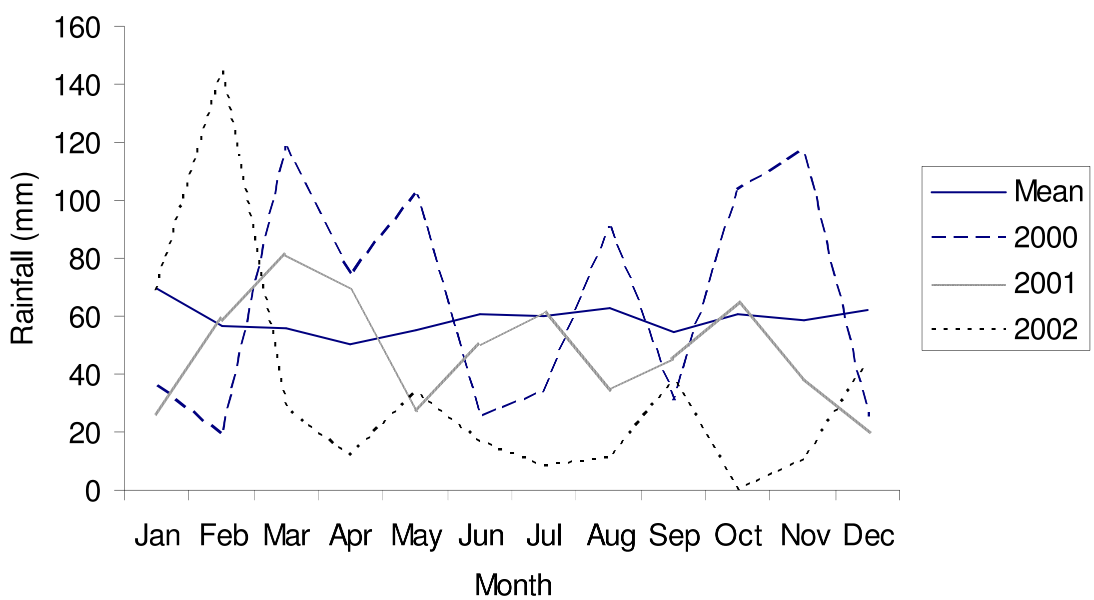

Figure 1.3: Mean monthly rainfall (mm) and the observed monthly rainfall prior to and during the study period (2000, 2001, 2002) for the town of Molong. Data sourced from the Bureau of Meteorology weather station at Molong, and monthly averages from historical records (1884-2001).

The central tablelands area produces a diverse range of agricultural commodities, with the higher altitude regions predominantly associated with horticultural enterprises with winter cereal cropping and sheep (meat and fibre) and cattle production more common on lower altitude lands. Extensive forestry (hardwood and plantation softwood) reserves also exist in patches throughout the region (Dwyer 1978; Australian Bureau of Statistics 2003).

Mammalian fauna

Settlement has brought about extensive, permanent changes to the environment and has led to the reduction and extermination of many indigenous species (Goldney 1987; NSW National Parks and Wildlife Service 2002). Regardless, many native species are reasonably common, including the eastern-grey kangaroo (*Macropus giganteus*), common wallaroo (*Macropus robustus*), swamp wallaby (*Wallabia bicolor*), common brushtail possum (*Trichosurus vulpecula*) and short-beaked echidna (*Tachyglossus aculeatus*).

Introduced free-ranging mammals that are common and widespread include foxes (*Vulpes vulpes*), hares (*Lepus capensis*) and mice (*Mus domesticus*), while rabbits (*Oryctolagus cuniculus*), feral cats (*Felis catus*), feral pigs (*Sus scrofa*) and feral goats (*Capra hircus*) are patchily distributed but may be locally abundant.

Selection of study area

The central tablelands area near Molong was chosen as the study area since it is broadly representative, in terms of land use, of a large region of New South Wales. Highly modified, fragmented landscapes like those on the central tablelands are highly suitable for foxes (Jarman 1986) and can support high density populations (e.g. Thompson and Fleming 1994). Conflict with land-use has meant that fox control is undertaken throughout the area, and is increasing at one of the highest rates throughout New South Wales (West and Saunders 2003). Additionally, much ecological research on foxes (e.g. Greentree *et al.* 2000; Molsher *et al.* 2000; Berghout 2001; McIlroy *et al.* 2001; Saunders *et al.* 2002a,b) has been undertaken in this region and are available to guide the current research.

1.9 Structure of the thesis

This thesis investigates factors affecting the efficiency of fox baiting in the central tablelands of New South Wales. It was motivated in part by acknowledgement from state government agencies (in particular the Department of Primary Industries) of problems associated with current management of foxes using poison baits, and in part by the lack of any solid theoretical or empirical underpinning of how such management should work.

The thesis consists of the present introductory chapter and 7 further chapters.

Chapter 2 compares the longevity of two commonly used bait types, Foxoff® and chicken wingettes, under field conditions on the central tablelands and western slopes of New South Wales. The presence and identification of soil micro-organisms capable of defluorinating 1080 in these areas is also investigated. The data were used to determine appropriate baiting strategies in terms of bait longevity and the potential for long-term environmental persistence and damage resulting from baiting campaigns.

Chapter 3 investigates the palatability and caching of Foxoff®, wingettes and day-old chicks under different seasons. Insights into caching behaviour are used to interpret the potential impacts of baiting campaigns and implications for baiting strategies

Chapter 4 assesses the use of conditioned taste aversion to reduce multiple bait uptake by individuals to improve the efficiency of baiting operations. Factors affecting the application of the technique in field situations are also investigated and discussed.

Chapter 5 documents the spatial and temporal coverage of baiting operations in the Molong Rural Lands Protection Board area. This case study is used to investigate baiting strategies on a landscape scale.

Chapter 6 determines fox density on one site on the central tablelands through evaluation of the density of breeding dens. The factors associated with finding and counting den locations and the implications of these for estimating fox density, are discussed.

Chapter 7 assesses the relative cost-effectiveness of using different bait types based on their longevity, palatability and cost during typical baiting strategies.

Chapter 8 is the general discussion. My findings are discussed in regard to other research, and the implications for management practices and directions for future research are considered.

CHAPTER 2

DEGRADATION OF 1080 IN BAIT AND SOIL

2.1 Introduction

Bait must retain its lethal dose of 1080 for a sufficient period to allow the target animal to find and consume the bait (McIlroy *et al.* 1986). A bait must also degrade so non-target hazards from the 1080 are reduced and long-term environmental persistence is avoided (Calver and King 1986). Considerable effort has often been invested in improving the attractiveness and palatability of bait without regard to 1080 persistence and longevity. Bait with long lasting toxicity will almost certainly provide a potential hazard to farm dogs and other non-target species (Twigg *et al.* 2000). Additionally, public concern about 1080 use for vertebrate pest control in Australia and New Zealand (King *et al.* 1994; Williams 1994; Oogjes 1996) supports the need to investigate, among other things, bait longevity and environmental persistence of 1080.

The longevity of 1080 baits can be considerably reduced by rainfall (Griffiths 1959; Wheeler and Oliver 1978). In eastern Australia, Foxoff® will lose approximately 78% of the initial 3 mg dose after 2.4 weeks in moist soil conditions (Saunders *et al.* 2000) but may remain at lethal levels for greater than 11 weeks when not exposed to rain. Unburied fresh meat bait (6.1 mg nominal dose) may be viable for between 6-12 months in the drier conditions of central Australia (Twigg *et al.* 2000) compared to less than two months in more temperate areas (McIlroy and Gifford 1988; Fleming and Parker 1991). Egg baits injected with 4.5 mg of 1080 remain lethal to foxes for at least 6 weeks, even after considerable (>80 mm) rainfall (Twigg *et al.* 2001). Kirkpatrick (1999) found that buried dried meat baits can remain lethal to foxes after 7 weeks if exposed to little rainfall, but when exposed to moderate rainfall only last about one week. These studies indicate that rainfall and climate are important determinants of bait longevity, and should be included as factors in investigating any bait intended for widespread use in fox control programs.

Chicken wingettes have been used as 1080 fox baits in New South Wales since their introduction in 1998 as a substitute for chicken heads. Preliminary trials observed that chicken wingettes had reduced leakage compared to red meat (T. Abblett, Wentworth Rural Lands Protection Board, pers. comm. 2001), suggesting greater 1080 retention and operator safety. Chicken wingettes are also seen to offer several advantages relative to other bait types including high palatability to foxes and, in turn, a low incidence of caching; reduced longevity and thus reduced withholding periods in high rainfall areas; and low cost in comparison to some other bait types (D. Bate and D. Croft, NSW Department of Primary Industries and Fisheries, pers. comm. 2002). These, however, are only perceptions and require supporting experimental evidence. No studies to date have assessed 1080 longevity in chicken wingettes or any other chicken substrate. Given that their use is becoming increasingly popular (West and Saunders 2003), bait degradation trials are necessary to determine the toxicity of wingettes over time and for different rainfall and climatic conditions.

Microbes found in bait materials are capable of defluorinating 1080 (Wong *et al.* 1991). Primary processing for poultry differs to red meat in ways that increase microbiological contamination and spoilage implications, suggesting that wingettes may have reduced longevity compared to other bait types. Chickens are scalded in hot water (~50^0C) to facilitate feather removal, and each bird contributes micro-organisms to the scald water which may then spread between birds (Frazier and Westhoff 1978; Adams and Moss 1995). Birds are defeathered using mechanically rotating rubber fingers which are liable to microbial contamination which may be passed from one carcass to another (Adams and Moss 1995). This problem is exacerbated since skin, and thus skin-associated organisms, are not removed (Frazier and Westhoff 1978). Additionally, poultry evisceration is normally automated and leads to a high rate of carcass contamination with gut contents (Adams and Moss 1995). These problems can lead to greater spoilage of chicken products and reduced bait longevity.

Apart from those found in the bait medium, micro-organisms capable of 1080 degradation may also be found in the soil environment. Defluorinating soil micro-organisms ensure that 1080 will not persist in the environment once removed from the bait (Twigg *et al.* 2000). Although some studies have determined the presence of defluorinating microbes in areas of

Western and Central Australia (e.g. King *et al.* 1994; Twigg and Socha 2001), no such studies have tested soils in eastern Australia. Given the high usage of 1080 in the eastern states for fox, wild dog, pig and rabbit control, the presence of defluorinating micro-organisms needs to be established to confirm that long-term environmental persistence of 1080 is not occurring in eastern Australia.

In New South Wales, RLPBs are responsible for preparing and distributing 1080 baits to landholders for baiting operations. Automated vaccination inoculators are often used to administer 1080 to meat baits (Korn and Livanos 1986; Fleming and Parker 1991), but 0.1 ml graduated insulin syringes are often used (e.g. Molong, Central Tablelands and Cooma RLPBs) since they require no initial calibration and are disposable. Inoculators deliver an accurate dose (Korn and Livanos 1986) but the accuracy of insulin syringes has not been assessed. This should be done to ensure field-prepared baits are consistently dosed with 1080.

In this chapter, the rate of 1080 degradation in chicken wingettes for two climatic and 3 rainfall regimes are investigated to assess the potential longevity of wingettes for fox control programs in eastern Australia. The degradation of wingettes relative to Foxoff®, another commonly used bait type, is compared for the central tablelands and western slopes of New South Wales, from original and historical data (Saunders *et al.* 2000). Decay models are constructed to examine the relationship between 1080 loss and rainfall, and to provide a predictive model for bait longevity for each bait type under likely climatic conditions. Additionally, the graduated syringe injection technique for bait preparation is examined and 1080 assay method is critically assessed. The presence of defluorinating soil bacteria in eastern Australia is investigated to provide evidence for environmental degradation of 1080. Finally, the likely determinants of 1080 loss from bait and the implications of these findings for baiting programs are discussed.

2.2 Methods

2.2.1 Study sites

The study was undertaken at Trangie Research Station (31^{0}98'61"S, 147^{0}94'89"E) and Orange Agricultural Institute (33^{0}32'39"S, 149^{0}08'36"E) in New South Wales. Trangie Research Station (TRS) is situated 5 km west of Trangie on the central western slopes and plains and is predominantly composed of native grassland for grazing and small areas of flood irrigation for cotton and lucerne pasture (Robards and Michalk 1975). The dominant soil group at TRS is the red-brown earths (Downes and Sleeman 1955), which is a light textured soil typical of those found in western New South Wales (Murphy and Eldridge 2001). The Orange Agricultural Institute (OAI) is situated on the southern outskirts of Orange on the central tablelands, and comprises mainly improved pastures for sheep and cattle grazing. The dominant soil at the site is a basalt derived deep red krasnozem. Both sites are representative of typical farmland where fox baiting is likely to undertaken by farmers in each region.

2.2.2 Treatments

The OAI trial began on the 5th October and was completed on the 14th December, 2001 and the TRS trial between 11th October and 21st December, 2001. Baits were buried on Day 0 and removed at weekly intervals for a total of 10 weeks. Methods were similar to those of Saunders et al. (2000) to allow for comparison of results.

At OAI, there were 3 treatments undertaken, each consisting of chicken wingettes exposed to a different rainfall regime. The treatments were:

1. Mean weekly rainfall
2. Prevailing rainfall
3. No rainfall

The amount of artificial rainfall applied to the treatment 'Mean weekly rainfall' was calculated from the long-term weekly rainfall averages for the trial period (October-December) for OAI. At OAI, the treatment 'Mean weekly rainfall' required applying a measured amount of artificial rainfall at weekly intervals. ‘Prevailing rainfall’ offered no protection to the bait. ‘No rainfall’ consisted of protecting the bait so no natural or artificial rain was applied during the trial period. At TRS, there were two bait types tested, Foxoff® and chicken wingettes (hereafter called wingettes); both bait types were subjected to the treatment ‘Prevailing rainfall’ only.

All baits were prepared and/or stored as per the standard for fox control programs in New South Wales. Wingettes were injected with a 0.1 ml dose of 30 mg mL^{-1} 1080 stock solution (92% pure Rentokil Tenate brand 1080) to give a 3 mg nominal dose. Graduated (1 ml) insulin syringes were individually filled to 0.1 ml and injected into the area of muscle between the radius and ulna bones in each wingette. A sample of insulin syringes (n = 3) was calibrated to ensure doses were accurate and repeatable. A 5 g sample of the powder concentrate was stored at room temperature and 10 ml sample of each stock solution was frozen for later analyses. Foxoff® baits are commercially manufactured and do not require injection with 1080. All Foxoff® were from the same manufacturing batch and were shelf-stored until use. Baits were randomly allocated to treatments, and stored in plastic bags.

Level burial sites at TRS and OAI were selected to avoid water-run-off from surrounding areas and fenced to exclude stock. Baits were buried 5 cm below the surface to emulate the recommended bait placement procedures for baiting operations on agricultural lands within New South Wales (Environment Protection Authority 2002). A soil corer was used to ensure that all baits were buried at the same depth. Baits were buried in 300 mm lengths of 100 mm diameter PVC stormwater pipe that had previously been buried to a depth of 200 mm. The PVC pipe sheltered the bait from runoff from surrounding soil but allowed normal micro-organism activity (Saunders *et al.* 2000). All baits were positioned at least 50 cm apart. The top of the each PVC pipe for the treatments ‘No rainfall’ and ‘Mean weekly rainfall’ was covered with a transparent 250 mm x 250 mm square of Laserlite 2000® (Laserlite, Cheltenham, Victoria) held in place by a small weight. This sheeting allowed the soil on top of the bait access to light and air, but protected it from natural rainfall. All baits were covered with predator-proof mesh cages to prevent their disturbance or removal by animals and birds. The cages were manufactured from a 750 mm diameter circle of 3/8” steel rod covered with a

1m high cylinder of galvanised chicken mesh, enclosed at one end. At weekly sampling periods, 5 baits from each treatment were removed and placed in individually numbered plastic bags. All retrieved baits remained frozen at -18^{0}C until analyses. Freezing at this temperature stops microbial growth (Adams and Moss 1995) and therefore further defluorination, without affecting 1080 recovery (R. Parker, Department of Natural Resources and Mines, pers. comm. 2002). An 80 g sample of soil was removed from directly underneath each bait, placed in a foil tray, weighed, and oven dried at 80^{0}C for 3 days to calculate soil moisture levels.

Rainfall (mm/day), minimum and maximum ambient temperature (^{0}C) were recorded daily on each site. Soil temperature at 10 cm was recorded daily at OAI and on week days at TRS.

2.2.3 1080 content assays

The 1080 content of bait was assayed by gas chromatography based on the method by Ozawa and Tsukioka (1989) and conducted by the Alan Fletcher Research Station, Queensland Natural Resources and Mines using their routine 1080 analyses procedures (Hannan-Jones 2002; Hannan-Jones 2003): each bait was individually blended with distilled water, and coarse filtered. The extract was divided and half kept for backup. Fluroacetate is then adsorbed onto an anion-exchange resin and eluted with 2% (W/V) sodium chloride solution. The eluent was acidified with hydrochloric acid and treated with 2,4-dichloroaniline and N,N'-dicyclohexylcarbodiimide. A reaction between the mixture and ethyl acetate derived fluoroacetate dichloroanilide, which was quantified with electron-capture detection by gas chromatography and gas chromatography-mass spectrometry. Assays were undertaken in runs with each run corrected for contamination and level of determination using comparisons between negative and positive controls and within positive controls. Each bait was adjusted for 67% recovery within runs as calculated from spiked fresh meat controls (n=6). The detection levels were greater than 0.07 mg. (Ozawa and Tsukioka 1989; Hannan-Jones 2002; Hannan-Jones 2003).

The purity of the stock solution and concentrate powder was tested using the derivation from the high performance liquid chromatography method (HPLC) (Kramer 1984), where the concentration of the bromophenacyl bromide fluroacetate is compared and confirmed with that of library standards or run standards (Hannan-Jones 2002). The determination level was 50 ug mL^{-1}.

2.2.4 Soil micro-organisms

Soils from OAI and TRS sites were collected to investigate the presence and capability of 1080 defluorinating soil micro-organisms. During Week 5 at TRS and Week 6 at OAI, a 30 g soil sample was removed from 5 cm below the surface at three sampling positions in each enclosure. Each sampling position was at least 50 cm from the nearest bait and protective cage. The soil samples were stored in individual 70 ml sterile containers at 7^0C until analyses.

2.2.4.1 Defluorinating activity of soil micro-organisms

The defluorinating activity of soil micro-organisms from each site was monitored after 7 days. Unautoclaved soil from each site (10 g), together with 40 ml of deionised water and 1 ml of 20 mM 1080 solution was kept at 27^0C in an orbital shaker (180 rev min^{-1}) for 7 days. The concentration of fluoride ions (F^-) were then measured using an Orion fluoride electrode (model 94-09-00), an Orion® EA 940 expandable ion analyser, an Orion single junction reference electrode 90-01 and an Orion automatic temperature compensation probe. Fluoride ions will bind to soil particles (Barrow and Shaw 1977). The extent of the binding was calculated by adding a known amount of fluoride ions to sterile soil, which was then allowed to stand for 24 h before measuring F^- concentration. Additionally, background levels of F^- in soil samples, 1080 solution and deionised water were measured. The amount of 1080 defluorinated by each isolate was calculated by assuming that the 20 mM 1080 solution contained 380 ug of F- (Twigg *et al.* 2001). The F^- concentrations resulting from defluorination were determined by subtracting the concentration of F- in a negative control from the measured F- concentration. Final concentrations were adjusted for dilution factors, binding of F^- to soil (and filter paper) and background F^- levels in soil, deionised water and 1080 solution.

2.2.4.2 Isolation of micro-organisms

Isolation methods were based on Bong *et al.* (1979), Wong (1992), Twigg *et al.* (2000) and Twigg and Socha (2001). An enriched broth using deionised water containing 2 g 1^{-1} KH_2PO_4 and 1 g 1^{-1} $(NH_4)_2SO_4$ adjusted to pH 6.8 using a few drops of 0.1M NaOH was made for bacterial incubations. For fungal incubations, the broth contained traces of 0.2 mg $1^{-1}$$CaCl_2$ and 10 mg 1^{-1} $FeSO_47H_20$ and adjusted to pH 5.6 with a few drops of 0.1M NaOH. The broths were autoclaved 3 times at 121^0C and 15kPa for 15 minutes and left to cool to <50^0C before adding 20 mM of filter sterilised (0.22 um Millipore) 1080 solution. This solution was dispensed in 10 ml aliquots into 120 ml polycarbonate bottles before adding 1 g of air dried soil to each bottle. Three replicates were undertaken for each site. Each bottle was incubated at 27^0C on orbital shaker (180 rev min^{-1}) for 10 days. A 100-fold dilution was made from each of the culture broths and plated onto either nutrient agar (NA) for bacteria, or potato dextrose agar (PDA) for fungi. Bacterial NA plates and fungal PDA plates were incubated at 27^0C. Single colonies were subsequently subcultured onto NA and PDA to ensure purity. Bacterial cultures were stored in Microbank® tubes at -80^0C. Whole-cell fatty acid methyl ester profiles of the bacterial isolates were determined using the Microbial Identification System® (MIS, Microbial ID, Inc. (MIDI), Newark, DE, USA). Bacteria were grown on trypticase soya broth (BBL) with agar (15 g L^{-1}) for 1 day at 27°C. Fatty acids were extracted and analysed using a Hewlett-Packard® 6890 Gas Chromatograph. The extraction process followed the sample preparation procedures described in the Microbial Identification System Handbook. Fatty acid peak areas were identified with the peak-naming component of this system and quantified. The fatty acid profiles of the isolates were compared with known reference strains in the MIS database, which generated a similarity index to express how close the profiles of bacterial isolates were to the mean fatty acid composition of their nearest species match. The fungal species were identified using morphological characteristics as described by Pitt (1988) and Domsch *et al.* (1993).

To ensure isolates were from the soil collected and were not laboratory contaminants, 2 replicates of sterile soil (autoclaved at $121^{0}C$ for 15 mins) from each site were incubated and plated onto NA and PDA. No micro-organisms were isolated from sterile soil incubations.

2.2.4.3 Defluorinating activity of microbial isolates

The isolated fungal and bacterial species were determined for individual defluorinating ability when grown in solution of 20 mM of 1080 with trace elements (bacteria: 2 g 1^{-1} KH_2PO_4 and 1 g 1^{-1} $(NH_4)_2SO_4$ adjusted to pH 6.8; fungi: 0.2 mg 1^{-1} $CaCl_2$ and 10 mg 1^{-1} $FeSO_47H_20$ and adjusted to pH 5.6) and with 10 g of sterile soil. Soil was sterilised 3 times by autoclave at $121^{0}C$ and 15kPa for 15 minutes. Bacterial suspensions containing 1.5 x 10^9 cells ml^{-1} were prepared from cultures < 72 hours old into 1 ml of 20 mM 1080 and 20 ml of broth. Fungal suspensions were prepared by scraping off aerial mycelium from cultures <72 hours old into 1 ml 20 mM 1080 solution and 20 ml of broth. Two replicates were done for each isolate.

Bacterial and fungal broths were incubated for 28 days at $27^{0}C$ in sterile 120 ml polycarbonate bottles. Each bottle was then centrifuged and the suspension filtered using Whatman No. 4 filter paper. A 10 ml sample of the supernatant was added to 40 ml of deionised water for F^- measurement. The amount of 1080 defluorinated was determined by measuring free F^- using a F^- electrode, and corrected for binding and dilution.

2.2.5 Statistical analyses

Regression analysis was used to model the changes in 1080 concentration over time, and to provide a predictive model of the decay rate (Twigg *et al.* 2000). Random regression models were chosen; this regression gives an overall mean response and allows for variable decay rates for different samples as well as random variation within a sample over time (e.g. Thompson and Beacon 1997). This is biologically intuitive, given the random variation in 1080 concentration between baits and within baits over time. Changes in the log 1080 concentration of baits over time were modelled using a random regression model. Included in the model for a given site/year were fixed regression effects for bait type and treatment.

Letting $Y_{ijk}(t)$ denote the log 1080 concentration for the k^{th} bait of type i (i = 1 for foxoff, 2 for wingette) with treatment j (j = 1 for mean weekly rainfall, 2 for prevailing rainfall, 3 for no rain) at time t, the model fitted is:

$$Y_{ijk}(t) = \mu + \alpha t + \beta_i t + \tau_j t + \gamma_{ij} t + b_{ijk} t + e_{ijk}(t)$$

where:

μ is the target log concentration at time zero

α is the overall mean regression

β_i allows differences in regression for different bait types

τ_j allows differences in regression for different treatments

γ_{ij} allows interaction between bait type and treatment with respect to regression

b_{ijk} are random regression deviations

$e_{ijk}(t)$ is random error for bait k of treatment j and type i when sampled at time t.

At time zero, given all baits have the same target concentration, the model is

$$Y_{ijk}(0) = \mu + e_{ijk}(0)$$

It is assumed for the analyses that b_{ijk} are independent $N(0, \sigma)$ random variables, the $e_{ijk}(t)$ are independent $N(0, \sigma)$ random variables and the b_{ijk} and $e_{ijk}(t)$ are independent. This model was used for analyses within a site, but was later extended for comparisons between sites. Differences in the mean regression parameter for the log 1080 concentration for bait types and treatments were examined using ANOVA procedures. The model was fitted to data only up to the time (t) that all subsequent baits had no detectable 1080. As results were recorded as zero, when 1080 was undetectable (ie. <0.07 mg: Hannan-Jones 2002, 2003) the data used in the model corresponds to log (x+0.06) with x the recorded 1080 concentration.

Model parameters were estimated using residual maximum likelihood (REML) to reduce bias associated with estimation of the fixed parameters (Venables and Ripley 2002).

Marginally, for a given *i*, and *j*, $Y_i(t) \sim N\left(\alpha + \beta_i t + \tau_j t + \gamma_{ij} t, t^2\tau^2 + \sigma^2\right)$ hence for a given concentration *c* we can determine that time (*t*0 say) such that

$$P(Y_{ijk}(t) \le c) = p$$

from

$$P(Y_{ijk}(t) \le c) = \Phi\left(\frac{\left[c - \mu + \alpha t + \beta_i t + \tau_j t + \gamma_{ij} t\right]}{\sqrt{t^2 \sigma_R^2 + \sigma^2}}\right)$$

where

$$c = (\Phi^{-1}(p) * \sqrt{t^2}\,\sigma_R^2 + \sigma^2) + \mu + \alpha t + \beta_i t + \tau_j t + \gamma_{ij} t$$

and

$$\left[\left(\Phi^{-1}(p)\right)^2 \sigma_R^2 t^2 - \alpha t^2 + \beta_i t^2 + \tau_j t^2 + \gamma_{ij} t^2\right] - \left[\alpha^2 ct - \alpha\beta_i t - \alpha\gamma_{ij} t\right] +$$
$$\left[c^2 - 2c\mu + \mu^2 + \left(\Phi^{-1}(p)\right)^2 \sigma^2\right] = 0$$

which corresponds to

$$\therefore a x^2 + bx + c = 0$$

so, the solution is

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

This expression was used to estimate the 0.05 and 0.95 quantiles, the proportion of baits that are at concentration Y for any given *t* (weeks).

2.3 Results

2.3.1 Weather data

The daily recorded rainfall for TRS and OAI for the period before, during and after the study period is shown in Figure 2.1 and 2.2 respectively. The rainfall that fell in each month of the trial periods and relationship relative to the long-term median rainfall for TRS (1922-2001) and OAI (1966-2001) are shown in Table 2.1.

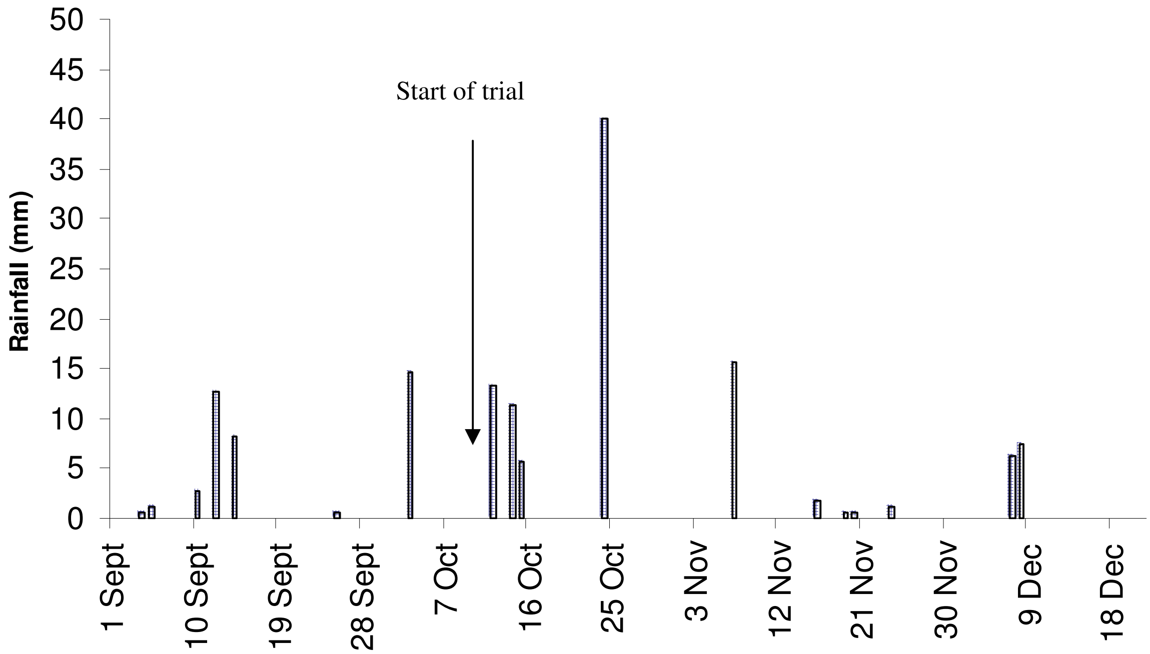

Figure 2.1: The recorded daily rainfall for TRS for the period immediately before and during the study period, specifically the 10th October to 21st December 2001.

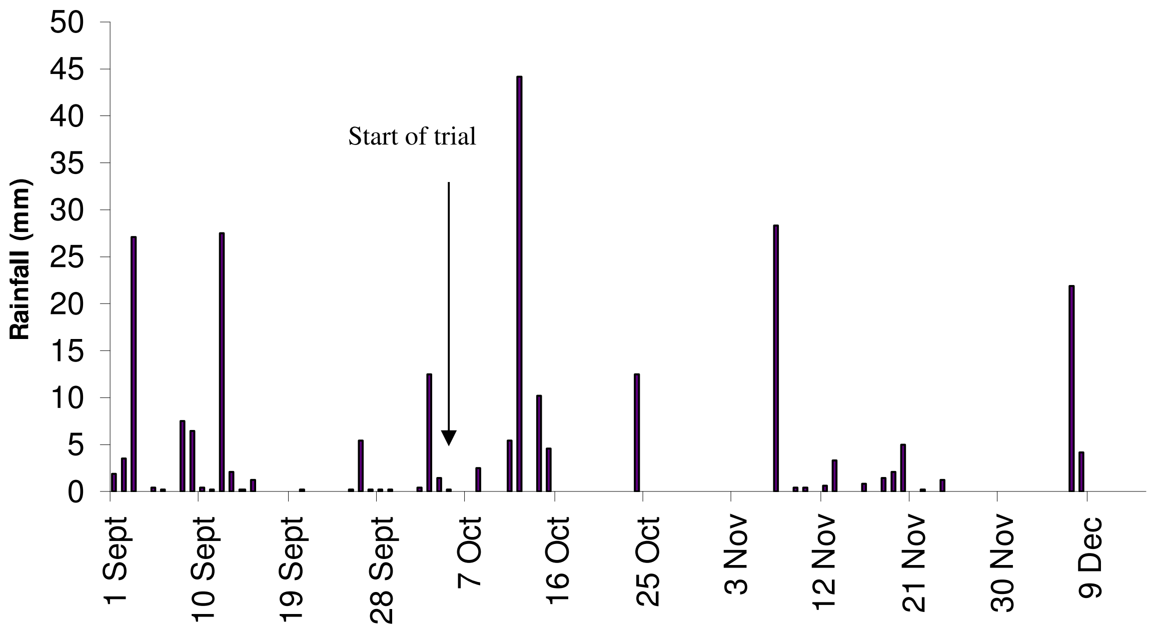

Figure 2.2: The recorded daily rainfall for OAI for the period immediately before and during the study period, specifically the 5th October to 14th December 2001.

The amount of rainfall that fell during the trial period at both OAI (164.9 mm) and TRS (82.1 mm) was less than the long-term median average for both sites (296.6 mm and 155 mm respectively). Rainfall at OAI was identical to the average in the month leading up to the trial (September), slightly higher (+12.2 mm) during October, but was considerably less than average in November (44.0 mm cf. 66.0 mm) and December (26.9 mm cf. 63.0 mm). At TRS the pattern of rainfall was broadly similar to OAI: the amount of rainfall was similar to the long-term mean for September (-2.3 mm), but considerably more fell in October (48.9 mm cf. 34.8 mm). Rainfall for November (19.6 mm) and December (13.6 mm) was less than the average (36.4 mm and 32.2 mm respectively). The 1997 trial at OAI was also lower than average, with only 260 mm falling during the trial period. A higher than average amount (117.3 mm) fell in the month before the trial (September), but less than average fell in October (51.0 mm), November (37.8 mm) and December (61.4 mm).

Table 2.1: The amount of rainfall (mm) that fell in the month prior to and during the trial period for OAI and TRS in 2001. The amount of rainfall (mm) that fell is shown relative to the long-term average (Median); for example +32 is 32 mm greater than the median.

Site	September		October		November		December	
	Rainfall (mm)	$\pm$ Median	Rainfall (mm)	$\pm$ Median	Rainfall (mm)	$\pm$ Median	Rainfall (mm)	$\pm$ Median
OAI	85.0	0	94.0	+12.2	44.0	-22.0	26.9	-36.1
TRS	26.0	-2.3	48.9	+14.1	19.6	-16.8	13.6	-18.7

The ambient temperature and soil temperature for the trial period is shown for TRS in Figure 2.3 and OAI in Figure 2.4. The average daily maximum (28.7^{0}C) and minimum (13.1^{0}C) at TRS were consistently greater than at OAI (19.2^{0}C and 7.5^{0}C respectively). Soil temperature at 10 cm was less variable than the ambient air temperature but still reflected the site differences. The average for TRS (21.2^{0}C), was over 6^{0}C warmer than OAI (14.6^{0}C).

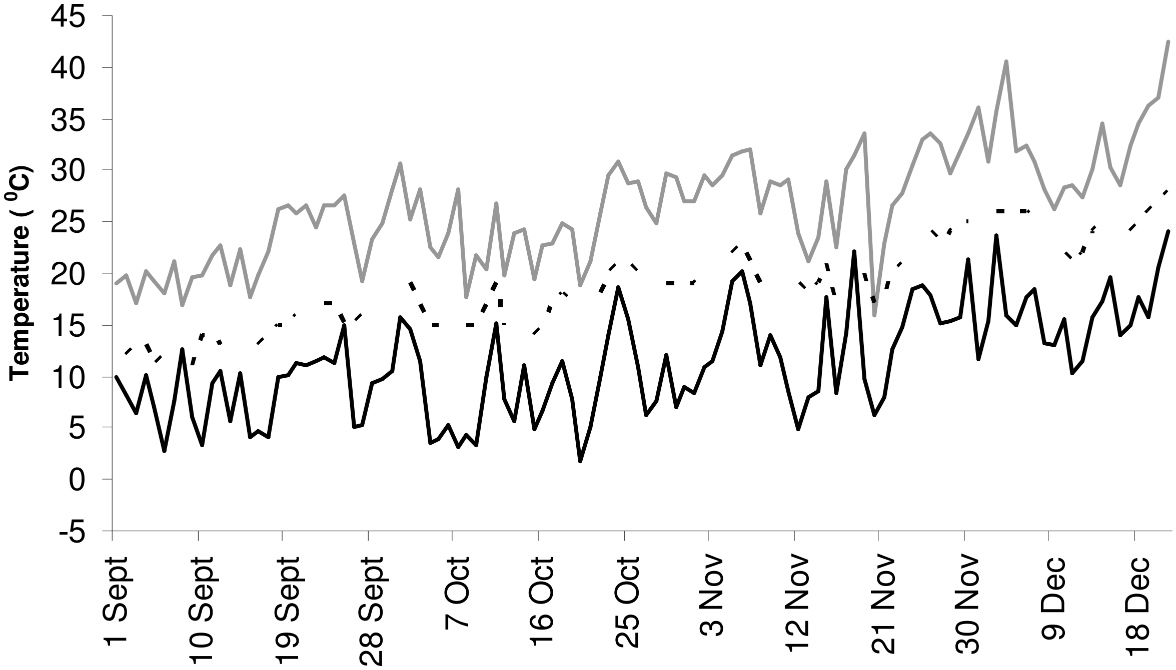

Figure 2.3: Daily ambient and soil temperature at TRS for the period immediately before and during the study period, specifically the 10th October to 21st December 2001. Minimum temperature, solid black line; maximum temperature, solid grey line; and soil temperature, dashed line. Note: Soil temperature only collected during week days.

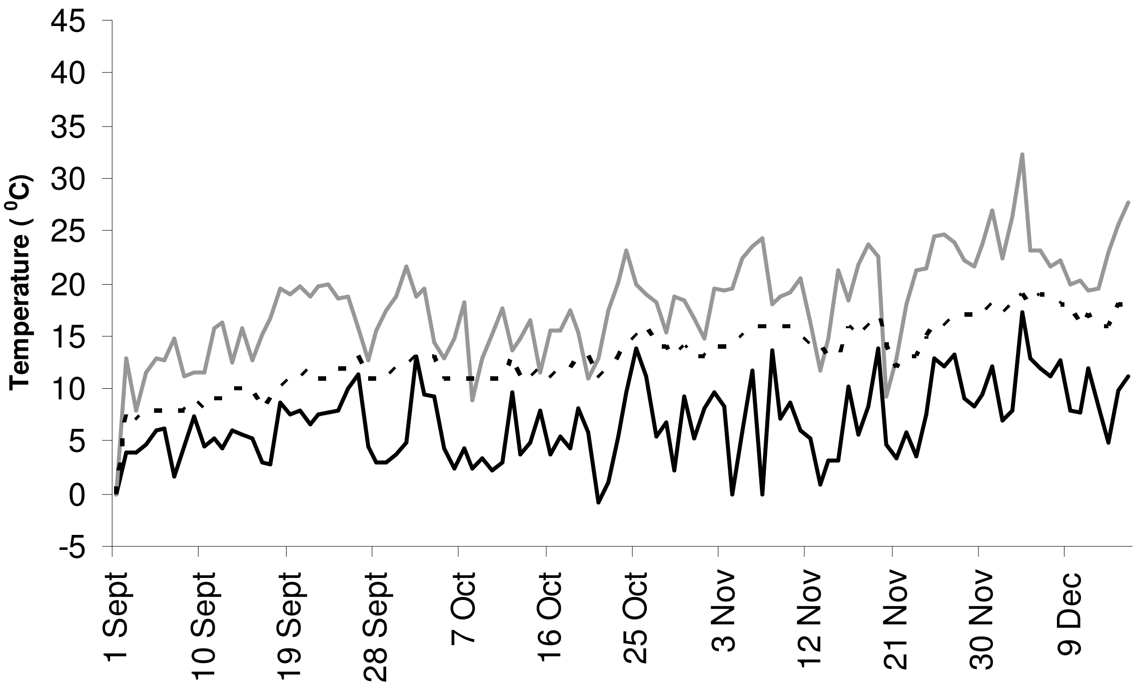

Figure 2.4: Daily ambient and soil temperature at OAI for the period immediately before and during the study period, specifically the 5th October to 14th December 2001. Minimum temperature, solid black line; maximum temperature, solid grey line; and soil temperature, dashed line.

2.3.2 Injection calibration and stock solution

There was little variation in the volume of stock solution delivered by the insulin syringe injecting method. The mean (± SD) amount of stock solution injected for a single dose using the syringe technique was 0.095± 0.003 ml (range = 0.089 - 0.102, n = 30). If the stock solution contained the nominal 30 mg ml^{-1} 1080 concentration, the mean dose injected into each bait would have been 2.85± 0.103 mg (expected range = 2.70 -3.05). Later analyses revealed that a sample of the stock solution contained 36.04 mg ml^{-1} at the time of preparing the OAI baits, and 31.96 mg ml^{-1} when the TRS baits were prepared. Aqueous 1080 solution stored at room temperature will remain stable for at least 12 months (L. Twigg, Department of Agriculture Western Australia, pers. comm. 2001), therefore the variation between the two samples is probably due to measurement error in the assay process (see Discussion). Therefore, a mean of the two solution sub-samples equates to an average dose of 3.23± 0.102 mg 1080 (range = 2.87 – 3.47).

2.3.3 1080 content

There was a large variation in the 1080 concentration of Day 0 baits. The mean (±SD) in Day 0 wingettes at TRS was 3.84± 0.85 mg (n = 8), and at OAI, 3.16± 1.53 mg (n = 3). Both OAI and TRS samples contained baits that had doses greater than 1.5 times the nominal dose of 3 mg. This is quite variable compared to the variation measured in the injection technique. The mean of the Day 0 Foxoff® baits was similar to the 3 mg nominal dose, but was still variable (2.97± 1.08 mg, n = 4).

2.3.4 1080 degradation

Not all replicates collected during this study were analysed for 1080 concentration. For Weeks one to four Statistical tests were only performed using data only up to the time where all subsequent baits had no detectable 1080. At OAI this included data up to and including Week 3; at TRS, up to and including Week 5.

An ANOVA comparing the 1080 concentrations of the treatments "mean weekly rainfall", "prevailing rainfall" and "no rain" for wingettes at OAI and the treatments "mean weekly rainfall" for both Foxoff® and wingettes at TRS indicated significant differences in the factors Time, Type of bait, Treatment and the interaction between Treatment and Time. As a result, a separate ANOVA was undertaken for each site to examine within site differences. Additionally, a Student-Neuman-Keuls (SNK) multiple range test (Snedecor and Cochran 1989) was undertaken to examine the relationship between each factor (Bait type, Site, Treatment) for each week of the trial.

The results from the ANOVA comparing the 1080 concentrations in the "mean weekly rainfall", "prevailing rainfall" and "no rain" treatments for wingettes at OAI indicated that there were significant differences in the factor Time but not Treatment (Table 2.2). There was also no interaction between Treatment and Time. This indicates that there was no significant difference in the decay rate of 1080 between the treatments during the course of the experiment. The treatments were combined given that there was no significant difference in the rate of 1080 degradation between treatments as indicated by the ANOVA and the SNK multiple range test.

Table 2.2: ANOVA of 1080 concentration per bait for wingettes for Treatments "prevailing rainfall", "mean weekly rainfall" and "no rain" at OAI, 2002.

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Treatment	2	0.404	0.202	0.280	0.758
Time	3	101.097	33.699	140.473	<0.001
Treatment * time	6	0.014	0.002	0.009	0.991
Residuals	22	15.833	0.720		

There was no significant difference in the rate of 1080 decay in wingettes at OAI and TRS for the treatment 'mean weekly rainfall' (Table 2.3). Moreover, both Site and the interaction between Site and Time were not significant. Nevertheless, a separate predictive model of the 1080 degradation of wingettes is presented for both TRS and OAI.

Table 2.3: ANOVA of 1080 concentration per bait for wingettes at OAI and TRS for Treatment "mean weekly rainfall".

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Site	1	4.366	4.366	2.509	0.127
Time	3	118.309	39.436	67.991	<0.001
Interaction of Site and Time	3	1.251	0.417	0.719	0.405
Residuals	23	40.022	1.740		

An ANOVA comparing the 1080 concentrations in wingettes and Foxoff® at TRS showed a significant difference in the Type of bait and Time, but no significant interaction between the Type of bait and Time (Table 2.4).

Table 2.4: ANOVA of 1080 concentration per bait for wingettes and Foxoff® at TRS, 2002.

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Type of bait	1	12.541	12.541	10.476	<0.001
Time	4	117.681	29.420	98.308	<0.001
Interaction of Type of bait and Time	4	2.198	0.550	1.836	0.189
Residuals	23	27.532	1.197		

Data from a previous study which measured the 1080 degradation rate of buried Foxoff® at OAI (Saunders *et al.* 2000) was compared with the rate of decay in wingettes collected in this study. An ANOVA was used to compare the rate of 1080 decay in Foxoff® and wingettes for the wet treatments common to both studies, "mean weekly rainfall" and "prevailing rainfall" (Table 2.5). A separate ANOVA was used to compare the dry treatments, "no rain" (Table 2.6). There was a significant difference between the wet treatments for Foxoff® and wingettes in the interaction between Type of bait and Time indicating a difference in degradation rates. The lack of significance in the Type of bait indicates that there was no difference in the amount of 1080 at the start of the experiment (Day 0). For the treatment "no rain", there was a significant difference in the rate of decay for wingettes and Foxoff®, indicated by a significant interaction between the Type of bait and Time. However, there was a significant difference in the rate of decay of the treatment “mean weekly rainfall” for Foxoff® at TRS and OAI (Table 2.7).

Table 2.5: ANOVA of 1080 concentration per bait for wingettes and Foxoff®, treatments “mean weekly rainfall” and “prevailing rainfall” at OAI.

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Type of bait	1	0.309	0.309	0.308	0.5803
Time	5	265.065	53.013	264.111	<0.001
Interaction of Type of bait and Time	5	11.874	2.375	11.834	<0.001
Residuals	111	111.385	1.003		

Table 2.6: ANOVA of 1080 concentration per bait for Treatment “no rain” for wingettes and Foxoff® at OAI.

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Type of bait	1	41.060	41.060	55.980	<0.001
Time	4	50.156	12.539	70.133	<0.001
Interaction of Type of bait and Time	4	10.377	2.590	41.152	<0.001
Residuals	65	45.438	0.699		

Table 2.7: ANOVA of 1080 concentration per bait for Foxoff® at OAI and TRS for Treatment “mean weekly rainfall”.

Source of variation	d.f.	s.s.	m.s.	*F*	*P*
Site	1	20.548	20.548	23.722	<0.001
Week	4	138.673	34.668	160.092	<0.001
Interaction of Site and Week	3	160.874	53.625	92.862	<0.001
Residuals	61	52.839	0.866		

A SNK multiple range test was undertaken to compare the mean 1080 content each week between all baits and all treatments undertaken in this trial. There was no significant difference in the amount of 1080 in all treatments at Week 0 (P>0.05). At Week 1 and Week 3, two separate groups were apparent; Foxoff® at TRS and the wingette treatments on both sites. At all other times there were no significant differences between the treatments (P<0.05). A second multiple range test compared the weekly mean 1080 content in Foxoff® at OAI from an earlier trial (Saunders *et al.* 2000) with Foxoff® and wingettes in this trial for the first 5 weeks. After Week 1, all Foxoff® treatments were significantly different (P<0.05) to all wingette treatments, both at OAI and TRS. During Week 2 and 3 results were inconclusive, there were no significant differences (P>0.05) between all treatments. At Week 4, three distinct groups were present; 1) the Foxoff® treatment "no rain" at OAI 2) Foxoff® treatments "mean weekly rainfall" and "prevailing rainfall" at OAI; and 3) all wingette treatments from OAI and wingettes and Foxoff® at TRS. At Week 5 only the Foxoff® treatment "no rain" was significantly different (P<0.05) to any other treatment.

The parameters in the random regression models for the bait types on each site are shown in Table 2.8. Although wingettes at TRS were not significantly different from OAI wingettes, the parameters are shown for comparison. A decay curve was then fitted to each treatment (Figures 2.5, 2.6 and 2.7).

Table 2.8: Fitted regression coefficients from the random regression models. The lower (5%) and upper (95%) confidence limits for each estimate are shown in parentheses.

Site	Bait type	Treatments	μ	α	b_{ijk}	e_{ijk}
OAI	Wing	1, 2, 3	1.05 (0.80, 1.31)	-1.46 (-1.67, -1.24)	0.42 (0.25, 0. 69)	0.34 (0.21, 0.57)
TRS	Foxoff®	1	1.26 (0.83, 1.70)	-0.79 (-1.06, -0.54)	0.46 (0.23, 0.96)	0.26 (0.12, 0.56)
TRS	Wing	1	1.37 (1.21, 1.53)	-1.46 (-2.09, -1.56)	0.23 (0.13, 0.38)	0.32 (0.17, 0.62)

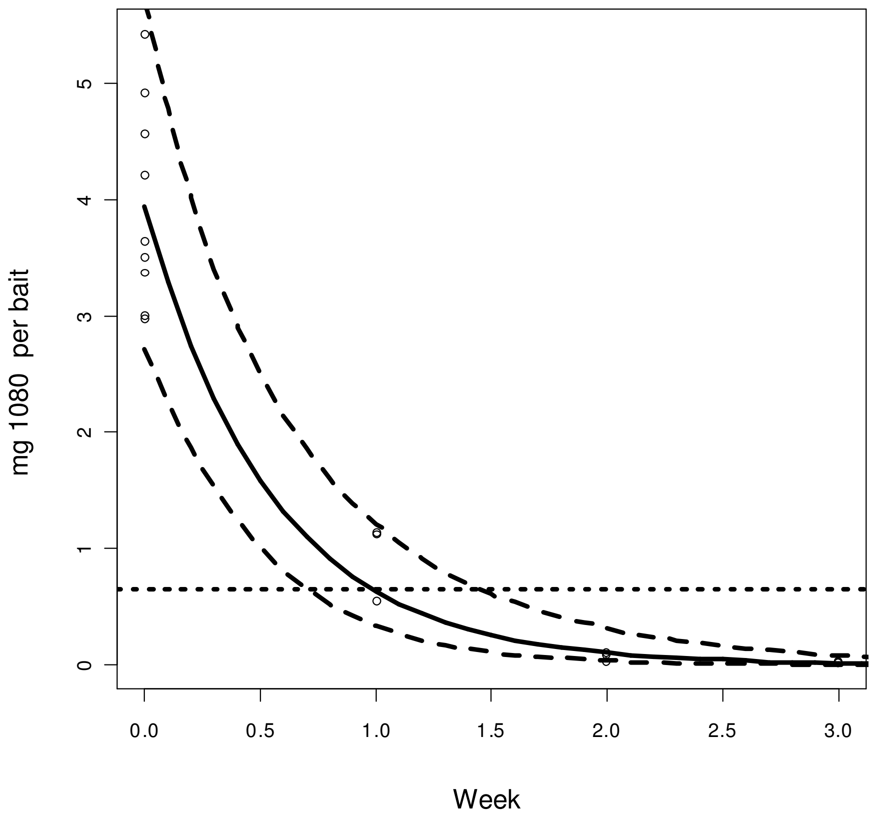

Figure 2.5: Fitted curves for the mean loss of 1080 (solid line) and 0.05 and 0.95 quantiles for wingettes at TRS exposed to ‘mean weekly rainfall’ up to and including three weeks after initial burial. Dotted line indicates minimum LD_{50} (0.65 mg) for a 5 kg fox.

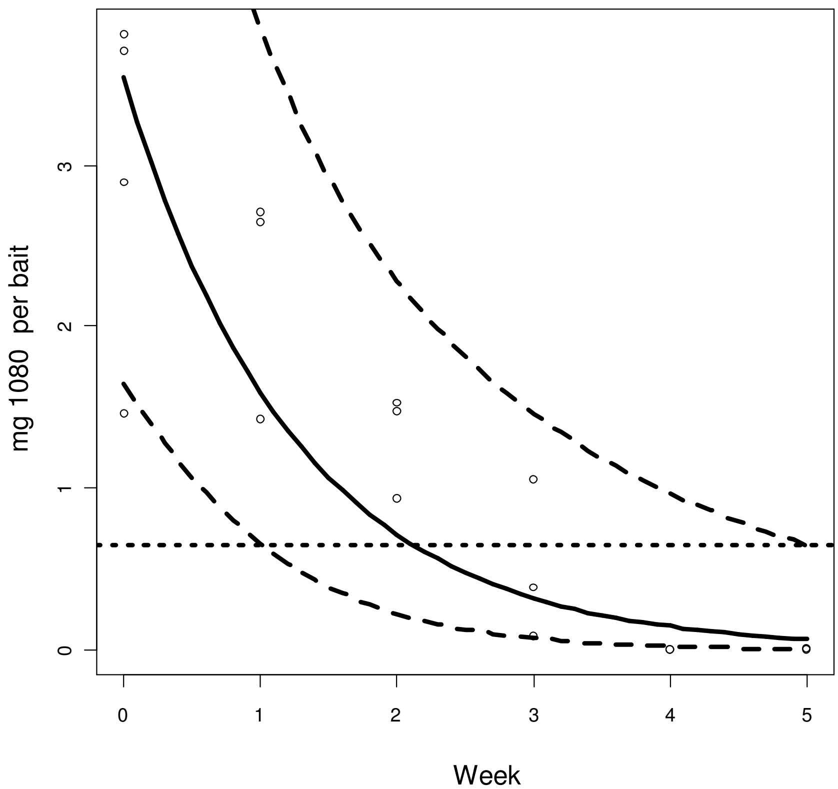

Figure 2.6: Fitted curves for the mean loss of 1080 (solid line) and 0.05 and 0.95 quantiles for Foxoff® at TRS exposed to 'mean weekly rainfall' up to and including five weeks after initial burial. Dotted line indicates minimum LD_{50} (0.65 mg) for a 5 kg fox.

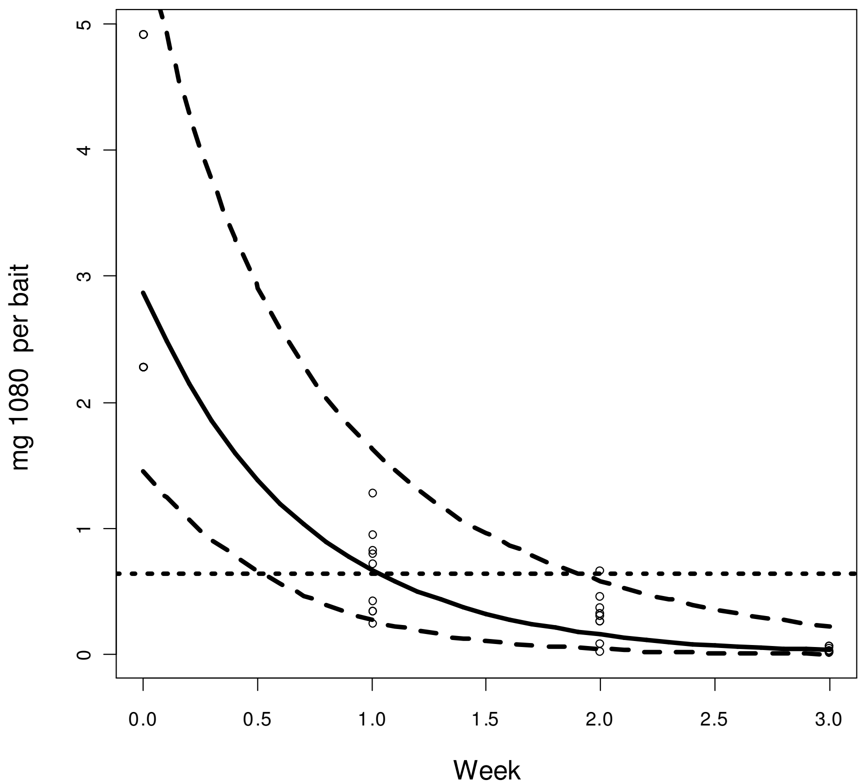

Figure 2.7: Fitted curves for the mean loss of 1080 (solid line) and 0.05 and 0.95 quantiles for wingettes at OAI exposed to 'mean weekly rainfall', 'prevailing rainfall' and 'no rain' up to and including three weeks after initial burial. Dotted line indicates minimum LD_{50} (0.65 mg) for a 5 kg fox.

A two-way fixed factor ANOVA of soil moisture content for all treatments at OAI indicated that there was no significant difference in the amount of moisture in each treatment ($F_{2,44}$ = 1.54, P>0.05) at any week ($F_{2,\ 44}$ = 1.75, P>0.05) or any interaction between week and treatment ($F_{4,44}$ = 0.65, P>0.05). Similarly, there was no significant difference between OAI and TRS wingettes treatment “mean weekly rainfall” for site ($F_{1,23}$ = 0.11, P>0.05), or time ($F_{3,\ 23}$ = 0.817, P>0.05) or interaction between the two ($F_{3,23}$ = 0.56, P>0.05).

2.3.5 Soil micro-organisms

A substantial amount of F^- was unable to be recovered from each soil. The mean recovery rate for adding 220-260 µg of F^- to 10 g of soil was 57.5±2.8%(SD, n=3) for TRS and 32.2±5.9% (SD, n=3) for OAI. The concentration of F^- in deionised water (0.0116±0.003 µg L^{-1} SD, n=3) and 20 mM 1080 solution (0.0374±0.006 µg L^{-1}, SD, n=3) was low but all values were nevertheless adjusted for these concentrations.

The defluorinating ability of unautoclaved soil from both sites was conflicting. TRS showed considerable defluorinating ability, with the micro-organisms defluorinating 47.8±17.7% (n=2) of added 1080 within 7 days. However, the amount of F^- released from the soil at OAI did not exceed the level of the sterile control after 7 days.

A total of thirty-one species of micro-organisms capable of defluorinating 1080 were isolated from the soils (Table 2.9 and 2.10). At TRS, 2 species of fungi, 9 species of bacteria, and 2 actinomycetes were isolated; at OAI, 14 bacteria, 5 fungi and 1 actinomycete were isolated. Two species of bacteria and 2 actinomycete species could not be identified. Actinomycetes are, taxonomically, a bacteria; given their significant differences in morphology and growth to the true bacteria (Bergy *et al.* 1989), they are categorised and presented separately here.

Defluorination by isolates

Ten isolates showed measurable defluorinating ability when grown in a 1080 and sterile soil suspension. Nine of these species were exclusively from the TRS soil, and one from OAI with one common species from both sites. The bacteria defluorinated an average of 27.9±25.2% of added 1080 (range = 0.3-76.5%), the actinomycetes averaged 12.6±5.25% (range = 7.3-17.8), and fungi 5.1±4.1% (range = 1.0-9.1). For each site, the micro-organisms at TRS averaged 18.4±20.3% defluorination and 56.6±14.5% at OAI.

Table 2.9: The mean percentage of 1080 defluorinated (n=2) by fungi isolated from soil at OAI and TRS in a solution containing 20 mM 1080 and 10 g of sterile soil incubated for 28 days at 27^{0}C. *No measure of variation (SD) available since only one replicate of isolate tested.

Micro-organism	Site	Mean F^- concentration ±SD	% 1080 defluorinated
Aspergillus versicolor	OAI	0	0
Monocillium sp. 1	OAI	0	0
Monocillium sp. 2	OAI	0	0
Penicillium regulosum	TRS	0.0359±0.011	1.02
Penicillium sclerotiorum	OAI	0	0
Penicillium sp. 1	OAI	0	0
Penicillium sp. 2	OAI	0	0
Penicillium sp. 3*	TRS	0.322	9.13
Scopulariopsis brumptii	OAI	0	0

Table 2.10: The mean percentage of 1080 defluorinated (n=2) by bacteria and actinomycetes isolated from soil at OAI and TRS in a solution containing 20 mM 1080 and 10 g of sterile soil incubated for 28 days at 27^0C. *No measure of variation (SD) available since only one replicate of isolate tested.

Micro-organism	Site	Mean F^- concentration $\pm$SD	% 1080 defluorinated
Acaligenes paradoxus	TRS	1.183$\pm$0.364	33.5
Alcaligenes paradoxus	TRS	0	0
Alcaligenes paradoxus	TRS	2.698$\pm$0.283	76.5
Alcaligenes paradoxus	TRS	1.475$\pm$1.581	41.8
Arthrobacter atrocyaneua	OAI	0	0
Arthrobacter oxydans	TRS	0.377$\pm$0.015	10.7
Bacillus cereus	OAI	0	0
Bacillus cereus	OAI	0	0
Bacillus flexus	OAI	0	0
Bacillus megaterium	OAI	0	0
Bacillus megaterium	TRS	0.326$\pm$0.364	9.2
Bacillus megaterium	TRS	0.011$\pm$0.016	0.3
Bacillus megaterium	TRS	0.435$\pm$0.229	12.3
Bacillus psychrophilus	OAI	0	0
Bacillus simplex	OAI	0	0
Bacillus thuringiensis kurstakii	TRS	0.199$\pm$0.196	5.7
Bordetella parapertussis	OAI	0	0
Burkholderia cepacia	OAI	1.486$\pm$0.559	42.1
Burkholderia glathei	OAI	0	0
Kocuria varians	OAI	0	0
*Micromonospora carbonacea**	OAI	2.506	71.0
*Micromonospora carbonacea**	TRS	0.488	13.8
Paenibacillus pabuli	OAI	0	0
Possible *Streptosporangium* sp.	TRS	0.629$\pm$0.133	17.8
Pseudomonas huttiensis	OAI	0	0
Streptomyces sp.	OAI	0	0
Streptomyces sp.	OAI	0	0
Streptomyces sp.	OAI	0	0
Streptoverticillium reticulum	OAI	0	0
Unknown	TRS	0	0
Unknown	TRS	0	0
Unknown	TRS	0.257$\pm$0.028	7.3

2.4 Discussion

2.4.1 Injection calibration and stock solution

The results of the calibration indicate that injecting baits with a 0.1 ml dose from a graduated 1 ml insulin syringe is an accurate and precise technique. The use of an automatic dispenser is highly accurate (e.g. 0.22$\pm$0.003 ml), but requires constant calibration since the volume increases with the number of injections (Fleming and Parker 1991). Insulin syringes are an acceptable substitute, especially for injecting smaller batches of bait where the extra time required to calibrate and clean a dispenser would negate any time savings.

The amount of 1080 in the stock solution for both TRS (31.96 mg ml^{-1}) and OAI (36.04 mg ml^{-1}) was greater than the nominal 30 mg ml^{-1}. This is most likely due to the high purity of powder (1139$\pm$ 131 g kg^{-1}) used to make the solution. The discrepancy between the purity stated on the label of each commercially manufactured tin (90%) and in the Material Safety Data Sheet (*minimum* of 90%) may result in a 10% error in the concentration of the bait-preparation solutions (Twigg *et al.* 2000). This is supported by the high purity of the 1080 powder used in this trial (100%) as confirmed by the laboratory analyses. As a result, Twigg *et al.* (2000) recommend that, in circumstances where the exact concentration of stock solution is required, such as in research trials, each tin should be assayed before it is used. I did not consider it important to assay the powder concentrate before use; it is irrelevant for consistent dosing (as occurs in the field) if the aqueous solution is up to 10% from the nominal concentration providing the same aqueous solution is used to prepare all baits within a trial and the amount injected is consistent there will be insufficient error to disrupt comparisons between baits and/or treatments. The variation between the two stock solution samples is at first worrying; the identical stock solution was used to inject both OAI and TRS baits, but the TRS baits were injected 5 days later. The relatively large difference in 1080 concentration seen here is unlikely to be caused by degradation of the solution. Two sources of error are possible; the solution may not have been uniformly mixed, resulting in some precipitation in the solution between injection periods or there is error associated with the assay process. The latter is more likely; the overall percentage recovery using spiked solutions was 106% (SD = 9.8%, range = 94.3-124%, n = 6) (Hannan-Jones 2002). The variation between stock solution samples seen here is within the spiked sample standard deviation (9.8%) of the mean of the two solutions (34 mg ml^{-1}). Given the variation in the technique it is probably safe to assume that the mean is approximately 34 mg ml^{-1} which is greater (13%) than the nominal concentration (30 mg ml^{-1}). This indicates that the mixing of the stock solution, originally calculated for a purity level of 90%, was accurate. To extend the recommendation of Twigg *et al.* (2001) to improve accuracy in baits prepared for field use, at least two replicates would be required to accurately determine the concentration of each tin. This would cost at least $120 per tin ($60+ per sample) which would add considerably to the cost of bait preparation. An accuracy improvement of up to 10% would probably not be worth this additional cost, especially given the measurement errors experienced in this study.

2.4.2 1080 content

The large variation in 1080 in the Week 0 baits has been reported before (e.g. McIlroy *et al.* 1986; Fleming and Parker 1991; Twigg *et al.* 2000) and could be due to a number of possibilities. A time lag between injection and analysis can result in poor recovery of 1080. Kramer (1984) suggested that this low recovery is due to enzyme reactions resulting in chemical transformation to a new organofluorine compound. Liquid chromatography (Kramer 1984) and Fluorine-19 nuclear magnetic resonance spectroscopy (Frost *et al.* 1989) methods measure the specific amount of fluoroacetate from 1080, whereas methods using the fluoride ion electrode are unable to distinguish between fluoride from fluoroacetate and other organofluorine compounds (Fleming and Parker 1991). Therefore, if fluoroacetate were being converted to organofluorine compounds by some metabolic process, the gas chromatography method used in this study would have been unable to detect or correct for such differences. However, Frost *et al.* (1989) were unable to detect any organofluoride compounds, indicating that conversion by metabolic processes was probably not responsible for the 'loss' of recoverable 1080. Frost *et al.* (1989) concluded that the incomplete recovery of 1080 is probably due to the binding of 1080 to the substrate in such a way that removal by aqueous solution is incomplete. Rigorous extraction techniques exchanging an alkaline solvent for water fails to increase the percentage recovery, suggesting that the 1080 is tightly bound to meat (Kramer 1984). This binding is time dependent; earlier studies that measured 1080 content immediately after injection found high recovery rates (90-94%, Livanos and Milham 1984) compared to much lower recovery rates (52 – 88%) when periods of several hours elapsed before assays were undertaken (Kramer 1984; Livanos and Milham 1984; Frost *et al.* 1989; Fleming and Parker 1991). In this study, Week 0 wingettes were injected and placed in the freezer within one hour, leaving a time lag of several hours before baits would have been frozen. This time lag could have been sufficient to facilitate binding, resulting in the low recovery rates of 1080 in wingettes. The 1080 is added to Foxoff® during manufacture and hence would also have considerable time before freezer storage to facilitate binding. Binding is generally not problematic since the use of positive controls (i.e. addition of a known amount of 1080) can be used to calculate the percentage recovery, which in turn is used to correct the measured samples. All baits were adjusted given the mean recovery of 1080 from spiked samples (assay #1, 66%, SD = 5.8%, range = 63-70%, n = 6; assay # 2, 68%, SD = 4.3%, range = 63-70%, n = 6.). However, the positive controls are used to all correct baits within an assay run, and not individual baits *per se*, therefore the variation in the amount of binding between individual baits may result in either under or overcorrection of 1080 content. There may be variability in the amount of binding due to variation in the composition of baits, or the injection site. For example, 1080 in bone tissue is usually 100% recoverable (R. Parker, Department of Natural Resources and Mines, pers. comm. 2003) compared to between 60-75% in meat (Hannan-Jones 2002; Hannan-Jones 2003). The amount of 1080 deposited in each tissue may differ between each injected bait, leading to variable recovery rates and hence under or overcorrecting of 1080 concentration. Conflicting recoveries within samples would cause error in correction estimates.

Despite considerable care being taken to inject the solution into the same position in each wingette, variation between wings probably exacerbates variation in recovery rates. The relative accuracy of the injection technique and the concentration of the stock solution support this conclusion. Variable recovery is less problematic after physical degradation, allowing for a more consistent recovery from the bait substrate. As meat physically degrades, the ability of 1080 to bind decreases, (Kramer and Merrell 1987) and the potential for leaching increases (e.g. McIlroy and Gifford 1988) suggesting more efficient water extraction, reducing variable recovery. Even though Week 0 baits showed large variation in recoverable 1080, the results from Week 1 onwards, when all baits showed signs of physical deterioration, probably would have been more consistent between baits. The remaining baits that were subject to field conditions were less likely to be affected by variable recovery and thus better reflect the true 1080 concentrations and losses from degradation processes.

Leakage or seepage of the stock solution from baits after injection is probably not responsible for the lower 1080 content of wingettes. Leakage does not affect the recovery of 1080 from meat baits unless a sufficiently large volume is injected to cause the solution to leak out. Only occasional leakage was reported by Kramer and Merrell (1987) during injections of a large amount of stock solution (1 ml) into thinly sliced fresh meat baits; no leakage was observed when the injected dose was halved to 0.5 ml. The small injection volume used in this study (0.1 ml) would mean that leakage would be even less likely. McIlroy and Gifford (1988) and Fleming and Parker (1991) observed little seepage at the time of injection from 0.2 ml injected baits. Additionally, Fleming and Parker (1991) found no trace of 1080 in the rinsings from the bag used to transport the baits to the field site. Seepage may be adsorbed to the surface of the baits (Korn and Livanos 1986) adding a multiplicable source of variation in 1080 content when many baits are transported within the same container since seepage from one bait may adhere to the surface of another (Fleming and Parker 1991). In this study, each bait was individually bagged so any seepage from one bait would have been unable to contaminate another. This indicates that if seepage did occur, it would only account for a loss of 1080 within baits and not contamination of 1080 from one bait to another. All the above arguments suggest that seepage is not an important contributor to the variation in the 1080 content in wingettes in this study.

It is difficult to determine the cause for the low 1080 content of one Foxoff® bait tested at Week 0. This bait may be an anomoly, associated with manufacturing or assay error. Recent batches of Foxoff® baits tested have shown little variation in 1080 concentration (2.74 ± 0.42 mg) (R. Parker, Department of Natural Resources and Mines, pers. comm. 2002). Variation appears more problematic with fresh meat-based baits, as noted in previous studies (Korn and Livanos 1986; Fleming and Parker 1991; Twigg *et al.* 2000). A recent study (A. Claridge, Department of Environment and Conservation, pers. comm. 2003) further illustrates this variation; fresh meat baits injected using insulin syringes for a 6.0 mg nominal dose averaged 5.97$\pm$1.49 mg (range = 4.23-8.60). Although it is impossible to confirm, the relative accuracy of the injection technique compared to the assay results suggest the variation in 1080 content in wingettes is a consequence of binding differences in the bait substrates. The Foxoff® bait matrix may be more uniform due to the manufacturing process, resulting in greater consistency in 1080 recovery. Regardless, the high variability of 1080 in Week 0 bait, especially fresh meat, should be further investigated to ensure that consistent doses are presented in baits prepared for use in the field.

2.4.3 1080 degradation

This study specifically investigated the role of various rainfall treatments on 1080 loss in wingettes and the impact of different climatic conditions on longevity of wingette and Foxoff® baits. The results indicate no difference in the rate of 1080 loss from wingettes in the rainfall treatments ‘mean weekly rainfall’, ‘prevailing rainfall’ and ‘no rainfall’ at OAI. Up to Week 3, 79.6 mm of rain fell on the baits in the ‘prevailing rainfall’ treatment, considerably more than the 45 mm that was added to the ‘mean weekly rainfall’ treatment. Surface laid fresh meats baits lose significantly more 1080 from leaching if subjected to rain on the first day (McIlroy *et al.* 1986) before the surface dries to form a crust. This crust offers some protection against leaching until baits begin to physically degrade (Fleming and Parker 1991). The similarities between decay rates in all three treatments and the large differences in the amount and pattern of rainfall received by the ‘prevailing rainfall’ treatment suggests that leaching of 1080 by rainfall was not an important mechanism for the degradation of wingettes. This is further supported by the insignificant difference between 1080 loss from wingettes at TRS and OAI, despite 13 mm of rain falling on all the baits (on Day 0) at TRS. It is likely that a threshold level of soil moisture is required to initiate the degradation process (e.g. Saunders *et al.* 2000; Twigg *et al.* 2000), a level reached in all treatments in this study (>15%). Soil moisture in each treatment at OAI was not significantly different for any week over the trial period. However, soil moisture was measured immediately after each bait was removed for analysis, leaving a lag period between the time when rain (artificial or natural) fell and the measuring of soil moisture. This was probably sufficient time for the water to infiltrate through the soil profile, resulting in the lack of measurable differences in soil moisture between treatments.

A comparison between the treatment 'mean weekly rainfall' for wingettes at TRS and OAI, and another between 'mean weekly rainfall' treatments for Foxoff® at TRS and OAI (from Saunders *et al.* 2000) suggest little difference in bait degradation rates on the central tablelands and the central-west slopes of New South Wales. Mean soil temperature at TRS (21^0C) was higher during the trial period than that at OAI (14.6^0C), but the amount of artificial rain added each week was less (11 mm vs 19.5 mm). The amount of evaporation at TRS (258 mm) was also greater than at OAI (165 mm) during the trial period. Warmer conditions favour heightened bacterial and fungal growth, leading to greater (faster) defluorination. Defluorination at 20^0C is 3 times faster than at 10^0C (Parfitt *et al.* 1994), suggesting that if other factors were the same, baits at TRS would last for significantly less time. However, the additional rainfall at OAI may have assisted the leaching of 1080 from the bait following physical degradation. Also, the rain (13 mm) that all baits received at TRS on Day 1 may have assisted to initiate the degradation process, which appeared uninfluenced by the greater evaporative loss during the trial period. Either way, both sites showed remarkably similar degradation rates for both wingettes and Foxoff®.

The similarity of the protocol used in this study with that of Saunders *et al.* (2000) allowed for the direct comparison between Foxoff® and wingettes at OAI. Saunders *et al.* (2000) found that Foxoff® exposed to no rain generally remained toxic for significantly longer periods than Foxoff® exposed to any amount of rain, despite the lack of a statistically significant difference in soil moisture between the treatments. The loss of 1080 from wingettes was independent of rainfall, suggesting that the 'washing through' effect of rainfall (i.e. leaching) has a greater influence on 1080 loss in Foxoff® than for wingettes. Wingettes may resist initial leaching since the skin protects against water infiltration, similar to the protection offered by formation of a skin on fresh meat baits by exposure to the sun and air (e.g. McIlroy *et al.*1986; Fleming and Parker 1991). It appears that 1080 loss from wingettes is more likely to be caused by biological factors.

One possible factor affecting the leaching of 1080 from bait was the application of the artificial 'mean weekly rainfall' treatment. In this treatment, the total volume of the average weekly rainfall was applied on one occasion per week. Obviously, application of artificial rainfall in this manner may vary from the natural pattern of rainfall which may fall on several occasions and at different intensities throughout each week. Such a protocol may have acted to increase the 'washing though' affect of the rain, increasing the leaching of 1080 from the bait. However, the results indicate that it did not influence the rate of wingette degradation compared to natural rainfall conditions given the lack of any leaching effect, and the insignificant differences between the 'mean weekly rainfall' and the 'prevailing rainfall' treatments at OAI. Similarly, it is unlikely to have exaggerated the leaching effect on Foxoff® given the lack of difference between artificial and natural rainfall treatments reported by Saunders *et al.* (2000). Nevertheless, the pattern of rainfall should be considered when assessing rates of 1080 bait degradation.

The degradation rates of wingettes and Foxoff® at TRS were not significantly different, despite the fact that Foxoff® remained viable for considerably longer periods (see Figures 2.5 and 2.6). This is probably due to the large variation in measured 1080 concentration for each bait type, especially wingettes. This is supported by the results of the SNK multiple ranges tests; Foxoff® were significantly different than wingettes only for week one and not the remaining weeks. The large variation, particularly at Week 0, may be a result of either variations in 1080 concentration or measurement variations (see section 2.4.3). The implications of such variation in measured bait concentration for are discussed further in Chapter 8.

The presence and defluorinating ability of micro-organisms is known to vary widely with different bait materials (Wong 1992). Microbial contamination can occur during handling, preparation and storage of bait material. Defluorination rates are generally high in fresh meat baits due to the organic-carbon rich environment for supporting micro-organisms (Wong 1992). Biochemical, enzymic reactions will also physically degrade meat (Adams and Moss 1995). As a result, the 1080 concentration in fresh meat baits will decline under moisture and temperature conditions favourable to micro-organisms and enzymic reactions. However, when stored in similar conditions the Foxoff® bait matrix appears a poor environment for supporting defluorinating micro-organisms. This is probably due to the combination of low abundance of 1080-detoxifying organisms in the bait and deficient environmental conditions for their growth. The low moisture content of Foxoff® (5.3$\pm$1.4%) relative to wingettes (54.4$\pm$1.4%) may be responsible, as micro-organisms will only metabolise substrates when sufficient water is available (Parfitt *et al.* 1994). The 1080 content of Foxoff® is highly shelf stable; in temperature and humidity conditions conducive to biological degradation, Foxoff® retain 97% of the initial 1080 for periods greater than six months (Staples *et al.* 1995). Independent of other factors, these arguments suggest that 1080 in wingettes degrade at a faster rate than Foxoff® due solely to biochemical and micro-organism activity. However, in this study, the degradation of wingettes was probably assisted by insect consumption, especially from blowfly maggots (Calliphoridae larvae). Maggots will consume bait material and the contained 1080 (McIlroy and Gifford 1988) resulting in significant losses. Maggots were observed on wingettes as early as Week 1 but were more common during Weeks 2 and 3. No maggots were observed on Foxoff® baits at any time.

2.4.3.1 Loss of 1080 and management implications

Data from this study can be used to estimate the time that bait will present a lethal dose for foxes, given an approximate LD_{50} (see Table 2.11). These estimates are not ubiquitous, but are representative of the situations likely to be encountered in eastern and mid-western New South Wales. The average body weight of an adult fox on the central tablelands is 5 kg (Winstanley *et al.* 1999); foxes in the drier, less productive western slopes region may average slightly less. The LD_{50} for foxes is approximately 0.13 mg kg^{-1} (McIlroy and King 1990), which equates to a lethal dose of 0.65 mg for an adult fox. Applying this to the fitted decay curve for wingettes buried and exposed to various rainfall regimes on the central tablelands and western slopes (Figures 2.5-2.7), wingettes will remain lethal to foxes for a mean of 1.1 week (Table 2.11). The 0.05 and 0.95 quartile confidence limits fitted to the model estimate that 95% of baits will remain lethal for periods up to 0.5 weeks, decreasing rapidly to leave only 5% lethal at 1.8 weeks. Similarly, wingettes at TRS will reach 0.65 mg of 1080 at 1.0 weeks; 95% are lethal at 0.8 weeks but 95% fall below a lethal dose 1.4 weeks after burial.

Table 2.11: The amount of 1080 required for a LD_{50} and mean time (weeks) wingettes and Foxoff® remain lethal to foxes, sheep and cattle dogs after bait is laid. Figures in parentheses are the estimated 5% and 95% population levels that are ≥ LD_{50} for each species.

	Species		
	Fox	Sheep dog	Cattle dog
Approximate amount 1080 (mg) required for LD_{50}	0.65	0.99	1.32
Wingette – mean time (weeks) ≥ LD_{50}	1.1 (0.5- 1.8)	0.7 (0.2-1.9)	0.5 (0.1-1.6)
TRS Foxoff® – mean time (weeks) ≥ LD_{50}	2.1 (1.0 – 5.0)	1.5 (0.6 -3.9)	1.2 (0.4-3.2)

Foxoff® degrade at a slower rate than wingettes and therefore remain lethal to foxes for considerably longer periods. Under average rainfall conditions on the western slopes of New South Wales, Foxoff® retain 0.65 mg of 1080 for an average of 2.1 weeks after burial, with 95% lethal for at least 1.0 weeks and 95% degrade to below lethal levels by 5.0 weeks. These results confirm previous studies. Saunders *et al.* (2000) found that Foxoff® exposed to various amounts of artificial rainfall on the central tablelands reached LD_{50} levels after 2.4 weeks. The difference between these two results is insignificant (as tested earlier) and probably due to the differences in the fitted models. Staples *et al.* (1995) tested the longevity of 60 g Foxoff® baits containing 3.3 mg of 1080 in both wet and dry soil conditions. Despite the larger bait matrix (60 g vs 30 g) and the 10% higher nominal dose (3.3 mg), after 2 weeks in wet soil the mean 1080 content was 0.69 ± 0.11 mg (n = 2).

With no rain, the degradation of 1080 in Foxoff® is highly variable but considerably slower than wingettes under similar conditions. After 3 weeks, no wingettes from any treatment (n = 16) contained detectable levels (>0.05 mg) of 1080. Many Foxoff® still contained sufficient 1080 to be hazardous to a fox or dog after 11 weeks (Saunders *et al.* 2000). Similarly, the results can be used to estimate potential impacts of baiting campaigns on non-target species

(Table 2.11). On agricultural lands in eastern New South Wales, the main non-target species at risk from 1080 poisoning are domestic and working dogs. Dogs are highly susceptible to 1080, with an LD_{50} of 0.066 mg kg^{-1} (Tourtellotte and Coon 1951). The average weight of a sheep dog is 15 kg and a cattle dog 20 kg (Fleming and Parker 1991), indicating lethal doses of approximately 0.99 mg and 1.32 mg respectively.

These results are important to not only determine periods of lethal effectiveness against foxes, but to calculate safe withholding periods for working dogs. Landholders in New South Wales are legally required to remove and dispose of all untaken baits at the completion of a baiting program (Environment Protection Authority 2002). However, foxes will cache baits (see Chapter 3) resulting in baits that cannot be retrieved and which constitute a threat to working dogs. The results from this study and Saunders *et al.* (2000) suggest that areas baited with Foxoff® require longer withholding periods, especially during dry periods, than areas baited with wingettes. Dry periods would be particularly dangerous since some Foxoff® retained high 1080 concentrations for extended periods. In wet soil conditions, an estimated period greater than 4 weeks after last baits are laid is needed before working dogs should be allowed on properties baited with Foxoff®, twice as long as required when wingettes are used. Consequently, wingettes may be more favourable for use in sensitive areas where long-term hazards from toxic baits are highly undesirable, or periods where shorter withholding periods for working dogs is required to ensure 'safety' regardless of season.

Increased longevity of bait can also be advantageous. Obviously bait must remain toxic for sufficient periods to ensure resident foxes will find and consume a lethal dose. If bait degrades too rapidly for foxes to have this opportunity, it may be detrimental to the efficacy of baiting programs. Reduced longevity would require bait to be replaced more often in continuous baiting programs, reducing cost-effectiveness. Saunders *et al.* (2000) suggest that consumption of a sub-lethal dose of 1080 from degraded bait may lead to bait aversion (see Chapter 5) reducing the likelihood of bait being consumed in subsequent encounters. Research is therefore needed to determine whether the uptake of wingettes by foxes occurs before deterioration to sub-lethal levels. Where baits are not retrieved (e.g. aerially deployed bait), bait longevity may also add a “time buffer” effect by remaining active to reduce the effect of reinvasion by immigrant foxes (Twigg *et al.* 2000).

2.4.4 Soil micro-organisms

Thirty-one species of micro-organisms capable of defluorinating 1080 were isolated from soils in the central tablelands and western slopes of New South Wales. Many of the species isolated, including *Alcaligenes*, *Arthrobacter*, *Aspergillus*, *Bacillus*, *Penicillium, Pseudomonas* and *Streptomyces,* are known to occur in Australian and New Zealand soils and have been previously reported for their defluorinating ability (Bong *et al.* 1979; Wong 1992; Meyer 1994; Walker 1994; Twigg and Socha 2001). The bacteria *Alcaligines*, *Arthrobacter*, *Bacillus* and *Pseudomonas*, and the fungi *Aspergillus* and *Penicillium* are known for their degradative capacity. These species are often involved in bioremediation, where their degrading capacity is applied for environmental cleanup of chemically contaminated sites (Paul and Clark 1996). However, the fungi *Monocilliuim* and *Scopularis*, the bacteria *Bordetella*, *Burkholderia*, *Kocuria* and *Micromonospora*, and actinomycetes *Streptosporangium* and *Streptoverticillium* have not been reported in earlier studies. The presence of a variety of micro-organisms capable of defluorination is not particularly surprising: the ability to metabolise fluoroacetate is common among soil micro-organisms (Walker 1994). However, the rate of defluorination varies considerably between species.
The isolated bacteria generally showed greater defluorinating ability than actinomycetes and fungi, which supports Wong *et al.* (1992). However, previous studies have found that the common soil fungi *Fusarium*, in particular *Fusarium oxysporum*, appears to be the most efficient microbial defluorinator (Wong *et al.* 1991; Wong 1992; Walker 1994; Kirkpatrick 1999; Twigg and Socha 2001). *Fusarium oxysporum* is ubiquitous in soils in Australia and New Zealand (Burgess *et al.* 1988) and may also be found on bait materials (Wong *et al.* 1991). It was not isolated in this study, possibly due to low abundance in the collected soil samples.

The defluorinating ability of unautoclaved soil was only measurable in the TRS soil, where 47.8$\pm$17.7% of added 1080 was defluorinated within 7 days. This is similar to Parfitt *et al.* (1994) who found that in New Zealand silt loams 50% of added 1080 was defluorinated within 10 days at 23^{0}C, and Wong (1992) who found that up to 70% was defluorinated in 9 days (at 28^{0}C day and 15^{0}C night). However, this was much greater than the 23% defluorinated in 28 days in soils from central Australia (Twigg and Socha 2001). These differences are probably due to the organic matter composition of each soil. Although not measured, the central Australian soils appear to have less organic matter relative to soils in more temperate climates (Twigg and Socha 2001). The relatively low organic matter would mean lower available carbon and nitrogen for micro-organism growth (Clark 1967), and therefore limit micro-organism defluorinating ability.

The amount of F^- released in the OAI soil did not exceed the sterile soil control. However, there is strong evidence to suggest that soils at OAI contain 1080 degrading micro-organisms. The measurable defluorination rates of two species isolated from OAI soil provide proof that such organisms are present. Secondly, the degradation of wingettes and Foxoff® at OAI strongly suggest that microbes are largely responsible. The relatively rapid degradation of buried Foxoff® compared to the longevity of shelf stored Foxoff® suggests the micro-organisms are likely to be sourced from the soil environment. Despite the inability to detect 1080 degradation in the soil, the circumstantial evidence indicates that the soil at OAI has defluorinating ability.

The identification of micro-organisms capable of defluorination may offer advantages in addition to reassurance of environmental degradation of 1080. If increased longevity is required, meat baits could be dried, or bacteriostats (e.g. mercuric chloride) and fungistats (e.g. paranitrophenol) added to retard microbial growth and hence defluorination (Thomson 1986; Wong 1992). An understanding of the organisms responsible will assist in selecting appropriate retardants. Alternatively, where swift degradation is required, there may be potential to add defluorinating micro-organisms to detoxify a bait after an appropriate period (Wong *et al.* 1991), or improve soil or bait conditions (e.g. moisture, aeration, temperature) to encourage microbial colonisation and growth (Clark 1967). Buried baits may be colonised by defluorinating microbes from the soil at a faster rate than surface laid baits, leading to reduced longevity (Wong 1992). Such strategies may be especially advantageous where Foxoff® is used in sensitive areas, given their greater longevity.

The results show that, using methods similar to Wong (1992) and Twigg and Socha (2001), that defluorinating micro-organisms are present in the soils on the central tablelands and western slopes of New South Wales. However, the defluorinating ability of the OAI soil and the many individual isolates was unable to be confirmed, despite strong circumstantial evidence indicating that defluorination was occurring. Wong *et al.* (1991) and Wong (1992) also reported similar findings, many isolates (48-85%) capable of defluorinating 1080 solution were unable to defluorinate 1080 in the presence of sterile soil. This problem may have been exacerbated in this study by the low 1080 concentration measured to determine defluorination rates. Dilutions were necessary to enable the measurement of fluoride ions, and together with the binding of 1080 to the soil and corrections necessary for background fluoride concentration in 1080 solution and deionised water, meant that the amount of fluoride ions that could be attributed to micro-organism defluorination was very low. Additionally, sterile soil incubations (negative controls) indicated that some defluorination (OAI $< 0.07 \mu g\ L^{-1}$ and TRS $< 0.03\ \mu g\ L^{-1}$) was occurring without micro-organisms. Twigg and Socha (2001) also found that defluorination did occur in sterile soil incubations. Once the data were corrected for this, the small concentration remaining was prone to error. The defluorination level of the isolates identified in this trial should be confirmed in the presence of 1080 without sterile soil, with greater precision to ensure measurable results. Regardless, the results indicate the presence of defluorinating micro-organisms in soils is eastern Australia will ensure no accumulation of 1080 from bait in the environment.

2.5 Conclusion

The results indicate that defluorinating micro-organisms are present in soils in eastern Australia, which will ensure no environmental accumulation of 1080 from baiting operations. The identification of these organisms may assist in selecting appropriate retardants to reduce their activity, or alternatively, where swift degradation is required, there may be potential to add defluorinating micro-organisms or improve soil or bait conditions (e.g. moisture, aeration, temperature) to encourage bait detoxification after an appropriate period. However, where reduced longevity is required, wingettes may be a useful alternative to red meat or manufactured bait. They degrade at a faster rate than Foxoff®, even when no rainfall is applied. Since rain had no effect on the degradation rate, wingettes may be used to ensure that baits degrade swiftly regardless of rainfall. Areas baited with Foxoff® will require longer withholding periods for working dogs than wingettes, especially during dry periods. Wingettes may also have advantages for use in sensitive areas where long-term hazards to non-target species from toxic baits are highly undesirable. However, these results are reliant upon the threshold of soil moisture being present. The results should be reviewed in dry soil conditions (<18% water content) before being applied to such conditions. For example, Twigg *et al.* (2000) found that fresh red meat in arid areas became highly desiccated within days, restricting breakdown and vastly increasing longevity. In addition, wingettes must be evaluated not only for longevity, but also for attractiveness, palatability and rate of uptake by foxes (Chapter 3), efficacy and cost-effectiveness (Chapter 7). All these issues must be considered before the use of wingettes in any situation can be fully endorsed.

CHAPTER 3

BAIT CACHING

3.1 Introduction

The effectiveness of poison baiting campaigns relies on presenting attractive and palatable bait. Baits should be attractive to ensure that the target species will find the bait, and should be highly palatable to ensure that the animal will consume the bait and the contained toxin (Allen *et al.* 1989). Traditionally, studies have assessed the palatability of bait types through investigating and comparing the rate or proportion of each bait type removed by the target species. This fails to account for any difference between attraction and palatability since it does not assess the fate of bait after it is removed from the station. For example, Saunders *et al.* (1999) reported that a significant proportion (10%) of Foxoff® baits removed by foxes are not consumed. Therefore, removal of bait without immediate consumption should be considered when investigating the potential of bait types in baiting campaigns (Van Polanen Petel *et al.* 2001).

Caching or hoarding is defined as handling food to conserve it for later use (Vander Wall 1990) and offers the participant greater ability to control food availability spatially and temporally (Maccarone and Montevecchi 1981). Caching may be a means of securing food from the attention of competitors, including other foxes (Macdonald 1987). Food preference is an important influence on the caching behaviour of individuals. Palatability influences caching behaviour; foxes are more likely to immediately consume preferred prey and cache less preferred prey (Macdonald 1976, 1977, 1987). This is supported by studies on bait types by Van Polanen Petal *et al.* (2001), who found that the preferred bait type presented to caged and wild foxes was eaten most and cached least.

Foxes are known to store food in preparation for periods of low food availability and periods when energy requirements are high, such as the birth of offspring (Macdonald 1977) and, in the higher latitudes, in preparation for winter (Maccarone and Montevecchi 1981). Caching can occur during periods of temporary food surplus (Macdonald 1976, 1977, 1987); there is evidence that even within foraging sessions food discovered before satiation is consumed (Henry 1986) whereas food discovered later is cached (Kruuk 1972). This suggests that caching intensity may increase when food availability is high, and/or nutritional demands are low.

As a result, caching behaviour is likely to vary seasonally. The intensity of caching is likely to be related to the availability of prey and nutritional status of the predator (Scott 1943; Macdonald 1976). Macdonald (1977) demonstrated that preference of individual foxes may change as a result of reproductive or nutritional circumstances. The nutritional and energy demands of foxes fluctuate as a result of the annual reproductive cycle. Foxes accumulate fat and protein reserves throughout the non-reproductive stage of the annual cycle, and deplete these reserves during the reproductive period (Winstanley *et al.* 1999). Reduced body fat levels relate to either reduced foraging activity or higher nutritional demands during the whelping and cub provisioning stage (Winstanley *et al.* 1999). It is difficult to interpret how these periods may influence preference and caching behaviour. Caching may be reduced when food is encountered during non-reproductive periods to accumulate body fat for periods of peak energy demand. Alternatively, reproductive periods may result in reduced caching of food since nutritional demands would be greatest at this time. Additionally, seasonal changes in available prey biomass may either promote or reduce caching when food is in surplus or deficit respectively. Caching behaviour may change as a result of these changes in foraging and nutritional demand. Any assessments of fox caching should, therefore, attempt to monitor fox caching behaviour over different seasons.

Caching could potentially reduce the safety, efficacy, and cost-effectiveness of control programs. There may be significant non-target implications when 1080 baits remain cached at the completion of baiting campaigns. Cached baits may pose a hazard to non-target animals that may recover the cache, exposing them to the toxin (Van Polanen Petel *et al.* 2001). Caches could remain hazardous for extended periods since they cannot be located and removed at the end of a control program (Thomson and Kok 2002). This is potentially hazardous to domestic animals such as working dogs that are used in previously baited areas. Similarly, caches may be located at considerable distances from where originally laid

(Saunders *et al.* 1999), and may be moved onto areas thought to be 'bait free'. The distance that baits are moved should be monitored to allow better formulation of distance restrictions for the placement of baits during baiting campaigns.

There may be implications for the success of baiting campaigns if cached baits remain in the field where immigrating or other foxes have access to these baits. 1080 will degrade with exposure with the soil and environment (see Chapter 2) and bait aversion may develop as a result of consuming a sub-lethal dose from degraded bait. This could reduce the effectiveness of future campaigns through making resident or immigrating foxes averse to consuming poison bait. Similarly, caching has implications for the effectiveness of oral vaccination campaigns; baits must be consumed within defined periods because of the limitations of the vaccine to initiate a sufficient immune response under environmental conditions (Macdonald *et al.* 1994; Pastoret *et al.* 1996).

Caching reduces the efficiency of baiting programs since a disproportionate number of baits are removed without immediate consumption. Monopolisation of baits by few individuals would reduce the effectiveness of baiting campaigns since these baits may be unavailable to other foxes to consume. This may reduce the overall efficacy of the baiting program, or mean that additional baits should be laid to target the remaining foxes in the population, reducing the cost-effectiveness. Caching therefore entails a 'waste' since baits are not used efficiently.

A recent survey of New South Wales Rural Lands Protection Boards (RLPB's) provides evidence that baiting is continuing to be the most popular control technique totalling 74% of control effort for management of foxes (West and Saunders 2003). Foxoff® are the most common bait type used in New South Wales, comprising over 48% of baits used in 2001 (West and Saunders 2003). Chicken wingettes are used predominantly in the southern areas of New South Wales, but their use has increased to 10% of RLPB's by 2001 since their introduction in 1998. Additionally they may be registered for use in Victoria in 2005 (C. Tan, Victorian Farmers Federation, pers comm. 2004). Day-old chicks are not a registered bait type for fox control in any Australian state or territory. Observations have shown that foxes find day-old chickens palatable (Macdonald 1977) and they are the recommended bait in the

Department of Environment, Food and Rural Affairs (DEFRA) in the United Kingdom for the distribution of rabies vaccines to foxes in the event of an outbreak.

Caching trials suggest that Foxoff® are readily taken by foxes but significant proportions may be cached (Saunders *et al.* 1999; Van Polanen Petel *et al.* 2001). Despite observations that wingettes are readily taken by foxes (T. Abblett, Wentworth RLPB pers comm. 2003), there has been no assessment of the palatability of wingettes. Day-old chickens may provide a highly palatable alternative but there is evidence to suggest that this palatability may change due to reproductive demands (Macdonald 1977). Wingettes, day-old chicks and Foxoff® should be assessed during different seasons to investigate their relative palatability, and if this palatability varies as a result of reproductive or environmental changes.

The objective of this chapter was to investigate bait caching by wild foxes with respect to the bait type and seasonal influences on caching. Additionally, the retrieval of caches per season and the distances that caches are made from the original bait station are investigated to help formulate strategies to improve the safety and efficacy of baiting programs during different periods throughout the year.

3.2 Methods

3.2.1 Study sites and seasons

Bait caching trials were undertaken at four sites on the central tablelands of New South Wales. The non-toxic baiting trials were undertaken on two properties "Larras Lake North" and "Fernleigh" which are situated near the locality Larras Lee, approximately 12 km north of Molong. The trials using 1080 baits were undertaken on another two sites; "Myrangle", situated west of Cumnock, approximately 30 km north-west of Molong, and "Nandillyan Heights", situated 7 km east of Molong. The properties are adequately spaced apart (>4 km) based on home range estimates (Saunders *et al.* 2002a) to ensure independence from foxes moving between sites.

Sites were chosen to represent mixed farming and grazing (sheep and cattle) properties typical of those situated on the central tablelands. All four sites had historically undertaken occasional fox baiting programs (less than one per year) but had not done so for at least 2 years before the commencement of the initial trial. Sites are primarily undulating to hilly areas of open grassland of native and improved pasture species intersected with patches of open woodland. At “Nandillyan Heights”, “Larras Lake North” and “Fernleigh”, the dominant association is the white box-apple box (*Eucalyptus albens* - *Eucalyptus bridgesiana*) community. Associated species include yellow box (*Eucalyptus melliodora*), blakelys red gum (*E. blakelyi*) and mugga ironbark (*E. sideroxylon*), with river red gum (*E. camaldulensis*) and river oak (*Casuarina cunninghamiana*) along the banks of streams (Dwyer 1978). At “Myrangle”, grey box (*E. woollsiana*), narrow-leaved ironbark (*E. crebra*) and cypress pine (*Callitrus glauca*) replaced *E. bridgesiana* and *E. sideroxylan* (Dwyer 1978).

The caching trials were undertaken over three seasons, autumn, winter and spring. The non-toxic trials were undertaken at “Larras Lake North” and “Fernleigh” during autumn 2001, spring 2001, winter 2002 and spring 2002. The 1080 poison trials were undertaken at “Nandillyan Heights” and “Myrangle” during winter in 2001 and 2002.

The cumulative rainfall deficiency for the nearest weather station (Molong) is shown in Figure 3.1. This represents the difference between actual rainfall and the long-term median rainfall, providing an assessment of the seasonal conditions (Foley 1973).

3.2.2 Bait preparation and laying procedures

Baiting was undertaken based on recommended methods for laying baits on agricultural lands of New South Wales (Korn and Lugton 1990). Bait stations were spaced at least 200 m apart and usually placed adjacent to farm tracks and fencelines along a transect that encompassed representative habitats on each site. Bait stations were an approximate one metre diameter area cleared of grass and vegetative litter covered with sifted soil (1-2 cm thick) with a single bait buried 5-10 cm below the surface. Tracks and/or sign (e.g. scent, faeces) left on the station were used to identify the species visiting and/or removing the bait.

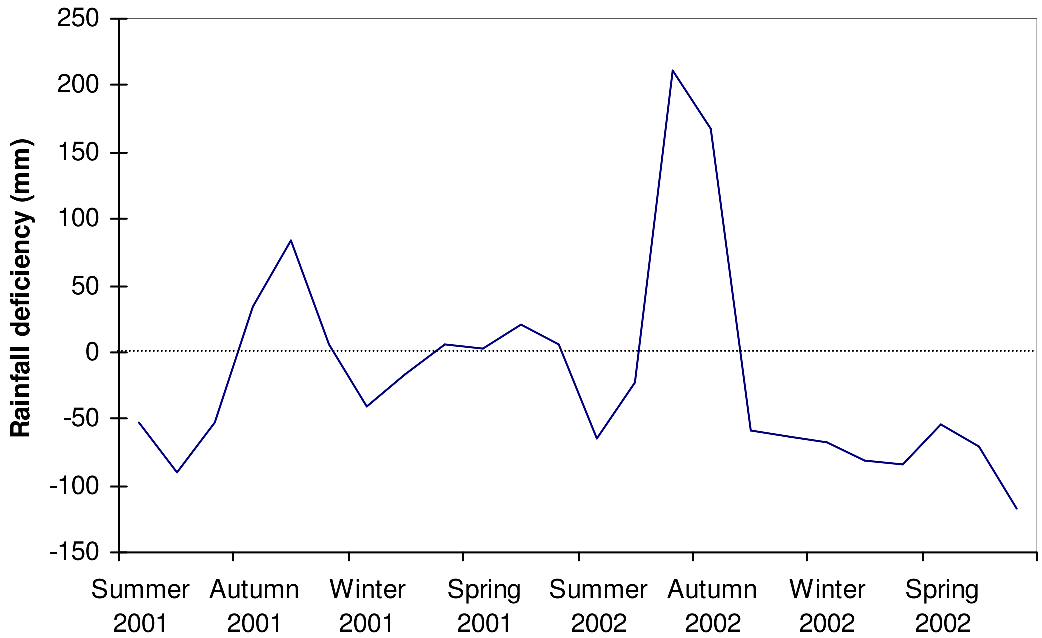

Figure 3.1: Cumulative rainfall deficiency (mm) (Foley 1973) for Molong weather station. Data sourced from the Bureau of Meteorology (2003).

To enhance subsequent uptake, all stations were free-fed with non-toxic bait without transmitter for a five to seven day period using one of three bait types. Baits were checked every one to two days during this period and any baits removed were replaced. Bait types were randomly allocated to bait stations in each trial period to reduce environmental factors resulting in greater uptake of one or more bait types. Following pre-baiting, a microtransmitter (150MHz, Sirtrack, Havelock North, New Zealand) was inserted into each bait. Transmitters were 1.5 x 3 cm in size and encased within epoxy resin to protect the transmitter from the weather and mastication by consumers. Previous studies incorporating transmitters in baits have shown no significant difference in the proportion of transmitter and non-transmitter baits taken by foxes (Saunders *et al.* 1999; Thomson and Kok 2002). Foxoff® baits were warmed sufficiently to soften and allow the bait to be moulded around the transmitter (adapted from Saunders *et al.* 1999). The transmitter was sewn into the abdominal cavity in the day-old chicken, and into the muscle between the radius and ulna bones in the wingette using monofilament nylon thread (4 lb breaking strain).

Methods were identical for all caching trials apart from the presentation of 1080 baits with the inclusion of the transmitters in the 1080 bait trials. 1080 baits were prepared using standard techniques (see Chapter 2) and contained a 3 mg nominal dose.

3.2.3 Bait uptake

At the two non-toxic sites, seasonal patterns in bait uptake were investigated through comparing the survival of the initial baits laid at the bait stations during the first five days of free-feed period. Following the initial trials, it became apparent that foxes would not locate all bait stations during the free-feed period. Additionally, some bait stations suffered severely from interference by domestic stock (sheep and cattle) and were abandoned. As a result, additional bait stations were free-fed in the following trials to allow those stations interfered by stock and/or showing low activity to be abandoned. This allowed the maximum benefit from the use of transmitters to investigate the proportion of bait caching in each trial. Apart from those abandoned or added, bait stations were kept constant for each trial following Trewhella *et al.* (1991) to ensure that any differences in bait uptake due to differences in the location of bait stations were minimised.

3.2.4 Bait consumption and caching

Following presentation of the microtransmitter baits, bait stations were checked daily for 10 consecutive days, and any bait removed tracked down. Following Saunders *et al.* (1999), each trial was undertaken for 10 days as a compromise between the duration of normal practice fox baiting programs (2-3 weeks), the labour required to check baits, and the transmitter battery life.

The fate of each removed bait was determined by tracking down individual baits on foot using a TR-4 receiver (Telonics, Arizona, United States) and hand-held Yagi antenna (Sirtrack, Havelock North, New Zealand). Transmitters that were found without the surrounding bait medium were assumed to have been eaten. Baits were recorded as cached if they were removed from the bait station and reburied or hidden elsewhere (Saunders *et al.* 1999; Thomson and Kok 2002). When baits were eaten a fresh bait with transmitter was replaced at the station. Cached baits were left at the cache site and checked daily until the end of the 10 day trial period when all baits and transmitters were recovered.

When located, the straight-line distance that baits were cached or eaten from their original location was paced and estimated in metres.

Spotlight counts were undertaken at both sites for three successive nights before the trial period to estimate fox density. These counts were undertaken with the aid of a 100 Watt spotlight from a four-wheel drive vehicle, along pre-defined transects.

3.2.5 Statistical analyses

Bait uptake

The Cox proportional hazard regression model (Cox 1972) was used to model the hazard function to determine whether the survival of bait at bait stations was influenced by the factors Season Year, Bait type and Site and the covariate Fox density. Fox density indices were calculated from the mean foxes seen per km of transect from 3 consecutive nights of spotlight counts on each site for the season when the trial was undertaken. This analysis allows for a baseline hazard function that is modified multiplicatively by covariates; this is particularly important when comparing covariates within populations since the effect of each covariate on survival can be determined. The results from the Likelihood ratio tests indicate whether there is a significant difference between the groups as tested (Venables and Ripley 2002). Factors and covariates within models were tested for significance through analyses of deviance procedures, non-significant factors were dropped from the models. Survival analysis was considered appropriate since baits presented at bait stations remain active or “alive” until taken by foxes when they became “dead”. To avoid bias associated with animals learning from continual replacement during free-feeding (Thompson and Fleming 1994), only the initial bait placed in a station was included in the analyses.

Bait caching

Given that bait stations were free-fed for a period before the inclusion of the transmitter baits, many bait stations had been located and/or regularly visited by foxes. Therefore visitation to and uptake of the transmitter baits is confounded by earlier visitation by foxes to the bait station. To account for this, the seasonal probability of a bait being cached is calculated from the transmitter baits that are removed by foxes i.e. the probability that foxes will cache the bait when it is removed from the station.

Logistic regression using generalised linear models (GLM) was undertaken to investigate the influences of relevant factors and covariates on the probability of bait being cached. Logistic regression was undertaken since it allows for meaningful biological interpretation when the response variable is dichotomous (in this case either cached or eaten) (Lemeshow and Hosmer 1998). Residual plots were undertaken to examine for heterogeneity of variance (Snedecor and Cochran 1989). A stepwise regression procedure was followed from the initial maximal model to produce the minimal adequate model as determined through the minimal Akaike's Information Criterion (AIC) with respect to the principle of parsimony (Akaike 1973; Burnham and Anderson 1992). Where necessary, AIC were corrected for over-dispersion through quasi-likelihood theory by including a variance inflation factor or interpreted using F-ratios (Crawley 2002). Variables were tested for significance through analysis of deviance, and coefficients through z statistics. The effect of site, season/year, night of trial, days since the bait was laid, bait type, fox density during season of trial, and bait removal during the free-feed period were examined for their effect on the response variable, a bait being cached when initially taken (see Table 3.1 for summary of variables). Biologically plausible second-order interactions were also included and tested for significance. To account for any differences in caching behaviour due to different fox densities, an index of fox density was included in the model.

Table 3.1: Description of variables used in the GLM to identify the main determinants of caching.

Variable (category)	Range of variable	Description
Cached (response)	0 or 1	0 = eaten 1 = cached
Days since laid (covariate)	0 - 6	Number of nights the bait has been presented following initial burial
Season Year (factor)	Autumn 2001, Spring 2001, Winter 2002, Spring 2002.	Season/Year that trial undertaken
Bait type (factor)	Foxoff®, Day-old chick and wingette	Bait types tested
Site (factor)	Larras, Fernleigh	Properties where trials were undertaken
Fox density (covariate)	1.29 – 1.86	Mean foxes seen per km of transect driven from 3 observations
Number baits taken (covariate)	0 - 6	Number of baits taken by foxes and unidentified species from that station during the free-feed period

Cache recovery

Since transmitters were retrieved at the end of each trial period (10 days) the fate of all cached baits could not be monitored for uniform periods. A censored survival analyses was required to analyse the period of time that baits remained cached before being retrieved and consumed by foxes. Similar to the caching analyses, cached baits were classified as 'alive' until retrieved by foxes ('dead'). This analysis provides a baseline hazard function that is modified multiplicatively by covariates; this is particularly important when comparing covariates within populations since the effect of each covariate on survival can be determined. The results from the Likelihood ratio tests indicate whether there is a significant difference between the groups tested (Snedecor and Cochran 1989; Venables and Ripley 2002). Factors and covariates within models were tested for significance through Analyses of Deviance procedures; non-significant factors were dropped from the models.

Caching distances

The distance that baits were cached from stations were analysed through linear regression.

Cache depth

A linear regression model was used to determine if the depth that the non-toxic bait was cached was significantly influenced by the Season Year of the trial, site where the trial was undertaken, and bait type used.

Free-feeding

Linear regression was used to determine if the probability of a non-toxic or toxic bait being cached was influenced by the number of free-feed baits removed by foxes or unknown species at each station during the initial free-feed period.

3.3 Results

3.3.1 Bait uptake

From the initial baits laid at each non-toxic site during each trial, the percentage removed during the first five days for the free-feed period ranged between 20.8% and 85.0% (Table 3.2).

Table 3.2: The number of baits initially laid, number taken by foxes and percentage removed by foxes during the first five days of the free-feed period at each non-toxic site during each trial.

Site	Season Year	Number laid	Number Taken	Percentage removed
Fernleigh	Autumn 2001	24	9	37.5
Larras	Autumn 2001	24	5	20.8
Fernleigh	Spring 2001	43	31	72.1
Larras	Spring 2001	52	26	50.0
Fernleigh	Winter 2002	40	34	85.0
Larras	Winter 2002	46	24	52.2
Fernleigh	Spring 2002	36	26	72.2
Larras	Spring 2002	37	30	81.1

The survival of the free-feed baits initially laid in the bait stations was significantly influenced by the Site (χ^2 = 29.0, d.f. = 1, P <0.001) and the Season Year of the trial (χ^2 = 17.52, d.f. = 3, P <0.001). There was no difference in the survival rates of the bait types (χ^2 =2.7, d.f. = 3, P = 0.45). Relative fox density also significantly affected the survival of bait (χ^2 = 10.56, d.f. = 1, P =0.001), with decreased survival of bait with increasing fox density (β = -1.024, z = -2.82, P = 0.005).

The estimated survival curves for Season Year and Site are shown in Figures 3.2 and 3.3 respectively. Autumn 2001 showed a significantly greater survival than spring 2002 (β = 1.292, z = 2.64, P = 0.008) and winter 2002 (β = 1.074, z = -2.16, P = 0.03), but was not significantly different to spring 2001 despite indications that survival was greater (β = 0.936, z = 1.91, P = 0.06). Similarly, the hazard rate on Larras (β = -0.874, z = -5.59, P < 0.001) was significantly less than Fernleigh, indicating greater survival.

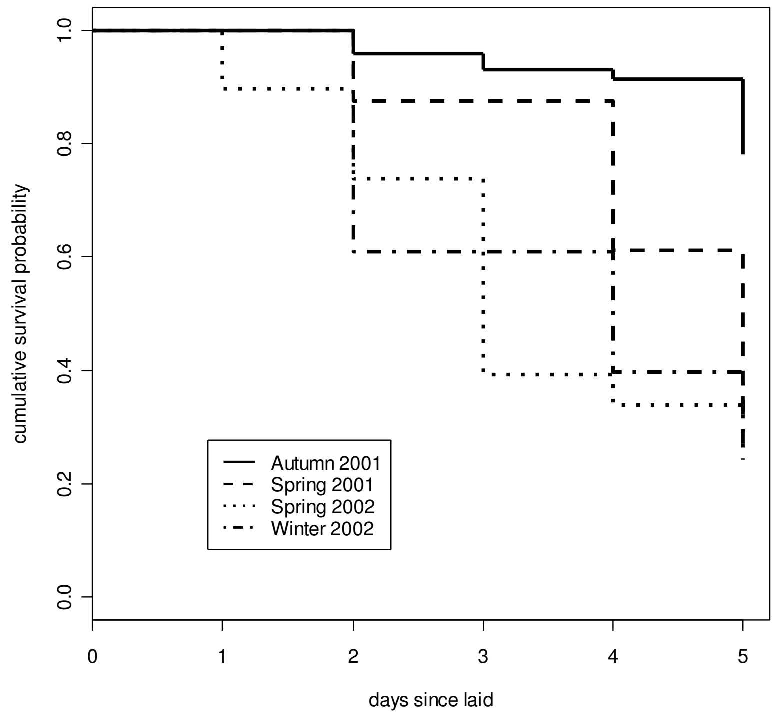

Figure 3.2: Survivorship of the initial baits laid for the Season Year of the non-toxic trials.

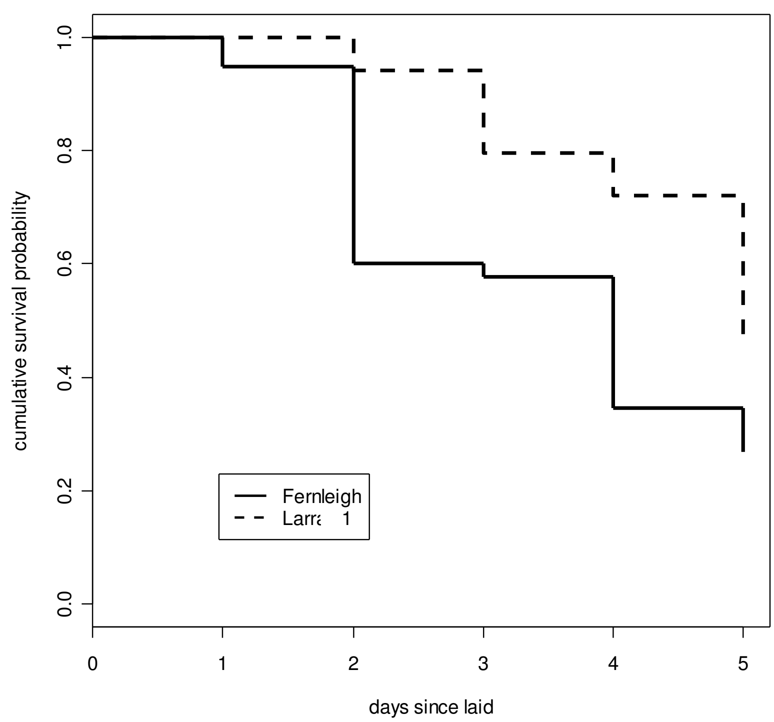

Figure 3.3: Survivorship of the initial baits laid at each site for the non-toxic trials.

3.3.2 Bait caching

Non-toxic

Day-old chickens, chicken wingettes and Foxoff® were used as bait during all trials apart from autumn 2001 trials where no wingettes were tested. In the Fernleigh spring 2002 trial, transmitters were inserted for the entire period. Therefore, the values used for the number of free-feed baits taken from the station during free-feeding were calculated from the number of baits either eaten or cached by foxes.

Figures 3.4, 3.5 and 3.6 show the proportion of baits cached by foxes from those removed for Larras, Fernleigh, and pooled for both sites respectively.

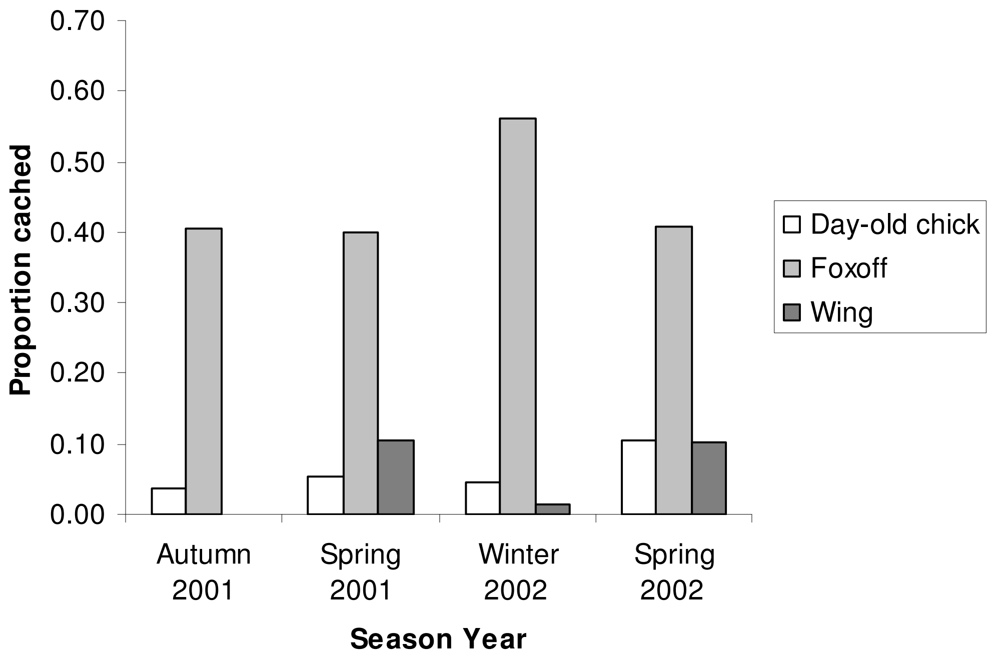

Figure 3.4: The proportion of non-toxic Foxoff®, day-old chick and wingette baits cached from those taken on Larras in the seasons tested.

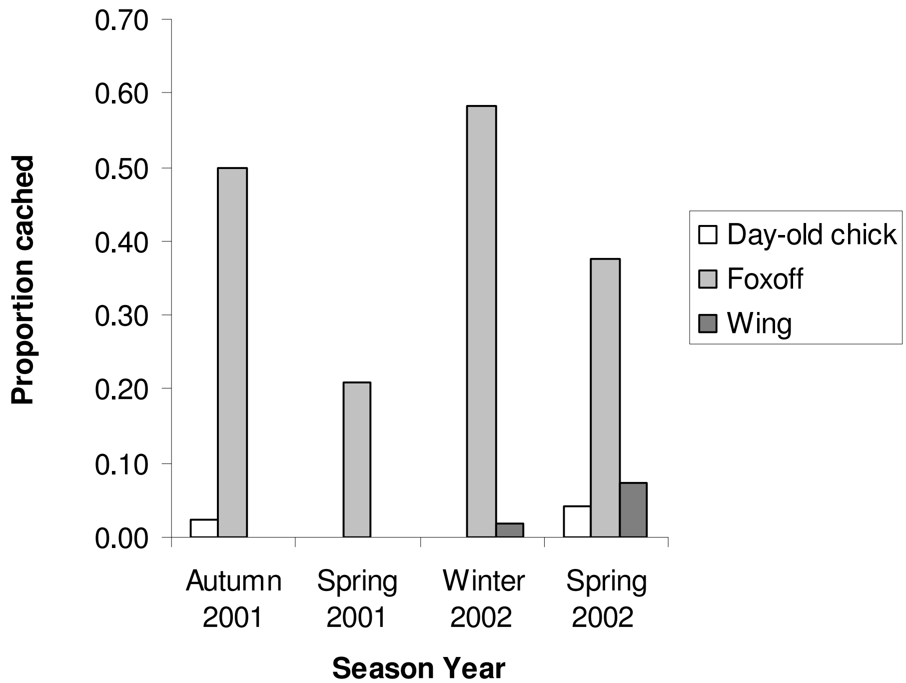

Figure 3.5: The proportion of non-toxic Foxoff®, day-old chick and wingette baits cached from those taken on Fernleigh in the seasons tested.

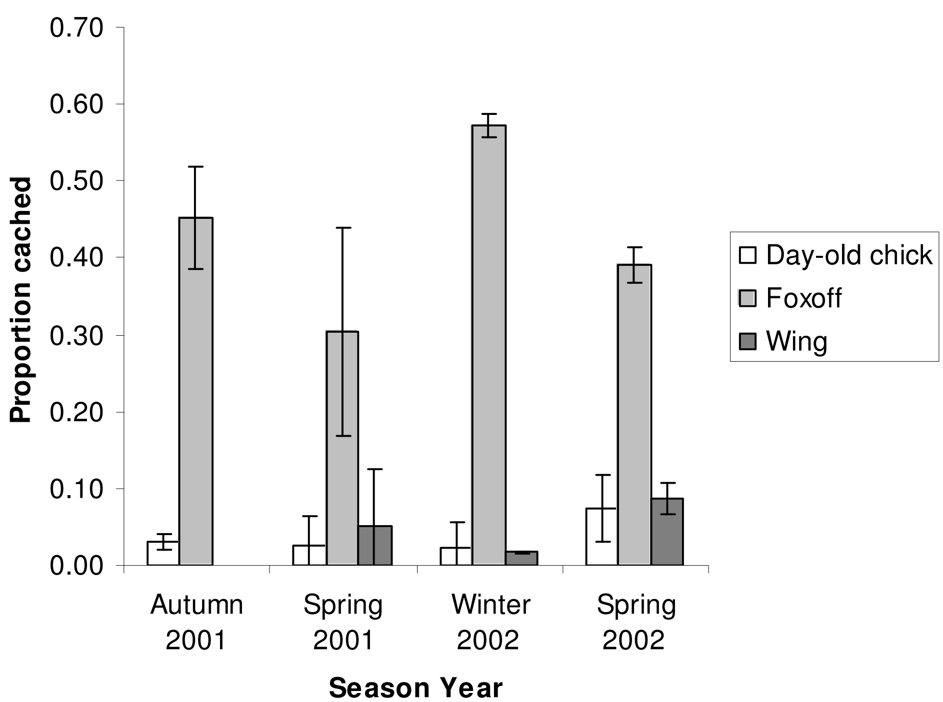

Figure 3.6: The proportion of non-toxic Foxoff®, day-old chick and wingette baits cached from those taken, for data pooled from Fernleigh and Larras in the seasons tested.

At Larras, of the three bait types, a greater proportion of Foxoff® baits were cached when removed by foxes in each season (Fig 3.3). The proportion of Foxoff® baits cached from those taken ranged between 0.40 in spring 2001 (n = 25 baits taken) to 0.56 in winter 2002 (n = 16). A low proportion of both day-old chicks and wingettes were cached during all trials. The proportion of day-old chicks cached from those taken ranged between 0.04 in autumn 2001 (n = 27) and 0.11 in spring 2002 (n = 89). Similarly, a low proportion of wingettes were cached, between 0.01 in winter 2002 (n = 66) and 0.10 in spring 2001 (n = 48).

Similarly, at Fernleigh, a greater proportion of Foxoff® were cached than both wingettes and day-old chicks in all trials in all seasons. The proportion of Foxoff® baits cached from taken baits ranged between 0.21 in spring 2001 (n = 43) to 0.58 in winter 2002 (n = 12). Day-old chicks and wingettes were cached at low levels in all seasons. The proportion of wingettes cached from taken ranged from 0.00 (spring 2001, n = 40) to 0.07 (spring 2002, n = 69). No day-old chicks were cached in spring 2001 (n = 53) and only 0.04 (n = 70) were cached in spring 2002.

When data for both sites was pooled, the mean proportion ($\pm$SD) of Foxoff® baits cached in winter 2002 (0.57$\pm$0.01, n = 28) was greater than autumn 2001 (0.45$\pm$0.07, n = 60), spring 2001 (0.30$\pm$0.13, n = 68), and spring 2002 (0.39$\pm$0.02, n = 59). However, a winter peak in caching is not reflected in the proportion of wingettes and day-old chicks cached. A greater proportion of both day-old chicks (0.07$\pm$0.04, n = 146) and wingettes (0.08$\pm$0.02, n = 158) were cached in spring 2002 than any other season.

Logistic regression revealed that Bait type (χ^2 = 158.19, d.f. = 2, P <0.001) was the principal variable influencing the probability of a bait being cached. Season Year was not significant overall (χ^2 = 6.67, d.f. = 3, P = 0.08), but interacted significantly with Site (χ^2 = 11.26, d.f. = 3, P = 0.01) and the number of baits removed (χ^2 = 12.85, d.f. = 1, P <0.001). No other variables or second-order interactions were significant. As a result, Season Year and Site were analysed within each site to determine seasonal differences.

At Fernleigh, caching was significantly influenced by the Season Year of the trial (χ^2 = 15.89, d.f = 3, P = 0.01), with spring 2001 having less baits cached than autumn 2001 (β = -2.18, z = -3.34, P < 0.001), spring 2002 (β = -1.63, z = -2.57, P = 0.01), and winter 2002 (β = -1.64, z = -3.23, P = 0.001). However, there was no significant interaction between the Season Year and the number of baits removed in the free-feed period (χ^2 = 6.36, d.f = 3, P = 0.10).

At Larras, Season Year did not significantly influence caching (χ^2 = 0.25, d.f = 3, P = 0.97). However, there was a significant interaction between the Season Year and the number of baits removed in the free-feed period (χ^2 = 9.46, d.f = 3, P = 0.02). The number of baits removed from a station in winter 2002 significantly increased the probability of a bait being cached compared to spring 2002 (β = -1.24, z = -2.11, P = 0.04) but not Spring 2001 (β = 0.63, z = 0.76, P = 0.45) or autumn 2001(β = -0.25, z = -0.27, P = 0.79).

Foxoff® were significantly more likely to be cached when taken than day-old chicks (β = 3.07, z = 10.02, P <0.001) and wingettes (β = 2.84, z = 9.2, P <0.001) but there was no significant difference between wingettes and day-old chicks (β = 0.24 , z = 0.70, P = 0.47).

Caching at Larras was significantly greater than at Fernleigh during spring 2001 (β = 2.30, z = 2.02, P = 0.04) but not for any other Season Year.

Toxic

A total of 59 from 129 (45.7%) toxic baits taken by foxes were cached on the two trial sites, Myrangle and Nandillyan. Logistic regression revealed that the factors bait type (χ^2 = 18.270, d.f. = 2, P <0.001) and Site (χ^2 = 4.972, d.f. = 1, P = 0.02) were significant, indicating a significant difference between the sites and the bait types in the probability of a bait being cached. On Nandillyan, a bait had significantly less probability of being cached than at Myrangle (β = -0.9475, z = -2.163, P = 0.0306). When taken by foxes, 26.2% of day-old chicks (n = 42) were cached, compared to 43.1% of wingettes (n = 51) and 74.3% of Foxoff® (n = 35). Foxoff® was more likely to be cached than day-old chicks (β = -2.23, z = -4.085, *P* < 0.001) and wingettes (β = -1.52 , z = -2.994, P = 0.002). The probability of day-old chicks being cached was not significantly different from wingettes (β = -0.71382, z = -1.556, P = 0.1197).

There was no significant difference between winter 2001 and winter 2002 (χ^2 =0.907, d.f. = 1, P = 0.341). Similarly, caching was not significantly influenced by the number of baits removed from each station during the free-feed period (χ^2 =0.501, d.f. = 1, P = 0.479), fox density (χ^2 =0.196, d.f. = 1, P = 0.658) or any second-order interactions.

Figures 3.7 – 3.9 present the proportion of toxic baits cached during winter 2001 and winter 2002 on Myrangle, Fernleigh, and both sites pooled respectively.

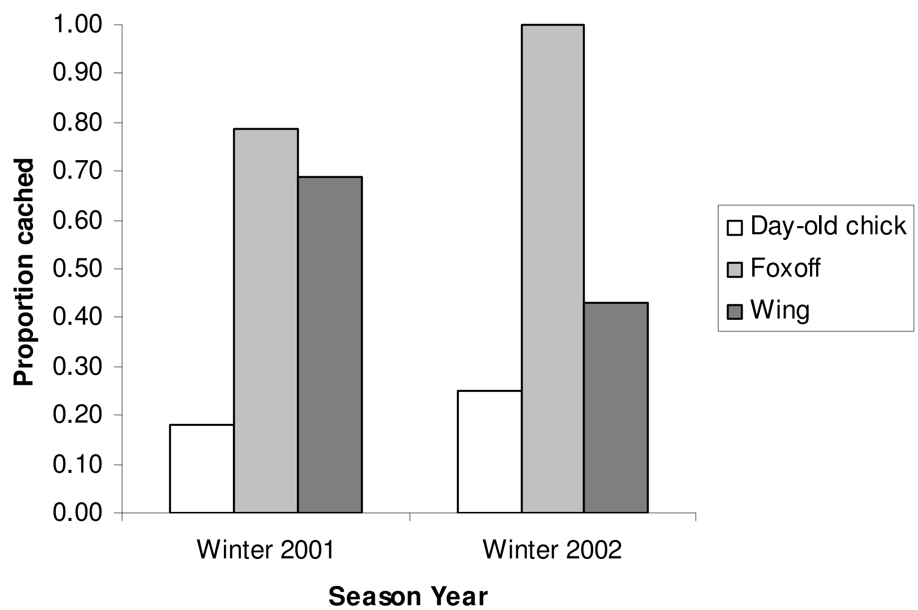

Figure 3.7: The proportion of toxic Foxoff®, day-old chick and wingette baits cached from those taken during winter 2001 and winter 2002 on Myrangle.

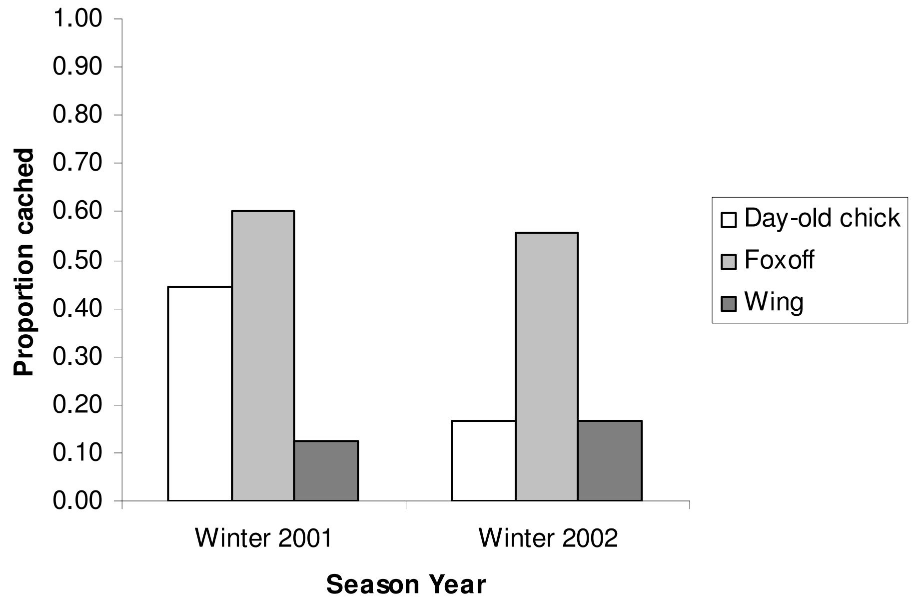

Figure 3.8: The proportion of toxic Foxoff®, day-old chick and wingette baits cached from those taken during winter 2001 and winter 2002 on Nandillyan.

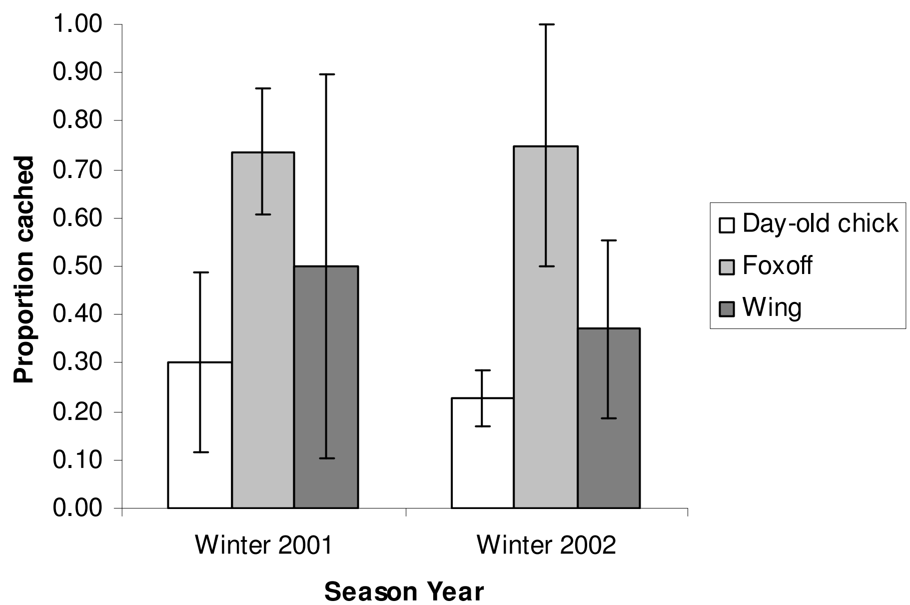

Figure 3.9: The proportion of toxic Foxoff®, day-old chick and wingette baits cached from those taken during winter 2001 and winter 2002 on the trial sites Myrangle and Nandillyan. Error bars indicate standard deviation.

Toxic vs Non-toxic

A comparison between the probability of toxic and non-toxic baits being cached when taken was statistically compared for the trials undertaken during winter 2002. After accounting for differences due to bait type, fox density and the number of baits removed during the free-feed period, poisoned baits on Nandillyan and Myrangle were significantly more likely to be cached than non-toxic baits on Larras and Fernleigh ($\beta = -2.95$, $z = 5.73$, $P < 0.001$).

3.3.2.1 Cache retrieval

A total of 125 cached non-toxic baits were monitored, 73 at Larras and 52 at Fernleigh. The majority were Foxoff® (68 %), followed by wingettes (16.8 %) and day-old chicks (15.2%). Only 13.6% of cached 1080 baits (n = 59) were retrieved in the four 1080 trials. Table 3.3 summarises the retrieval times in days for the cached baits throughout the non-toxic and toxic trials.

Non-toxic

The mean ($\pm$SD) number of days that day-old chicks (2.69 ± 1.93, n = 19), Foxoff®, (3.05 ± 2.12, n = 85) and wingettes (3.00 ± 1.91, n = 21) remained cached before consumption by foxes appears to be similar. However, the mean and variance of the survival times (see Table 3.4) are not reliable indicators of the differences between covariates in survival analyses (Crawley 2002).

Table 3.3: The number of Foxoff®, day-old chick and wingette baits eaten from those that were cached in the trials at Larras, Fernleigh, Myrangle and Nandillyan. *No measure of variation (SD) available since only one cache was retrieved.

Site	Season / Year	Bait type	Number cached	Total number of cached baits retrieved	Mean days til eaten (±SD)
Non-toxic					
Fernleigh	Autumn 2001	Foxoff®	14	2	7.75±5.32
Fernleigh*	Autumn 2001	Day-old chick	1	1	3.00
Larras	Autumn 2001	Foxoff®	13	9	2.67±1.80
Larras*	Autumn 2001	Day-old chick	1	1	1.00
Fernleigh	Spring 2001	Foxoff®	9	8	3.00±2.00
Fernleigh	Spring 2001	Day-old chick	0	-	-
Fernleigh	Spring 2001	Wingette	0	-	-
Larras	Spring 2001	Foxoff®	10	7	2.86±2.67
Larras	Spring 2001	Day-old chick	4	2	4.00±1.41
Larras	Spring 2001	Wingette	5	3	2.33±1.53
Fernleigh	Winter 2002	Foxoff®	12	6	3.67±2.88
Fernleigh*	Winter 2002	Day-old chick	3	2	1.00
Fernleigh	Winter 2002	Wingette	5	4	4.50±1.00
Larras	Winter 2002	Foxoff®	11	6	2.67±2.07
Larras	Winter 2002	Day-old chick	8	6	2.67±2.25
Larras	Winter 2002	Wingette	9	5	2.20±2.17
Fernleigh	Spring 2002	Foxoff®	7	3	3.67±1.53
Fernleigh	Spring 2002	Day-old chick	0	-	-
Fernleigh	Spring 2002	Wingette	1	0	-
Larras	Spring 2002	Foxoff®	9	7	3.50±2.12
Larras*	Spring 2002	Day-old chick	2	1	5.00
Larras	Spring 2002	Wingette	1	0	-
1080					
Nandillyan*	Winter 2001	Foxoff®	3	1	5.00
Nandillyan	Winter 2001	Day-old chick	4	0	-
Nandillyan	Winter 2001	Wingette	1	0	-
Myrangle*	Winter 2001	Foxoff®	11	1	4.00
Myrangle	Winter 2001	Day-old chick	2	0	-
Myrangle	Winter 2001	Wingette	11	2	4.5±4.95
Nandillyan	Winter 2002	Foxoff®	5	0	-
Nandillyan*	Winter 2002	Day-old chick	1	1	3.00
Nandillyan	Winter 2002	Wingette	1	0	-
Myrangle	Winter 2002	Foxoff®	7	0	-
Myrangle	Winter 2002	Day-old chick	4	2	3.5±3.53
Myrangle*	Winter 2002	Wingette	9	1	2.00

Table 3.4: The mean number of days that baits were cached before consumption by foxes in the trial periods on Larras and Fernleigh.

Site	Season Year	Number cached	Number eaten	Mean days til eaten (SD)
Fernleigh	Autumn 2001	15	2	3.33 (2.52)
Fernleigh	Spring 2001	9	8	2.78 (1.99)
Fernleigh	Winter 2002	20	12	3.20 (2.95)
Fernleigh	Spring 2002	8	3	5.63 (3.07)
Larras	Autumn 2001	14	10	2.36 (1.55)
Larras	Spring 2001	19	12	3.58 (2.89)
Larras	Winter 2002	28	17	3.04 (2.73)
Larras	Spring 2002	12	3	6.17 (2.89)

Analyses of deviance revealed that the survival time of non-toxic baits was significantly influenced by the Season Year of the trial (χ^2 = 11.94, d.f = 3, P = 0.01) and the distance cached from the station (χ^2 = 5.41, d.f = 1, P = 0.02). The survivorship of the different bait types was not significantly different (χ^2 = 3.41, d.f. = 2, P = 0.18). There was no significant difference between Larras and Fernleigh in the survival time of cached baits (χ^2 = 0.42, d.f = 1, P = 0.52) but the term Site was not removed from the model since the interaction between Site and Season Year was significant (χ^2 = 18.72, d.f. = 3, P = 0.003). The final model took the form:

Survival ~ Site (ns) + Season Year + Season Year:Site + ln (Distance)

As a result, the cumulative survival curves consisting of the baseline hazard function with the estimated survival function for a given Season Year are shown in Figure 3.10. Each survival function represents the mean survival for an average individual bait with average values of the covariates Site and log (distance cached). Each curve is an estimate of individual survival in each stratum with an average Site and log (distance).

The factor Season Year was significant (d.f = 3, χ^2 = 11.94, P = 0.01), indicating that cached baits were retrieved after significantly different periods between seasons. The model coefficients indicate that autumn 2001 (β = -1.821, z = -2.811, P = 0.005) had significantly less hazard (i.e. less likely to be retrieved) compared to winter 2002. Autumn 2001 also showed significantly less hazard than spring 2001 (β = -2.7004, z = -3.833, P = 0.001) but was not significantly different to spring 2002 (z = -1.715, P = 0.086). Spring 2001 (z = 1.776, P = 0.076) and spring 2002 (z = -0.537, P = 0.59) were not significantly different to winter 2002. Similarly, spring 2001 was not significantly different to spring 2002 (β = 1.452, z = 1.72, P = 0.08). This is probably due to the low number of baits retrieved during spring 2002 (n = 6) compared to autumn 2001 (n = 15), spring 2001 (n = 20) and winter 2002 (n = 29).

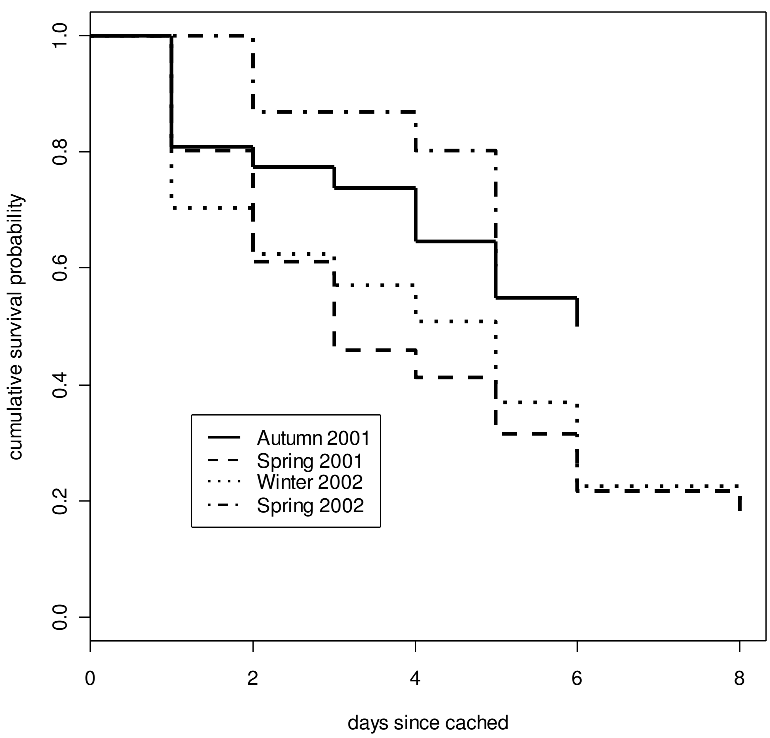

Figure 3.10: Cumulative survival of cached non-toxic baits for the Season Year of trial.

Table 3.5: Number of baits cached, number subsequently eaten, and mean number of days that baits are cached until eaten. Percentage of cached baits subsequently eaten are shown in parentheses.

Season Year	Number of baits cached	Number of cached subsequently eaten (%)	Mean days til eaten $\pm$SD
Autumn 2001	29	13 (44.8)	4.62 $\pm$ 3.23
Spring 2001	28	20 (71.4)	3.32 $\pm$ 2.63
Winter 2002	48	29 (60.4)	3.10 $\pm$ 2.79
Spring 2002	20	6 (30)	5.95 $\pm$ 2.89

Despite that Site was not significantly different overall, the significant interaction between Site and Season Year (d.f. = 3, χ^2 = 18.72, P = 0.003) indicates that baits survived for significantly different rates within the two sites. As a result, the seasonal survival of cached baits was investigated within each site separately.

The model coefficients indicate that at Larras, spring 2002 (β = -1.6045, *z* = -2.351, P = 0.019), showed significantly greater survival compared to autumn 2001. Both spring 2001 (β = -0.4263, *z* = -0.972, P = 0.33) and winter 2002 (β = -0.0447, *z* = -2.829, P = 0.92) were not significantly different to autumn 2001, but winter 2002 had reduced survival times (β = 1.56, *z* = 2.46, P = 0.0140) compared to spring 2002 but not spring 2001 (*z* = 1.81, P = 0.071).

At Fernleigh, Spring 2001 survival was significantly less than autumn 2001 (β =2.3471, *z* = 3.142, P = 0.002) and winter 2002 (β = 1.8905, *z* = 2.898, P = 0.004), but was not significantly different to spring 2002 (*z* = 0.906, P = 0.31). Spring 2002 was not significantly different to autumn 2001 (z= -1.013, P = 0.31) and winter 2002 (z= 1.244, P = 0.21) but showed greater survival than spring 2001 (β =1.4294, *z* = 2.052, P = 0.04). Survival was not significantly different in spring 2001 compared to winter 2002 (*z* = -0.804, P = 0.42).

The distance to the cache from the bait station was significant, with a negative correlation between the distance cached and survival (β = -0.333, z = -2.082, P = 0.0370).

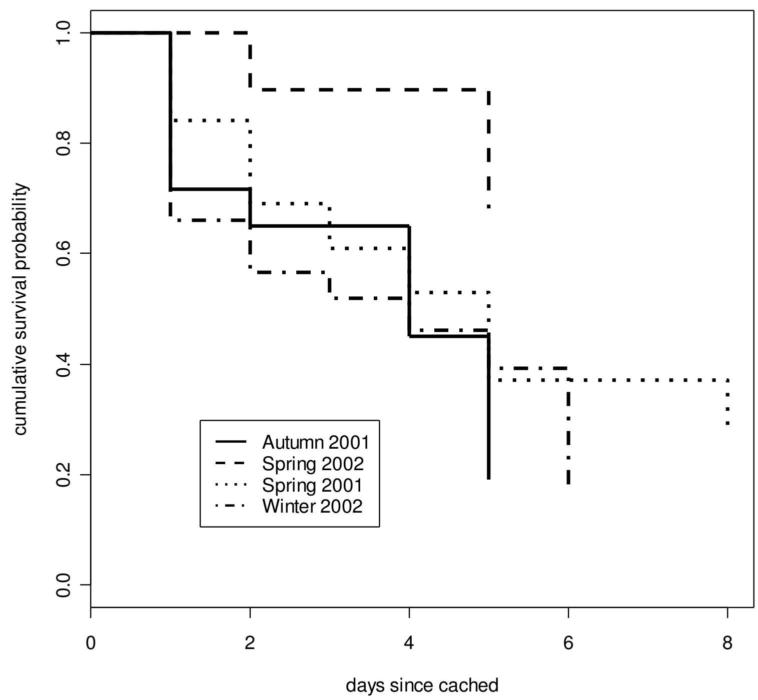

Figure 3.11: Survivorship of cached baits at Larras for the Season Year of the trial.

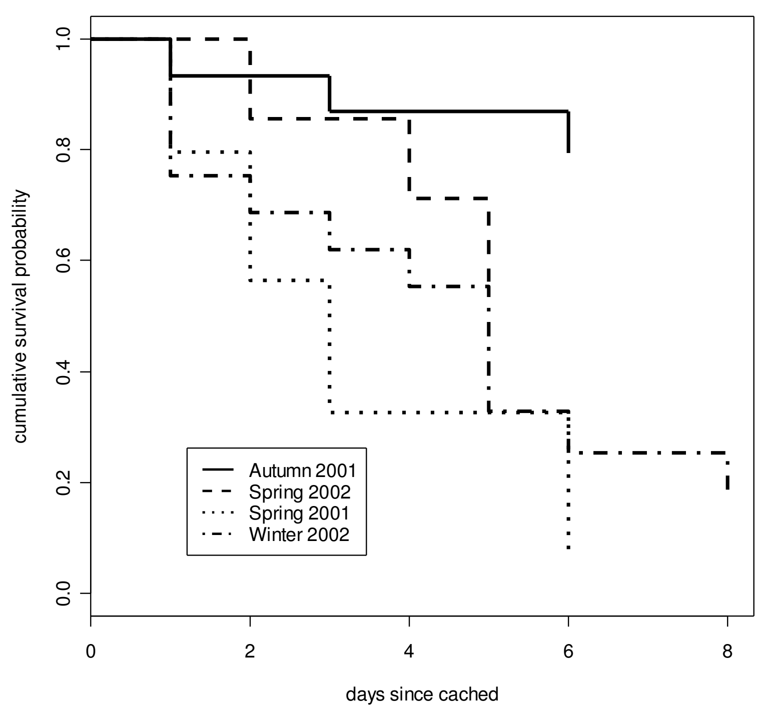

Figure 3.12: Survivorship of cached baits at Fernleigh for the Season Year of the trial.

Toxic

There was no significant difference between the survival rate of toxic cached baits between Season Years (χ^2 = 0.048, d.f. = 1, P = 0.826), Sites (χ^2 = 0.156, d.f. = 1, P = 0.693) or Bait types (χ^2 = 3.33, d.f. =2, P = 0.189). No second order interactions were significant.

Toxic vs. non-toxic

Analyses indicated no difference within the non-toxic and toxic sites in survival of cached baits. Therefore, the two non-toxic and toxic sites were pooled and the survival rates of cached baits were compared for winter 2002. There was a significant difference in the survival rate of cached non-toxic baits than toxic baits (χ^2 = 24.56, d.f. = 1, P < 0.001), with toxic baits having a significantly lower hazard rate (β =-2.176, z = -3.991, P <0.001).

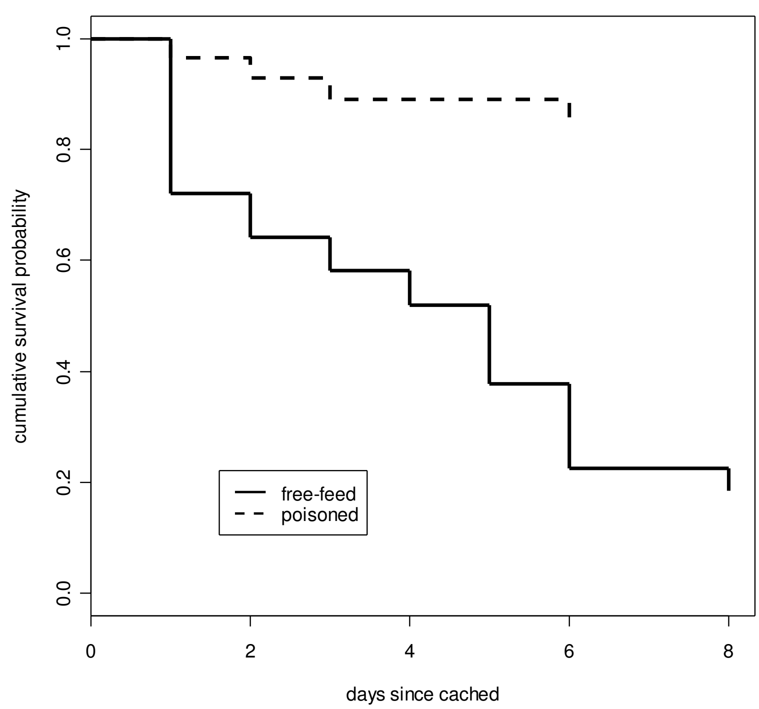

Figure 3.13: Survival of non-toxic (free-feed) and toxic (poisoned) cached baits during winter 2002.

3.3.2.2 Caching distances

Table 3.6 and 3.7 summarise the distances that non-toxic and toxic baits were cached and eaten from stations in each Season Year respectively. Figures 3.12 and 3.13 show the distances that non-toxic and toxic baits are cached and eaten from stations. The mean distance bait was cached from the bait station was 135.9 m, and the median was 90 m. Only 27% of cached baits were located within 100 m of the bait station, 55% were less than 200 m, and 68% were less than 300 m. Those transmitters with the baits eaten from them were located significantly closer (F = 123.95, P <0.001, d.f. = 1) to the bait station than those that were cached, with a mean of 48.0 m and a median of 9 m.

A linear model to determine if the distance that the non-toxic baits were cached was significantly different for the season year of the trial, site, and bait type was undertaken. The distance that bait was taken to be cached was not normally distributed and was subsequently log transformed. Stepwise linear regression revealed that Season Year and number of baits removed by a fox during the free-feed period significantly influenced the distance a bait was cached from the station (F = 7.2753, P = 0.008, d.f. = 1). There was no significant difference in the caching distances of bait types (F = 0.5092, P = 0.602, d.f. = 2). The number of baits removed by a fox in the free-feed period was positively correlated with the distance that baits were cached (β = 0.17888, t = 3.338, P = 0.001). Season Year was also significant (F = 5.2478, P = 0.001, d.f. = 3). Caching distances in autumn 2001 were not significantly different to spring 2001 (t = -0.408, P= 0.68) or winter 2002 (t = -1.112, P = 0.268) but were significantly less than spring 2002 (β = 0.91528, t = 3.436, P<0.001). Baits were also cached at significantly greater distances in spring 2002 than spring 2001 (β = -1.01568, t = -3.742, P<0.001) and winter 2002 (β = -1.1957, t = -4.1414, P <0.001).

There was no significant difference between the caching distances of non-toxic or toxic bait (χ^2 = 1.152, d.f. = 1, P = 0.233) during winter 2002.

Table 3.6: Summary of distances (m) for non-toxic baits cached or eaten. Cached baits are those that are cached when taken from the bait station, eaten are those that are eaten after being taken from the bait station.

	Cached				Eaten			
Season Year	Mean (SD)	Median	Range	N	Mean (SD)	Median	Range	N
Autumn 2001	99.0 (87.9)	65	19 – 340	29	26.8 (44.9)	12	0.1 – 249	100
Spring 2001	127.2 (136.6)	74	3 – 575	28	59.0 (128.7)	8.5	0.1 – 843	252
Winter 2002	112.5 (82.4)	90	14 – 880	48	27.4 (63.4)	5	0.1 – 604	205
Spring 2002	264.3 (235.0)	207	9 - 338	19	76.2 (150.2)	16	0.1 - 1300	312
Overall	135.9	90	3 - 880	124	48.0	9	0.1 - 1300	869

Table 3.7: Summary of distances (m) that toxic baits were cached or eaten. Cached baits are those that are cached when taken from the bait station, eaten are those that are eaten after being taken from the bait station.

	Cached				Eaten			
Season Year	Mean (SD)	Median	Range	N	Mean (SD)	Median	Range	N
Winter 2001	78.2 (85.6)	102	0.5-279	32	58.0 (92.6)	27	0.5-445	30 (total 31)
Winter 2002	104.0 (92.2)	86	5-398	27	55.9 (76.0)	34	0.1-289	35 (total 38)
Overall	90.0 (88.8)	57	0.5-398	59	56.8 (83.4)	27	0.1-445	65 (69)

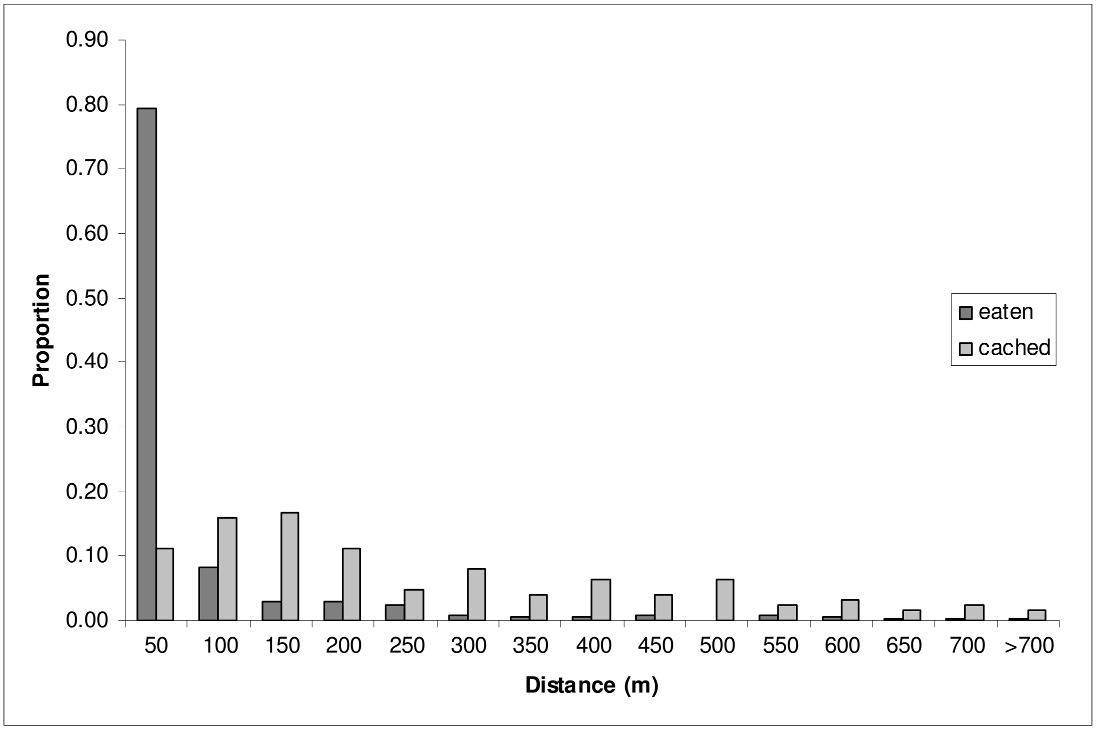

Figure 3.14: The distance from the bait stations that non-toxic baits were eaten (n = 869) or cached (n = 124).

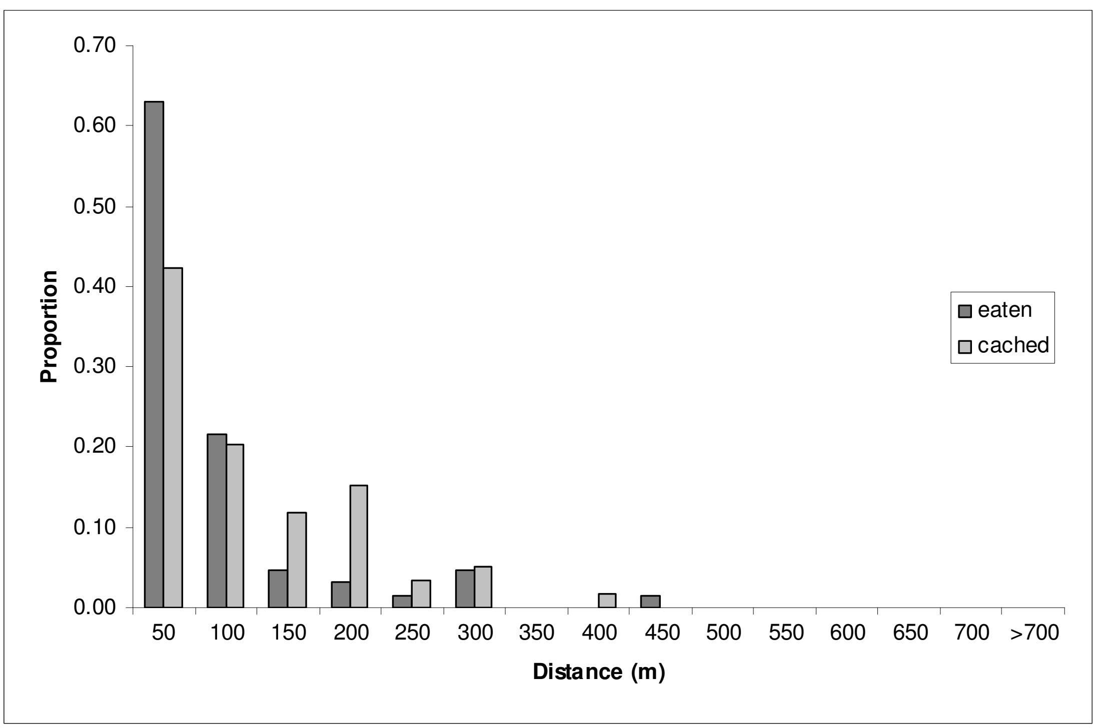

Figure 3.15: The distance from the bait stations that toxic baits were eaten (n = 65) or cached (n = 59).

3.3.2.3 Cache depth

Of the baits that were cached, 65.2% were buried (n = 184) and covered with between 0 and 120 mm of soil (median of 10 mm, mean ($\pm$SD) = 18.1$\pm$23.2 mm).

A linear model was used to determine if the depth that the non-toxic bait was cached was significantly different for Season Year, Site, and Bait type. The depth that baits were cached was not normally distributed and was subsequently log transformed. There was no significant difference in the caching depths for the bait types (F = 0.5092, P = 0.602, d.f. = 2), for any Season Year (F = 0.7463, P = 0.5278, d.f. = 3) or between Sites (F = 0.5868, P = 0.4460, d.f. = 1).

3.3.2.4 Free-feeding and caching

The number of baits removed by foxes or unknown species in the free-feed period from a station was positively correlated with the probability of a non-toxic bait being cached during winter 2002 (β = 0.513, z = 3.319, P = 0.009). The relationship was not significant during the other seasons, nor for toxic baits (χ^2 = 0.501, d.f. = 1, P = 0.479). Wingettes showed a significant increase in the probability of being cached with increasing number of free-feed taken, (β = 2.214, z = 2.557, P = 0.010); Foxoff® (β = 0.411, z = 1.851, P = 0.064) and day-old chicks (β = 0.334, z = 0.834, P = 0.404) showed some indication of increasing probability of being cached, but were not significant.

3.4 Discussion

Bait caching may be detrimental to the efficacy, safety and cost-effectiveness of poisoning programs. Greater understanding of the influences of caching will assist in developing strategies to minimise the effect of caching on control programs. The results indicate that caching intensity varied considerably depending on the bait type, the season of presentation and whether the bait contained 1080. The manufactured Foxoff® bait was cached significantly more than the two fresh chicken baits in every season, but caching intensity peaked during winter 2002, probably as a result of a combination of its low palatability and high availability of alternative food to foraging foxes. 1080 baits appear to be less palatable to foxes than non-toxic baits which has serious implications for fox baiting programs.

3.4.1 Bait uptake

Bait type did not significantly influence the uptake of baits initially presented at bait stations and there was no consistent seasonal influence on bait uptake for both sites. At each site the survival of the non-toxic baits was significantly influenced by the Season Year of the trial, both Larras and Fernleigh showing a general increase in the total percentage of baits removed from the initial to the final trial, with the exception of spring 2002 at Fernleigh (72.2%) which declined from winter 2002 (85%). Additionally the survival of baits was negatively correlated with fox density, with greatest survival when fox density was relatively low.

These relationships probably reflect associative animal learning, or contagion (Thorpe 1963; Thompson and Fleming 1994). Presenting non-toxic bait at the same site at three month or greater intervals could lead to resident foxes becoming habituated to the presence of baits and hence the rate of bait uptake would increase. Similarly, daily bait replacement encourages revisitation by individual foxes. The survival analyses used to investigate bait uptake, therefore, only included the initial baits placed at each bait station in an attempt to reduce bias associated with learning within each trial. The results indicate that it is likely that learning, both within each trial period and between trial periods may have contributed to increased uptake of the initial baits laid. This major confounding factor seriously affects the interpretation of these analyses for practical implications for fox baiting programs, and should be used with caution.

These findings are supported by other field studies investigating bait uptake. Although not commented upon, the results of Trewhella *et al.* (1991) strongly suggest a similar relationship when investigating seasonal bait uptake by urban foxes in Bristol. Bait uptake rates were measured at the same sites (stations) at two-monthly intervals; the results indicated a gradual increase in the overall bait uptake rate throughout the year. Therefore the rate of bait uptake cited by Trewhella *et al.* (1991), calculated from when bait take asymptotes, is confounded by the prior visitation of foxes to that station. Studies investigating the uptake of attractant and flavour-enhanced baits in the United Kingdom found some evidence of learning by resident foxes (J. Woods and G. Smith, Central Science Laboratory, pers. comm. 2003). In the current study, the difference between bait survival between sites indicates that site differences (e.g.

food abundance) or behavioural differences (e.g. foraging activity) may confound the ability to assess overall seasonal influences on bait uptake. This study demonstrates that to adequately assess seasonal changes in bait uptake, trials should be undertaken on both permanent and single-use sites, replicated over many years, to account for confounding by revisitation and differences between fox populations and sites.

3.4.2 Bait caching

The probability that non-toxic bait would be eaten or cached when taken was significantly influenced by the type of bait and the number of baits removed from that station in the free-feed period. There was also a significant interaction between the Site and Season Year, indicating that seasonal changes in the probability of bait being cached were significant within sites, but there were no trends consistent on both sites for all bait types.

The probability that bait would be eaten or cached when taken was strongly influenced by bait type. Foxoff® were cached significantly more in both non-toxic and 1080 trials. In the non-toxic trials, a total of 66.9% of Foxoff® compared to 5.7% wingette and 4.5% day-old chick baits were cached when taken by foxes. The toxic trials showed an even higher rate of caching; an average of 74.3% of Foxoff® were cached compared to 43.1% wingette and 26.2% of day-old chick baits. Results from semi-tame or captive foxes indicate that caching is related to the palatability of the bait substrate, with preferred baits eaten more frequently cached less often (Macdonald 1977; Van Polanen Petel *et al.* 2001). Therefore the results from this study indicate that Foxoff® are less palatable than day-old chicks and wingettes, and that toxic baits are less palatable than non-toxic baits.

Previous studies have shown Foxoff® to be relatively unpalatable when compared to other bait types. Van Polanen Petel *et al.* (2001) tested the caching of deep fried liver (DFL), dried deep fried liver (DDFL) and Foxoff®. DFL was preferentially eaten, followed by DDFL and then Foxoff®.

The results indicate that 1080 baits are significantly more likely to be cached, and less likely to be retrieved than non-toxic baits. Consumption of toxic bait would have resulted in an individual dying and thus unable to cache any subsequent bait, unless these baits were encountered in the latent period before any poisoning symptoms appeared. Symptoms usually appear between 30 minutes and 4 hours following consumption of toxic bait (Chenowith and Gilman 1946; Egekeze and Oehme 1979; Sheehan 1984; Staples *et al.* 1995; Marks *et al.* 2000); foxes may encounter and potentially cache multiple baits within this period. In the non-toxic field trials, exposed transmitters (i.e. indicating consumed bait) were occasionally found adjacent to freshly dug holes or depressions, suggesting that they were caches that had been made earlier in the night before being retrieved. In the toxic trials, these individuals may die before being able to retrieve their caches, leaving many caches intact. Since foxes usually do not locate another foxes cache (Macdonald 1976, 1977), toxic caches would be more likely to remain intact after the death of the responsible individual, especially over the relatively short period that caches were monitored.

1080 is reportedly tasteless and odourless when used in 3 mg concentrations added to bait (Sheehan 1984). There is some evidence from conditioned taste aversion field trials that foxes can detect bait that is injected with levamisole, a tasteless and odourless chemical (see Chapter 4). These baits appeared to be avoided following previous consumption of levamisole treated bait. Aversion to 1080 has been reported in other species such as brushtail possums (*Trichosurus vulpecular*) (O'Connor and Mathews 1999) usually as the result of non-lethal bait consumption. Such aversion mechanisms are probably not responsible here; there was no 1080 baiting undertaken on both field sites for at least two years prior to the initial trial in 2001. Additionally, all caches were retrieved before periods when they were likely to contain sub-lethal doses, so foxes wouldn't have had the opportunity to consume a sub-lethal dose. Lastly, there was no difference in proportions of baits cached between the 2001 and 2002 trials, indicating that the initial trial did not result in a bait averse population.

It is possible that 1080 is detectable and its addition into bait reduces the palatability of the bait. All baits used to assess caching in the 1080 and non-toxic trials were handled in the same manner; transmitters were inserted in all baits using the same techniques. The only difference was the addition of 1080; the fresh chicken baits were injected with 1080 solution, while Foxoff® were commercially manufactured to contain 1080. 1080 is known to reduce the palatability of bait to brush-tail possums, dunnarts (*Sminthopsis* spp.) and some rodents (Morgan 1982; Sinclair and Bird 1984; Calver *et al.* 1989) and may be responsible for the increased caching of 1080 baits by foxes. Free-feeding may have promoted caching of the toxic baits. Free-feeding would have habituated foxes to the taste of non-toxic bait; the subsequent inclusion of 1080 may have prompted a neophobic reaction, reducing the bait palatability and increasing the likelihood of being cached. It is difficult to determine whether the increased caching of 1080 relative to non-toxic bait is a result of a low overall palatability of 1080 bait, a reduction in 'same-night' retrievals, or a combination of both. Regardless, the fact that a lower proportion of 1080 baits are consumed should be investigated further since it has implications for the efficiency and safety of fox baiting campaigns.

The percentage of non-toxic Foxoff® cached peaked during winter 2002 on both sites, with 56% and 58% of those taken cached on Larras and Fernleigh respectively. This may be related to either nutritional or behavioural changes relating to fox reproduction. A study assessing the seasonal fat deposition and body composition of foxes in central-west New South Wales (Winstanley *et al.* 1999) concluded the greatest decline in body condition occurred during the peak whelping and cub-raising period (August to November). The greatest decline in condition for females was during September, which coincides with the peak in whelping (McIlroy *et al.* 2001). Body fat declined in males during the mating period (July) reflecting the energy demands of defending a breeding territory (Winstanley *et al.* 1999). This may reflect the reduction in foraging; males may be so busy defining and defending their territory and searching for mating opportunities that foraging becomes a secondary concern (Saunders and McLeod In Press). Alternatively, the reduction in body fat may reflect low food availability. Therefore, a decline in body condition means that energy demands are not met by dietary intake, which may be caused by either low food availability or foxes foraging less and relying on energy reserves to meet demand. The winter 2002 caching trials were undertaken in July, when male body condition is declining while female body condition is peaking. If males are reducing their foraging activity during this period, then the peak in Foxoff® cached during this period is probably a result of the overabundance of food available to females during this period. This is supported by some findings in the literature. Caching behaviour is closely linked to food ingestion (Vander Wall 1990), which is regulated at two levels, short and long term. Short term regulation occurs as a result of satiation following feeding, longer term it is affected by the individual's nutritional status. As a result, satiation responds to local conditions of food availability, whereas the latter is a function of nutritional deficit or obesity (Herberg and Blundell 1967; Herberg and Blundell 1970; Vander Wall 1990; Rice-Oxley 1993).

Fox density is at its lowest during winter since the annual whelping period only commences in later August/early September (McIlroy *et al.* 2001). Since the number of baits available was more or less constant during each trial, each individual would have an increased number of baits available to it during this period.

The fact that the winter peak in caching is not reflected in the proportions of the two chicken bait types cached, may be explained through interpreting some observations recorded during the trials. Observations whilst recovering or monitoring transmitter baits during both toxic and non-toxic trials suggest that foxes can access multiple baits within the one night. On several occasions during the non-toxic trials up to three transmitters were found within a few metres of one another, suggesting that a single fox was responsible for removing at least three baits within the one night. Foxes have been reported to consume food until satiated, after which point any subsequent food located is cached for later consumption (Henry 1986). Additionally, foxes may cache less-preferred prey, returning only if more-preferred prey is not available or satiation is not reached (Macdonald 1977). Therefore, if individual foxes removed multiple baits, and consumed the more palatable types until satiated, the less palatable bait types would be more likely to remain cached. This may be the reason for the peak in caching of Foxoff® during winter, when fox density is lowest, since the more preferred baits encountered (chicken wingettes and day-old chicks) would be consumed until satiation, after which the 'excess' baits would remain cached.

Alternatively, the apparent increase in caching activity during winter may be due to foxes storing food in preparation for the whelping/cub-raising period (Macdonald 1977) where energy demands are greatest (Winstanley *et al.* 1999). This is unlikely since the retrieval of caches during this period was not significantly different to the other trial periods.

Additionally, long-term storage in caches is probably restricted to very cold climates where spoilage is reduced (Macdonald *et al.* 1994).

The reduced caching of Foxoff® in both spring 2001 and spring 2002 also coincides with the period of peak energy demand in foxes (August-November) (Winstanley *et al.* 1999) suggesting that bait would be more readily taken during these periods. Additionally, the winter peak in caching of Foxoff® was not reflected in the other bait types, with less than 1% of day-old chicks and 2% of wingettes cached during this period respectively. The lack of consistent seasonal peaks in caching for all bait types suggests that there may be some seasonal change in dietary preference driven by complex behavioural and physiological changes influencing the response of foxes to different food types.

There was a significant interaction between Season Year and the number of baits removed from a station before inclusion of transmitters. Similarly, the number of baits removed from a station before the inclusion of transmitters had no significant effect on caching. The interaction indicates that the continual replacement of free-feed bait in a station significantly increased caching only during winter 2002. Since caching is a response to an overabundance of food (Vander Wall 1990) it is possible that continual replacement of non-toxic bait may promote caching. However, in autumn 2001, bait was significantly less likely to be cached with an increase in the number of baits taken from a station. Therefore, an alternative hypothesis may be that continual replacement of baits reduces caching, since foxes become habituated to the presence of food, and 'switch' to consuming bait. However, the relationship between bait replacement and increased consumption was generally negative for all trials but only significant for the autumn 2001 trial. There is no obvious explanation why this occurred during the autumn 2001 trials and not the other trial periods, but should be investigated further.

There were significant site differences in caching, with significantly more baits cached at Larras than at Fernleigh. This was probably just due to differences in fox behaviour at both sites. Although food availability was not measured on both sites, the sites were within the same region, had similar levels of fox density (as evidenced by the spotlight abundance indices) and would have received similar amounts of rainfall. Since the density of foxes is positively correlated with the productivity of the country (Saunders *et al.* 1995), the abundance of food was probably similar on the two sites. However, this would not explain any short-term changes in food abundance likely to have occurred on these properties due to differences in management, e.g. stocking levels throughout this period.

3.4.2.1 Cache retrieval

Foxes are generally scatter hoarders with caches only usually containing one prey item. Foxes are thought to relocate caches by remembering the precise location of each cache site through spatial and/or visual cues (Macdonald 1976, 1987). Foxes usually retrieve caches by directly approaching the cache site (Murie 1936; Scott 1943) and, when caches are moved a short distance from the original cache site, foxes will rarely recover them (Macdonald 1987). This suggests that caches should be retrieved only by the animals that are responsible for making that cache, or through observations of animals that make that cache (Jeselnik and Brisbin 1980; Macdonald 1987; Vander Wall 1990).

Macdonald (1976) found that caches containing more preferred prey are retrieved earlier than those containing less preferred prey. It is therefore surprising that there was no significant difference in the retrieval rates of the cached bait types, particularly with the marked differences in bait palatability between Foxoff® and the two chicken bait types. Additionally, if foods with a greater potential for spoilage are probably retrieved at a faster rate (Vander Wall 1990) then you would expect that day-old chicks and wingettes should be retrieved earlier. This suggests that fresh bait types may be resistant to caching as a function of their greater potential for spoilage (see Chapter 2), while Foxoff® may be prone to caching as a result of its greater shelf life. However this study could not account for the order that individual foxes retrieved baits, only the retrieval rates of all the caches could be compared. Individuals may not have accessed or cached all bait types, and then would not have been able to retrieve caches in order of preference. Additionally, the large variation in retrieval times of all baits, and the small sample size of the cached fresh bait types made comparisons difficult.

Despite that a high proportion of Foxoff® taken were cached in this study, many caches were retrieved. Overall, 58.4% of non-toxic baits cached were retrieved within four days. This contrasts with some other studies that report that foxes and other canids usually recover meat within one day (Murie 1936; Scott 1943). This retrieval rate appears similar to other studies (Saunders *et al.* 1999; Thomson and Kok 2002) where 78% and 80% of non-toxic baits (Foxoff® and dried meat respectively) were retrieved within ten days. However, due to the need to conserve transmitter life, all caches had to be retrieved at the end of a ten-day trial period; therefore not all caches could be monitored for uniform periods. Despite this, it appears that foxes will retrieve and consume the majority of non-toxic caches.

The probability of a cache being retrieved was influenced by the Season Year of the trial (Figure 3.9). Retrieval of caches in spring 2002 was generally less than that in other trials but this was inconsistent between the two sites. On Larras, the probability of a cache being retrieved was less during the spring 2002 trial than all other trials apart from the one undertaken in spring 2001. Baits cached during spring 2002 at Fernleigh remained cached for significantly longer periods than all other seasons tested apart from autumn 2001.

The abnormal environmental conditions during mid to late 2002 may be partly responsible. A severe drought occurred on the central tablelands during this period (evidenced by cumulative rainfall deficiency: Figure 3.1), which produced a higher than normal mortality of domestic stock, including spring-born lambs (S. Brown, Larras Lake North, pers. comm. 2002). This higher than normal mortality of stock would have resulted in elevated levels of carrion being available to foxes. Since caching is directly related to food abundance, elevated food abundance may have resulted in increased caching during this period. During this period, bait uptake during the free-feed period was generally greater than during other trial periods. This result was, therefore, probably due to the abnormal seasonal conditions than any true behavioural shift.

3.4.2.2 Caching distances

There was no difference between the cache distances of toxic and non-toxic baits, nor between bait types. The mean distance baits were cached was 135.9 m, with 55% caches located less than 200 m and 68% less than 300 m, with a maximum of 880 m from the original location. This is greater than that found by Thomson and Kok (2002) in Western Australia (86.9 m) where 58% of cached baits were found within 50 m. Distances were comparable with studies in similar habitats in eastern Australia where the mean distances were 156 m and 112 m /126 m respectively (Saunders *et al.* 1999; Van Polanen Petel *et al.* 2001).

These results provide evidence consistent with previous studies (Saunders *et al.* 1999; Van Polanen Petel *et al.* 2001; Thomson and Kok 2002) that baits may be cached at considerable distances from their original location. However, non-toxic baits were cached at greater distances during spring 2002 (mean = 264.3 m) than all other trial periods (Table 4.6). Mean distance during spring 2001 also appeared greater (127.2 m) than during either autumn 2001 (99.0 m) or winter 2002 (112.5 m), although this was not significant. The apparent Spring peak in caching distance was also noted by Thomson and Kok (2002) and is probably due to foxes caching baits closer to dens to provision cubs (Macdonald 1977; Macdonald *et al.* 1994). The harsh seasonal conditions during spring 2002 may have increased the area foraged by individuals, resulting in greater movement of caches closer to den sites or areas secure from other foxes. If caching distances during spring campaigns are consistently greater than other periods, then baiting during this period may offer greater potential risk to non-target species through moving baits onto areas thought to be bait free.

3.4.2.3 Cache depth

The majority of cached baits in this study were buried (65.2%), with a median of 10 mm (range 1-120 mm) of soil covering the bait. This supports other studies that found that burial depths range from shallow depressions such as 10 mm (Saunders *et al.* 1999; Thomson and Kok 2002) to 70-100 mm (Henry 1986). Baits that were not buried were usually well concealed and hidden under leaf or grass litter, under shrubs, grass tussocks or other vegetation but some were simply dropped on to the surface. Cache sites were typically located in open habitats, with no common distinguishing features to characterise their location. Given that cache sites are typically well hidden (Murie 1936; Kruuk 1964; Macdonald 1976; Henry 1986; Saunders *et al.* 1999; Thomson and Kok 2002) and appear to be usually retrieved only by the fox that made the cache (Macdonald 1976), it is probable that few cached baits would be retrieved by other animals. This would especially be the case for the study area where there are few non-target animals present that are capable of removing and consuming bait (see Section 1.8 and 8.2). Additionally, the 1080 in baits usually degrades rapidly under field conditions, allowing only a finite period where cached baits would constitute a significant non-target threat (see Chapter 2). However, Kortner *et al.* (2003) suggested that one spotted-tailed quoll (*Dasyurus maculatus*) may have died following the consumption of cached 1080 bait 5-6 weeks after the completion of a fox baiting campaign. Clearly cached baits do present some risk to individual non-target animals, but the level of risk is probably low.

3.4.2.4 Free-feeding and caching

Free-feeding a bait station appears to encourage caching. Additionally, the number of baits removed from a station during the free-feed period was positively correlated with the distance that baits were cached. This suggests that prolonged free-feeding may not only result in an increased incidence of caching, but the resultant caches may be located further from the original location. As discussed above, free-feeding may reduce the palatability of 1080 baits through habituation to the taste of non-toxic bait before presentation of the different, possibly less palatable bait. Although not significant across all trial periods, free-feeding also appears to encourage caching of identical successive baits presented. Continual replacement of non-toxic baits in a particular location would habituate foxes to a readily available, replenishable food source. Depending on the environmental food availability and relative palatability of the food (bait) presented, this habituation may encourage foxes to either consume or cache these baits. Either way, free-feeding encourages re-visitation by individual foxes resulting in an increase in the number of baits available to each fox and hence, increase in the number of baits required for a baiting campaign. As a result, such strategies may reduce the efficiency of baiting practices.

3.4.3 Management implications

This study provides some important results that should be considered to improve the safety and efficiency of baiting campaigns.

The results from the bait uptake and caching trials highlight the importance of assessing the fate of baits after being taken rather than just bait uptake. Studies investigating palatability through bait uptake should be assessed with caution since uptake may not be directly correlated with bait palatability. For example, field trials based on bait uptake found that Foxoff® and DK-9 (both manufactured baits) were the most acceptable, followed by chicken heads, meat (mutton), and various types of offal (P. Fleming, NSW Agriculture unpublished data). How this uptake of each bait type relates to consumption is unknown. An excellent example of the discrepancy between bait uptake and consumption is presented by Kortner *et al.* (2003) where 19 from 20 Foxoff® removed by spotted-tailed quolls (*Dasyurus maculatus*) were found uneaten a short distance from the bait station. This indicates that although baits may be removed, it does not provide a good indication of the palatability of bait. Experiments that are undertaken to assess the palatability of bait should use transmitters or other means (e.g. tracking spool) to assess whether removed baits are consumed, or misleading results may be obtained.

The low palatability of 1080 bait relative to non-toxic bait may have serious efficiency and safety implications for current fox control campaigns. If foxes can detect and avoid 1080, then baiting programs would be less efficient than if a less detectable toxin is used. If foxes are caching multiple 1080 baits before succumbing to bait, then these baits will be unable to be located and retrieved by the operator at the completion of the campaign.

If experiments on bait uptake and consumption are undertaken using non-toxic bait and the results applied to 1080 baiting campaigns, the palatability of baits may be significantly overestimated. For example, experiments using biomarkers in a non-toxic matrix to simulate the proportion of the population susceptible to 1080 baiting (e.g. Murray *et al.* 2000) may significantly overestimate this proportion through presenting relatively more palatable bait.

Results from these experiments should be recognised as potential overestimates and subsequently treated with caution.

Baits appear to be cached at greater distances during spring; additionally, those baits cached at greater distances are less likely to be retrieved, so the risk may be compounded during spring campaigns. Therefore, extra caution should be applied during spring campaigns to avoid farm dogs consuming bait. Strategies such as placing bait stations at further distances from property boundaries, or neighbouring landholders imposing a larger 'buffer zone' where domestic dogs are excluded should be considered to reduce the potential for poisoning.

The common practice of free-feeding in conservation areas to assess which animals are visiting and removing bait from bait stations may be increasing the likelihood of caching by foxes, especially if baiting is undertaken with less palatable bait types. Foxoff® is often used in conservation areas since it is has a long-shelf life and is easy to handle and prepare (see Chapter 5). It is also relatively unpalatable to some non-target species (Kortner *et al.* 2003). Free-feeding may be a good measure to assess which animals are visiting a bait station, but it may act to put non-target species at risk through increasing the proportion of baits that are cached and not retrieved at the end of the campaign.

One of the most important findings of this study is that caching may be reduced in any season by presenting a highly palatable bait type. The results indicate that wingettes and day-old chicks offer a significant advantage of reduced caching relative to Foxoff®. Using a highly palatable bait type such as chicken wingettes or day-old chicks will ensure that a high proportion of those taken by foxes are eaten, and fewer will be cached and remain cached at unknown locations where they cannot be retrieved. This will minimise the risk to domestic pets and other non-target species from consuming cached baits. However, other issues, such as bait longevity and cost-effectiveness are important considerations in deciding which bait type to use.

3.5 Conclusion

The results from the caching trials show that considerable proportions of baits removed by foxes may be cached. Bait caching may be detrimental to the effectiveness and efficiency of baiting campaigns and have implications for non-target safety. Since the intensity of the caching is largely dependent upon the palatability of the bait, presenting highly palatable bait would be one strategy to reduce caching, and hence, caching associated problems. This implies that wingette and day-old chick bait would be more suitable for fox management than Foxoff®. However, other considerations, such as bait longevity (Chapter 2), handling, and cost-effectiveness may be equally or more important, and need to be considered when choosing an appropriate bait type.

CHAPTER 4

CONDITIONED TASTE AVERSION[1]

4.1 Introduction

The success of rodent baiting campaigns is often hampered by the gradual decline in the number of animals in the target population willing to consume bait. Some individuals will consume enough bait to constitute a lethal dose and die, but those that consume a sub-lethal dose will recover (Prakash 1988). Many of these survivors will suffer malaise and gastro-intestinal illness may, by associating consumption of the bait with this illness may become bait-shy (Chitty 1954). These rats will refuse to consume further bait, or reduce the amount of bait consumed when subsequently encountered. This phenomenon was originally termed ‘bait shyness’ or ‘poison shyness’, but now these terms are used to describe different phenomena. ‘Bait shyness’ is aversion associated with the bait substrate, whereas ‘poison shyness’ is aversion is associated with the active poison in the bait (Barnett and Cowan 1976). Both phenomena are forms of an acquired aversion and they have probably evolved as a defence against dietary poisoning (Reidinger and Mason 1987) by guarding against re-consumption of harmful food. When the aversion is associated with the taste of the food, as distinct from visual, odorous or other cues (Garcia *et al.* 1955), it is known as conditioned taste aversion (CTA). Therefore, CTA occurs when an animal associates the taste of a food with illness and avoids consuming that food in subsequent encounters (Garcia *et al.* 1974).

CTA could be used to influence feeding behaviour to help meet wildlife management objectives (Cowan *et al.* 2000). Potential uses include reducing predation on domestic livestock and endangered species or reducing damage to agricultural products (Nicolaus *et al.* 1989a). If used to generate an aversion to consuming particular prey, animals consuming prey treated with a CTA agent should subsequently avoid consuming that prey (Cowan *et al.* 2000). CTA offers a unique advantage to lethal control because individual and population-level effects are usually persistent. In contrast, if management focuses on lethal control, a rapid reinvasion of new, non-averse individuals will simply negate the effect of removing

[1] Field CTA component published in Mammal Review, 2004, Vol. 34, p325-330.

predators (Nicolaus *et al.* 1989a). CTA was first proposed to reduce sheep predation by coyotes (*Canis latrans*) (Gustavson *et al.* 1974) by invoking a two-stage learning process. Phase one involves inducing an aversion to the flavour of the food; this aversion will prevent consumption of the food but not attack of live prey. The second phase occurs when the cues associated with live prey (e.g. auditory, visual, olfactory) are associated with the flavour, thus preventing attack (Gustavson *et al.* 1974). Some studies suggest that CTA was successful in reducing predation on sheep by coyotes (Gustavson *et al.* 1976; Ellins *et al.* 1977; Gustavson *et al.* 1982), whereas others have suggested that CTA towards bait did not transfer to the killing of live animals (Conover *et al.* 1979; Bourne and Dorrance 1982; Burns 1983).

In other research, reduction of predation using only the initial pairing of illness with consumption of the food appears to have been more successful. Egg predation has been successfully reduced by CTA in species including free-ranging crows (*Corvus brachyrhynchus*) and ravens (*Corvus corax*) (Nicolaus *et al.* 1983; Nicolaus *et al.* 1989b; Dimmick and Nicolaus 1990; Avery *et al.* 1995), mongooses (*Herpestes auropunctatus*) (Nicolaus and Nellis 1987) and rats (*Rattus norvegicus*) (Massei *et al.* 2002). Dingoes (*Canis familiaris dingo*) (Gustavson *et al.* 1983) and foxes (Massei *et al.* 2003) have refused to consume untreated meat following consumption of treated meat. These successes with 'stationary' prey suggest additional potential uses of CTA in wildlife management rather than just reducing predation on live prey. Following developments in research on orally administered vaccines and contraceptives, baits are being increasingly used in wildlife management (e.g. Bradley *et al.* 1999; Masson *et al.* 1999). Many studies on carnivores, and in particular foxes, have used baits to deliver rabies vaccines, regulate fertility and control population size (e.g. Marks *et al.* 1996; Farry *et al.* 1998; Selhorst *et al.* 2001). Most of these studies have also stressed the need to improve the cost-effectiveness of baiting campaigns by reaching the maximum proportion of animals with the minimum number of baits. For foxes, multiple bait uptake, bait caching and monopolisation of bait by individuals (Chapter 3), are amongst those factors that may reduce the success of a baiting campaign (Trewhella *et al.* 1991; Saunders *et al.* 1999). A method that could deter individual foxes from eating or removing excessive baits, or denying others access to bait could improve the cost-effectiveness of baiting campaigns (see Chapter 7).

CTA has been experimentally induced in animals by administering an illness-inducing chemical post-food ingestion. Animals tend to associate adverse internal events with cues related to food (Galef and Osbourne 1978). Oral ingestion of the CTA agent is not essential, but the agent must be administered within a short enough period to allow the onset of symptoms to be associated with the conditioned stimulus being consumed. As a result a range of administration methods has been tried; CTA agents have been added into food (Gustavson *et al.* 1974; Gustavson *et al.* 1976; Conover *et al.* 1977; Bourne and Dorrance 1982), injected intraperitoneally (Gustavson *et al.* 1974) and via oral intubation (Gill *et al.* 2000; Massei *et al.* 2002). However, for practical purposes of reducing predation in wildlife management, it will probably be necessary to add the CTA agents into the food to target the predator (Cowan *et al.* 2000). If the agent is to be orally administered then it should ideally be tasteless and odourless to prevent detection. Few chemicals can be successfully incorporated into baits that completely retain the taste and smell of target food (Nicolaus *et al.* 1989b).

The ability of CTA to modify feeding behaviour is reliant upon finding suitable CTA-inducing chemicals (Gill *et al.* 2000). Issues of safety and detectability severely limit the number of compounds that may be used for practical applications of CTA in wildlife management. In addition to the ability to induce a robust CTA with a single dose, agents for field application should 1) be undetectable at doses likely to induce CTA; 2) be safe in terms of LD_{50} to potential target and non-target species likely to consume the bait; 3) be physically stable so as to allow its incorporation into baits for field use; and 4) have sufficient delayed activity to allow its full ingestion without illness (Nicolaus *et al.* 1989b; Cowan *et al.* 2000; Gill *et al.* 2000; Massei *et al.* 2002). Many chemicals have been tested for their potential to induce CTA in carnivores, such as lithium chloride, carbachol, and thiabendazole (e.g. Burns and Connolly 1980; Burns 1980; Bourne and Dorrance 1982; Gustavson *et al.* 1983; Nicolaus and Nellis 1987; Conover 1989). However, carbachol can be lethal to some mammals (Nicolaus and Nellis 1987) while both lithium chloride and thiabendazole are likely to be detectable at doses causing CTA (Conover *et al.* 1977; Burns and Connolly 1980; Ziegler *et al.* 1982).

Levamisole hydrochloride has successfully induced CTA to various food types in laboratory rats (Gill *et al.* 2000; Massei and Cowan 2002). Levamisole is an anthelmintic used in oral drenches for domestic stock, poultry and cats and dogs (Arundel 1985) and as an immodulator in anti-cancer therapy (Budavari 1996). It is rapidly absorbed in dogs with peak levels attained in 12 minutes, and causes up to ten percent of test subjects to vomit (Arundel 1985). Levamisole is tasteless and odourless (Remington 1975) and therefore has potential to be added directly to food for field use as a CTA agent. When tested with captive foxes, levamisole induced complete avoidance of the experimental food for periods from seven weeks (beef-flavoured minced turkey) (Massei *et al.* 2003) to greater that 12 months (pheasant meat) (G. Massei unpublished data). Further trials are required to determine the suitability of levamisole as a CTA agent for field use.

Understanding the factors that influence the strength and persistence of CTA is necessary for any practical application (Cowan *et al.* 2000). Previous studies have identified influences including type and severity of illness (Prakash 1988), length of time between consumption and onset of illness (Garcia *et al.* 1974), strength and intensity of the conditioned taste stimulus (Nowlis 1974), cue saliency and familiarisation (e.g. Nachman *et al.* 1977). Previous exposure to a flavour will decrease the ability of an animal to induce CTA to that flavour (Nachman *et al.* 1977). However, prior experience with a variety of novel flavours different to that used during conditioning may influence the acquisition and persistence of CTA. Capretta *et al.* (1975) found that immature rats that were pre-exposed to several distinctive flavours would be more likely to accept a novel flavour than those with less varied gustatory experiences. Observations from field studies (Boice 1971; Quy *et al.* 1992) suggest that wild rats living in dynamic environments with high food diversity are less neophobic than rats living under more constant conditions. If pre-exposing animals to a diversity of foods reduces neophobia to novel food, then the ability to acquire and retain an aversion to a novel food may extinguish with previous exposure to novel tastes. Most laboratory studies have raised animals on a single food before measuring CTA (e.g. Massei *et al.* 2002).

The amount of the food eaten during conditioning may also influence CTA. Barker (1976) and Bond and Westbrook (1982) found that the amount of food eaten during the initial presentation at conditioning was positively correlated to the strength of the aversion. However, Massei and Cowan (2002) found that persistence of the aversion was negatively correlated with the amount eaten during conditioning. Further investigations are needed to clarify the nature of this relationship.

CTA has often been studied using laboratory rats (*Rattus norvegicus*) as a model species to predict the CTA behaviour for other mammalian species because CTA has been assumed to have a common underlying physiological and neuroanatomical basis amongst mammals (Bures *et al.* 1998). However, the dietary habits of the model species must be considered (Daly *et al.* 1982; Ratcliffe *et al.* 2003). Dietary generalists have the ability to modify their feeding behaviour after an illness-inducing food encounter; monophagous specialists, such as the common vampire bat that feed exclusively on blood, lack the neurophysical pathways required for taste aversion learning (Ratcliffe *et al.* 2003). Dietary generalists such as *R. norvegicus* are omnivores (Lund 1994) and therefore neuroanatomically more suitable for CTA studies. In most cases, predictions based on CTA studies of *R. norvegicus* have been highly accurate when applied to other species, even in determining appropriate dose rates (Nicolaus *et al.* 1989a).

In this chapter, I report on two experiments on CTA. Given the problem of excessive bait uptake, caching and monopolisation by foxes, and the recent success in inducing CTA in pen trials, the ability of levamisole to induce CTA to bait in free-ranging foxes is examined. The second aims to determine whether CTA in rats can be influenced by pre-exposure to a varied diet; as noted above, this is an important consideration when developing strategies for field use of CTA. Foxes were unavailable for this trial, therefore laboratory rats (*R. norvegicus*) were used as a model species, given their generalist feeding habits (Lund 1994) and successful use as a model species for CTA (e.g. Nicolaus *et al.* 1989a; Massei and Cowan 2002).

4.2 Methods

4.2.1 Field studies of bait aversion in foxes

4.2.1.1 Study sites

The study was conducted on two agricultural properties, "Gundabooka" and "Larras Lake North", situated near the towns of Cumnock and Molong respectively in the Central Tablelands of New South Wales study area (see Figure 1.1). The treatment site ("Gundabooka") and control site ("Larras Lake North") are mixed grazing and cropping properties approximately 800 ha in area. Both properties consist of native and improved pasture grasses intersected by patches of open *Eucalyptus* woodland and cultivated areas of cereal and pasture crops. They were chosen for their similarity in habitat, management practices and location. The properties are spaced over 5 km apart. Based on the average home range size for foxes in this area (Saunders *et al.* 2002a) these sites were adequately distanced to ensure independence from the effects of foxes from each other.

4.2.1.2 Baiting

The basic protocol for the experiment on the treatment site follows the pre-treatment, treatment and post-treatment design (Reynolds 1999). Pre-treatment consists of presenting untreated food to examine whether food consumption would normally occur. When untreated baits are consumed, treated food (containing the aversive chemical) is presented. Following consumption of treated food, untreated food is re-presented to determine if an aversion to the food has been induced. Any changes in food consumption following treatment (i.e. during post-treatment) are likely to be due to foxes developing CTA to this food.

At the control site, each station was baited with untreated day-old chickens for the entire trial period and any consumed were replaced. This allowed the response of foxes to untreated day-old chickens to be determined. Day-old chickens (hereafter called bait) were used since they are highly attractive and palatable to foxes all year (Chapter 3). On the treatment site, pre-treatment consisted of placing untreated bait at each station until a fox removed it. A microtransmitter (Sirtrack, Havelock North, New Zealand) was then sewn into the abdominal cavity of a fresh chicken bait and reburied in the station. Incorporating a transmitter allowed the fate of the bait to be determined (eaten, cached, moved etc.) by radio-telemetry, as described by Saunders *et al.* (1999). At each station on the treatment site, the treatment stage started following the consumption of the first bait with a transmitter. Treatment consisted of presenting a further day-old chicken injected with levamisole hydrochloride in the abdominal cavity. Levamisole hydrochloride was obtained from Sigma-Aldrich, Castle Hill, Australia. Because levamisole can generate CTA to meat at 70 mg kg^{-1} of fox body weight (Massei *et al.* 2003) and as the mean body weight of foxes in this area is 5 kg (Winstanley *et al.* 1998) a dose of 350 mg of levamisole was injected into each treated bait. Post-treatment consisted of presenting untreated bait with transmitter to determine if an aversion to the bait has occurred.

Between 23rd January and 8th February 2002, 30 and 27 bait stations were monitored every 1-2 days at the control and treatment sites respectively. All stations were placed adjacent to farm tracks, fences, and other prominent positions in open woodland, woodland and grassland habitats or along ecotones between habitats. No stations were placed in cultivated paddocks. Bait stations consisted of a circle of sifted soil 1 m in diameter with a single day-old chicken buried 7 cm below the soil in the centre. Tracks left on each bait station were used to ensure that foxes were responsible for bait uptake. Bait stations were positioned at least 400 m apart from each other to maximise the number of individual foxes visiting stations.

4.2.1.3 Bait uptake and consumption

Treated baits at the treatment site were monitored every 1-2 days for a seven-day period (i.e. after they were initially laid) and each bait consumed was replaced with another treated bait. At the end of the treatment period, an untreated bait, equipped with a transmitter, was placed at each bait station. These baits were monitored daily for 5 days and replaced when consumed. Since not all baits were initially found and taken on the same day, these periods were 'staggered' for each bait station, encompassing 12 and 10 days for the treatment and post-treatment stages respectively. Bait stations on the control site were monitored on identical days to those on the treatment site and any baits removed were replaced. Fox activity for each station was recorded as visit (station discovered but bait not unearthed or removed), uncovered (bait exposed but not removed) or taken (bait removed). No microtransmitters were inserted into baits at the control site as previous trials had shown that >96.2%±0.42SE of untreated day-old chickens are eaten following discovery by foxes (Gentle, unpublished data). Given that levamisole-treated food reduced palatability of subsequent presented food (Massei *et al.* 2003), transmitters were incorporated into baits on the treatment site to ensure that any changes in palatability due to levamisole could be determined.

4.2.1.4 Fox abundance

Spotlight counts were undertaken on both sites at the beginning of the pre-treatment stage to determine relative fox density. Foxes were counted for three successive nights with the aid of a 100 Watt spotlight from a four-wheel drive vehicle. Counts were undertaken along a pre-defined transect, which was representative of the main habitats (open grassland, open woodland, woodland, and cultivation) within each site. The transects were 9.9 km and 11.9 km in length on the control and treatment sites respectively.

4.2.1.5 Analyses

Each site was analysed separately using logistic regression with random station effects. Lack of replication at the site level means that formal testing of site differences was not possible. Station/day records were included in the analyses once the initial untreated bait was consumed. A second indicator variable identified occasions when previous treated bait had been eaten at that station. Logistic regression was used to model the probability over time that a bait is taken on the logit scale log (p/(100-p)) where p is the percentage of baits eaten. Generalised linear mixed models were fitted in ASREML (Gilmour *et al.* 1999). Analysis of deviance (McCullagh and Nelder 1983) was carried out to test the hypotheses 1) that rate of bait uptake changed during the trial period and 2) that rate of bait uptake from a station was affected by consumption of treated bait at that station.

4.2.2 Laboratory study of diet diversity and CTA in Norway rats

The second experiment was undertaken to determine if exposure to a diverse diet affects the foxes ability to acquire and retain CTA. This is important for potential field applications of CTA since foxes are omnivores and are exposed to a wide diversity of food items in field situations (Saunders *et al.* 1995). However, given the logistical difficulties in keeping and handling caged foxes, this trial was undertaken using laboratory rats (*R. norvegicus*). The aim of this experiment was to test whether 1) the strength and persistence of CTA in immature laboratory rats is influenced by exposure to a varied diet and 2) the amount of food eaten at conditioning will influence the strength and persistence of CTA. The strength of CTA can be determined by the willingness of animals to eat the food following conditioning (using aversive chemicals) against that food. This may be determined experimentally by observing whether animals will eat the food following conditioning and if so, the amount they consume. The persistence of CTA, or the period that animals are reluctant to eat the food following conditioning, is determined by the number of post-conditioning encounters that it takes to resample the conditioned food and the amount of conditioned food eaten. Additionally, the amount of food eaten immediately before conditioning may be an important cue that assists in CTA acquisition, therefore influencing the strength and persistence of CTA.

4.2.2.1 Study animals

Thirty-five TAS strain rats (Tuck and Son, Battlebridge United Kingdom) were used during this experiment. Freshly weaned rats (21 days old) were chosen to ensure that prior feeding experiences did not influence their behaviour. Each rat was individually housed in a wire mesh cage in temperature (19-23^{o}C) and humidity (40-70%) controlled rooms on a 12 h light / 12 h dark cycle. Each cage contained a food pot and a food hopper. Water was provided *ad libitum*. Shredded paper bedding and a cardboard container were supplied for environmental enrichment. Cages were cleaned and bedding replaced at least twice per week.

The basic experimental design is shown in Figure 2.1. Rats were randomly allocated by sex and bodyweight into two groups. Both groups were continuously given SDS pellets (SDS Diet Services, Witham, United Kingdom) in the food hopper. Group 1 (varied diet) animals were additionally given one food item per day selected from a total of 7 food items. All 7 foods were presented to group 1 animals before a specific food was presented a second time. Specific foods were raisins, unsalted raw peanuts, ground maize, quail eggs, white maggots, porridge oats and icing sugar (40:1), and ground SDS pellets. Group 2 (single diet) were fed on only ground SDS meal. Individuals were given 40 g of their respective group food in their food pot each day for 17 days before conditioning.

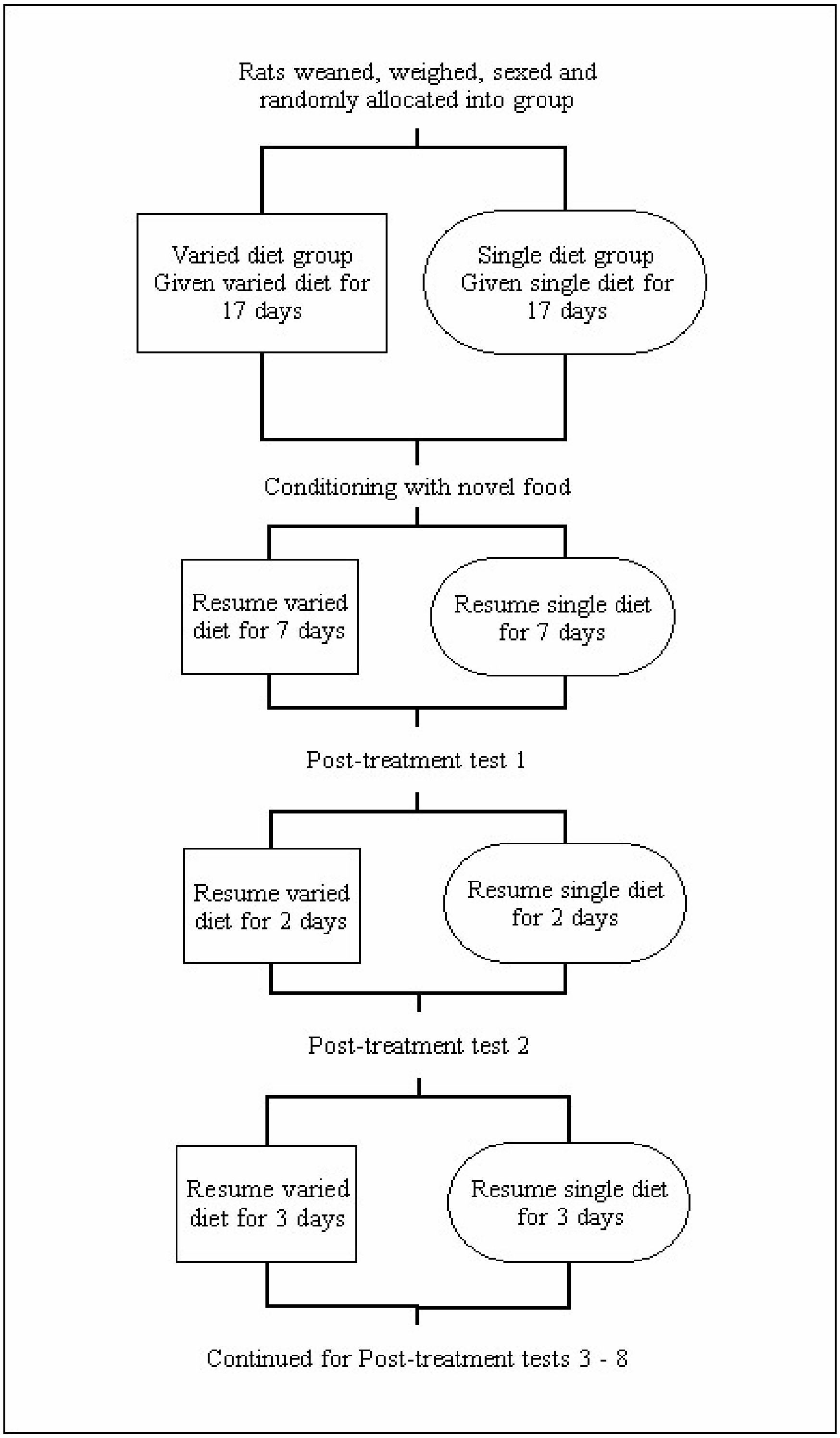

Figure 4.1: The basic experimental design for the diet diversity and CTA experiment, indicating the order of procedures undertaken on the varied and single diet groups.

4.2.2.2 Conditioning

All rats were deprived of food for 16 h before undergoing conditioning. I used a novel food of crushed digestive biscuits and cinnamon (40:1) for conditioning since it is highly palatable to rats (Gill *et al.* 2000; Massei and Cowan 2002). Each rat was presented with ca. 40 g of the novel food in a different container to their normal food pot. Individuals were observed during the 30 minute presentation of the novel food, after which the residual food was removed and re-weighed.

Rats that consumed less than 0.5 g in the initial 30 minute period were presented with the novel food for another 30 minutes. Only rats that consumed greater than 0.5 g of the novel food after this time were used for conditioning. I used thiabendazole suspended in polyethylene glycol (Sigma-Aldrich, Poole U.K) (200 molecular weight) to condition rats. Thiabendazole has been shown to induce strong and persistent CTA in laboratory rats (Massei and Cowan 2002). Body weights from the day before conditioning were used to calculate dose (200 mg/kg body weight) and intubation volume (2 ml/kg). The solution was given to each rat via oral intubation (gavage) to ensure that the aversion was associated with the novel food and not the taste of the thiabendazole (Gill *et al.* 2000; Massei and Cowan 2002). Rats were monitored for ill effects and returned to their normal diet only when they showed signs of recovery (not less than 2 h after conditioning).

4.2.2.3 Post-treatment testing

Rats' food consumption was monitored following conditioning; post-treatment testing began 7 days after conditioning when all rats had resumed normal feeding habits. Eight post-treatment tests were performed at two to three day intervals three times per week. Rats were deprived of food for 16 h before each test. Each test followed a two-choice protocol (e.g. Dragoin 1971) with approximately 40 g of crushed digestive biscuits and ground cinnamon (40:1) and ground wheat and pulegon (Sigma-Aldrich, Poole, U.K.) (600 g: 1 ml) presented in identical containers to those used during conditioning. Pulegon is a mint-flavoured deterrent that reduces food palatability. Ground wheat and pulegone (hereafter known as wheat) was used as the alternative choice for post-treatment testing since previous trials had shown it to be significantly less palatable than crushed digestives and cinnamon (hereafter known as biscuits) (Gentle, unpublished data). Offering a less palatable food as an alternative choice during post-treatment tests gives added incentive to re-consume the biscuits and cinnamon. Animals were observed during this period and the weight of food eaten (g) recorded following completion of the 15 minute test period.

4.2.2.4 Analyses

The first post-treatment test was analysed separately to establish differences in aversion strength. This test was the first occasion that the rats were presented with the biscuits following conditioning. Therefore, the willingness of each rat to eat the biscuits and the amount of biscuits eaten are a measure of the aversion strength. Rats were classified as having eaten the food when >0.2 g was consumed during each test period. The proportion of rats consuming biscuits in the initial post-treatment test and averaged across all post-treatment tests, and the amount of biscuits consumed averaged for each group were compared to determine if the strength of the aversion differed between groups. Differences in the persistence of the aversion were tested by comparing the proportion of rats in each group (varied or single diet) consuming the biscuits in the final post-treatment test and across all post-treatment tests. Nonparametric statistics were used for hypotheses testing since the data were not normally distributed. Data were analysed using a two-group randomisation test (Manly 1991), using 500 randomisations.

4.3 Results

4.3.1 Field studies of bait aversion in foxes

4.3.1.1 Bait uptake and consumption

The transmitters indicated the proportion of baits consumed from those removed on the treatment site. Totals of 115 and 255 baits were consumed during the trial period representing 25.7% and 50% of all baits available on the treatment and control sites, respectively. The probability of a fox revisiting a station once the initial bait was consumed is shown in Figure 4.2. At the treatment site the overall rate of fox revisitation to a station (63.6% ± 6SE) remained constant during the trial period, regardless of whether untreated or treated bait was consumed from that station. The probability that treated bait would be eaten from a station where previous treated bait was consumed was significantly less ($F_{1, 215}$= 9.7, P<0.01) than the probability of untreated bait consumption at stations where only untreated bait was consumed. There was no interaction ($F_{1, 128}$ = 0.04, P>0.05) between consumption of treated bait and subsequent avoidance of untreated bait at a station. The rate of bait uptake for treated and untreated bait did not change significantly at the treatment site for the trial period ($F_{1, 208}$=0.05, P>0.05) despite some evidence of a gradual decline (Figure 4.2). At the control site, fox revisitation after an initial bait was consumed was initially low (37.2% ± 7.5SE) but increased to peak at 86.4% (± 4.5SE). At this site foxes removed all baits when stations were visited; therefore the rate of bait uptake was identical to the visitation rate. There was a significant ($F_{1, 300}$=31.3, P<0.05) increase in the rate at which baits were taken with a linear response on the underlying logit scale.

The cumulative totals of all baits eaten on the treatment and control sites are presented in Figure 4.3. The rate of bait consumption on the treatment site was similar to that on the control until late into the treatment stage when it slowed considerably. This remained low until the post-treatment stage when the consumption rate increased.

4.3.1.2 Fox abundance

Between 10 and 12 foxes were seen per night on the control site, and between 14 and 18 on the treatment site. When corrected for the transect distance, fox abundance at treatment (1.3 foxes km^{-1} ± 0.08SE) and control sites (1.1 foxes km^{-1} ± 0.05SE) was similar.

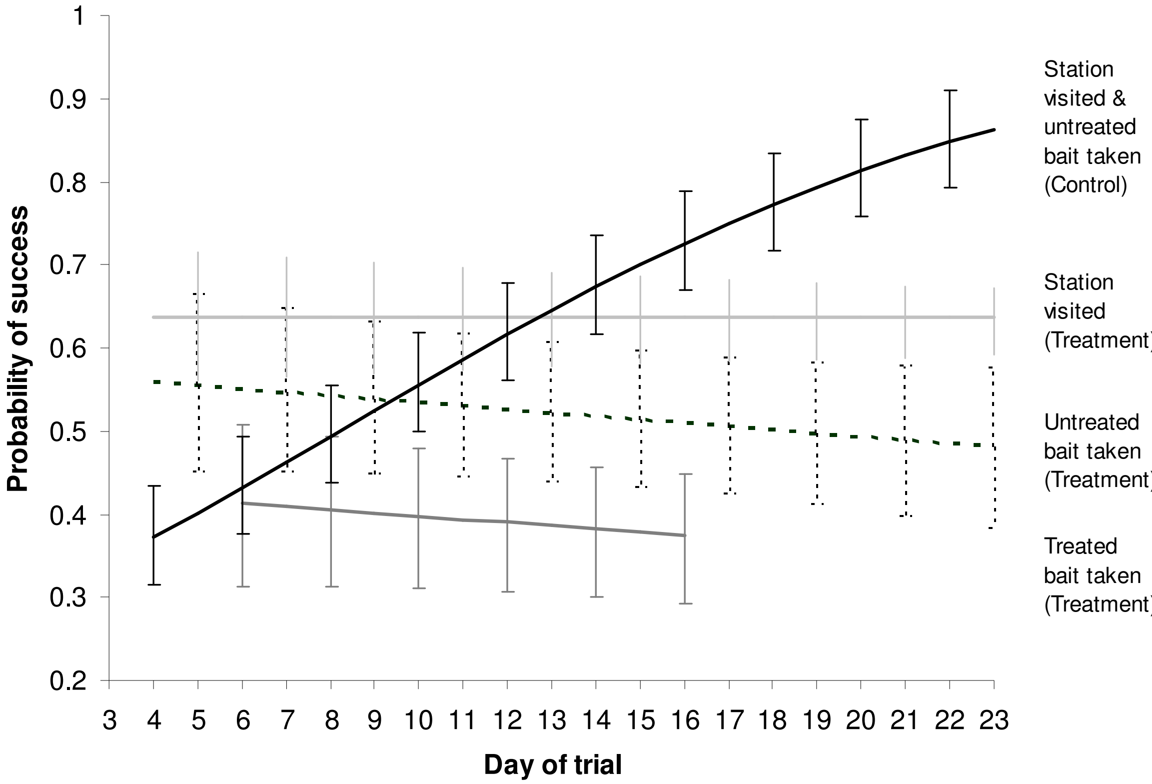

Figure 4.2: Logistic functions showing the probability of a fox visiting a station on each site (Treatment or Control) and the probability of a fox consuming a bait from each group (treated and untreated bait) on each site (Treatment or Control) during the trial period. Sites (Treatment or Control) are shown in parentheses. Error bars show standard error estimates. The probability is calculated for bait stations given prior discovery, i.e. once bait has been taken from that station.

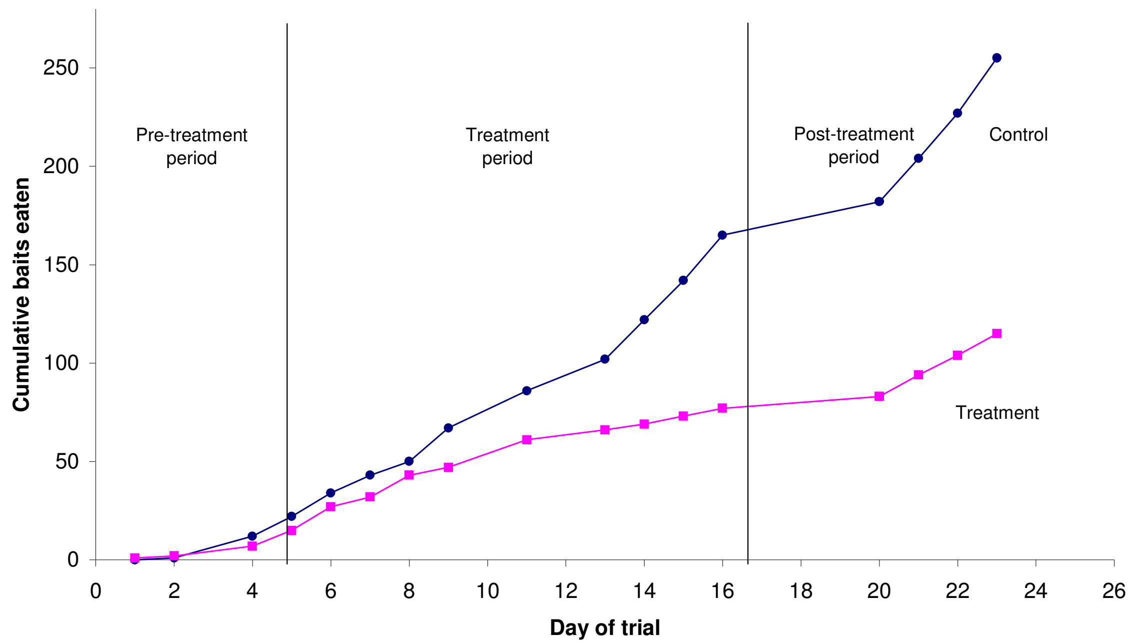

Figure 4.3: The cumulative number of baits eaten on the treatment and control sites during the pre-treatment, treatment and post-treatment trial periods.

4.3.2 Laboratory study of diet diversity and CTA in Norway rats

4.3.2.1 Study animals

Only 28 of the original 35 rats were used in this experiment. Three rats failed to consume greater than 0.5 g of biscuit during conditioning and four were unsuccessfully conditioned (orally intubated) with thiabendazole and were therefore excluded from the experiment.

4.3.2.2 Conditioning

The amount of biscuit eaten during conditioning was significantly different between groups (Randomisation test: <1/500, $P<0.001$) with the single diet group (mean = 1.27 g, SE =0.13, n=13) consuming more than the varied diet group (mean = 0.95 g, SE = 0.10, n=15). The amount of biscuit eaten during conditioning was compared with the number of post-treatment tests before rats consumed greater than 0.2 g of biscuits. There was no correlation (Figure 4.4) between the amount eaten during conditioning and the number of presentations before extinction of CTA for the single diet (Pearson's r = 0.22, P = 0.463) and varied diet (Pearson's r = 0.15, P = 0.598) groups.

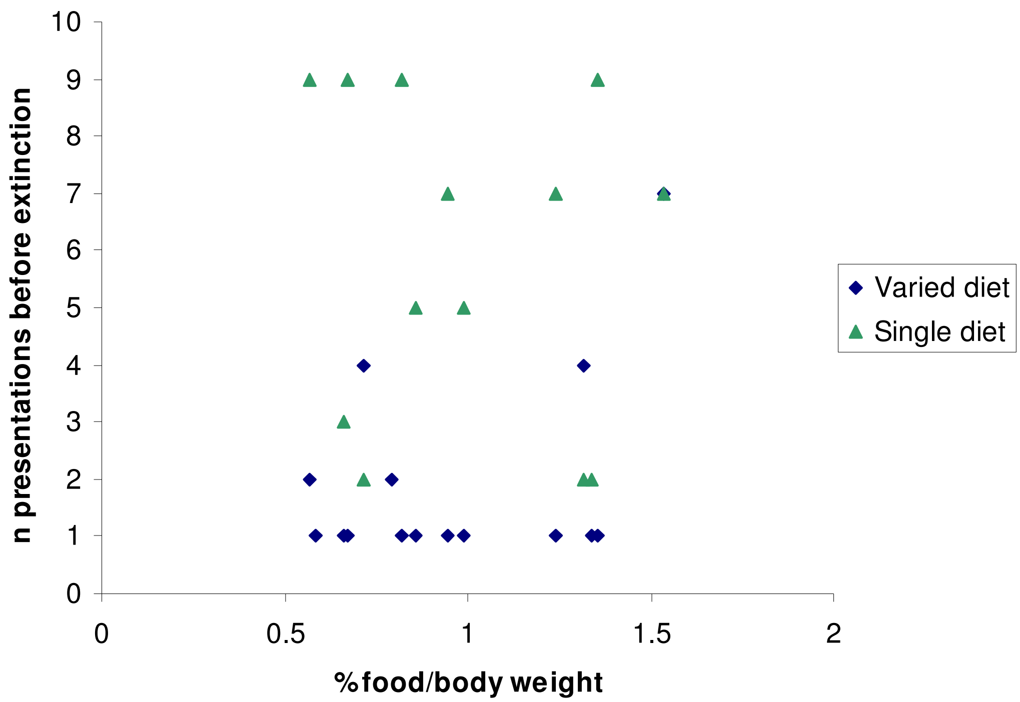

Figure 4.4: The mean consumption of biscuits expressed as a percentage of rat body weight at the initial presentation versus the number of post-conditioning tests before rats consumed >0.2 g of the biscuits.

4.3.2.3 Post-treatment testing

In the initial post-treatment test, no rats from either group consumed the biscouts and cinnamon so comparisons were based on the second post-treatments (Figure 4.5). A significantly greater (16/500, P=0.032) proportion of rats in the varied diet group consumed biscuit (0.667) than the rats in the single diet group (0.231). There was no difference however, in the amount of biscuits eaten expressed as percentage of total food eaten by the varied and single diet groups (84/500, P=0.168).

The mean amount of biscuit eaten expressed as percentage of total food eaten (see Figure 4.6) was not significantly different between the varied and single diet groups for the second post-treatment test (84/500, P=0.168), the final test (185/500, P=0.370) and across all tests (70/500, P=0.140). However, from the rats that were eating the biscuits within each group, the single diet rats ate significantly more than varied diet rats across all post-treatment tests (8/500, P=0.016).

Both groups readily consumed the alternative food during these tests, with no difference in the proportion of rats consuming wheat in the initial test (500/500, P =>0.999), second test (500/500, P=1.000) and across all post-treatment tests (460/500, P=0.920).

The single diet group showed an attenuated aversion, with a significantly lower proportion of rats consuming biscuit across all post-treatment tests (25/500, P= 0.05). This trend remained until the final test (see Figure 4.5), with a significantly (1/500, P=0.002) lower proportion of the single diet group (0.154) consuming biscuit than the varied diet group overall (0.600). There was no significant difference in the amount of biscuit eaten per group across all post-treatment tests (70/500, P=0.140) and in the final test (185/500, P=0.370). Given that there was no difference in the amount of biscuit eaten between the two groups, the average amount of biscuits eaten for rats consuming biscuits in each group was analysed. Rats in the single group that consumed biscuits consumed significantly more than those in the varied diet group across all tests (8/500, P = 0.016) and in the final test (5/500, P=0.010).

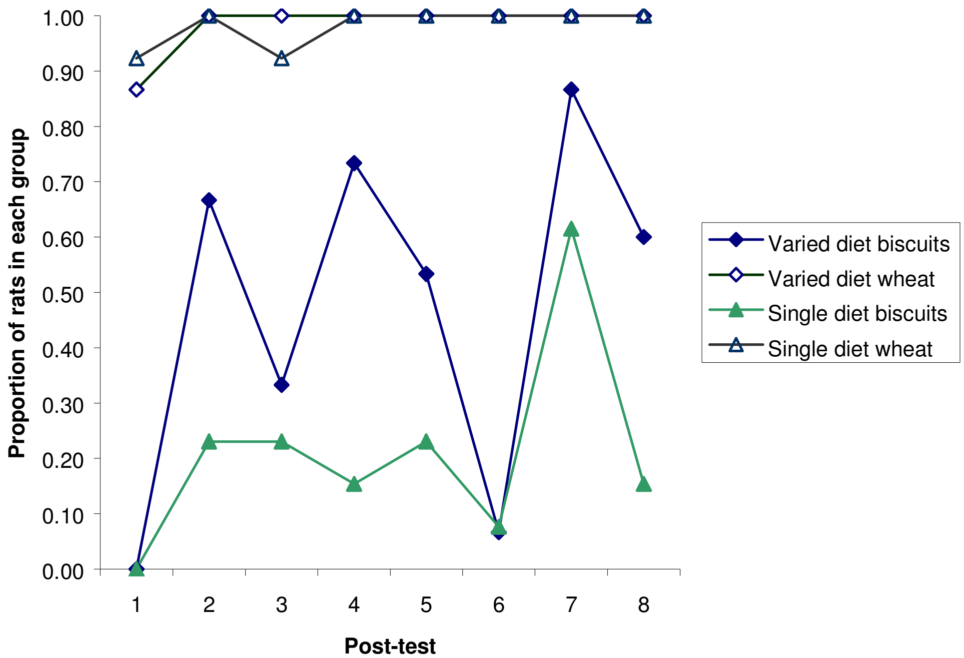

Figure 4.5: The proportion of rats in the varied and single diet groups consuming >0.2 g of biscuit and cinnamon (biscuits) or wheat and pulygon (wheat) in each post- test.

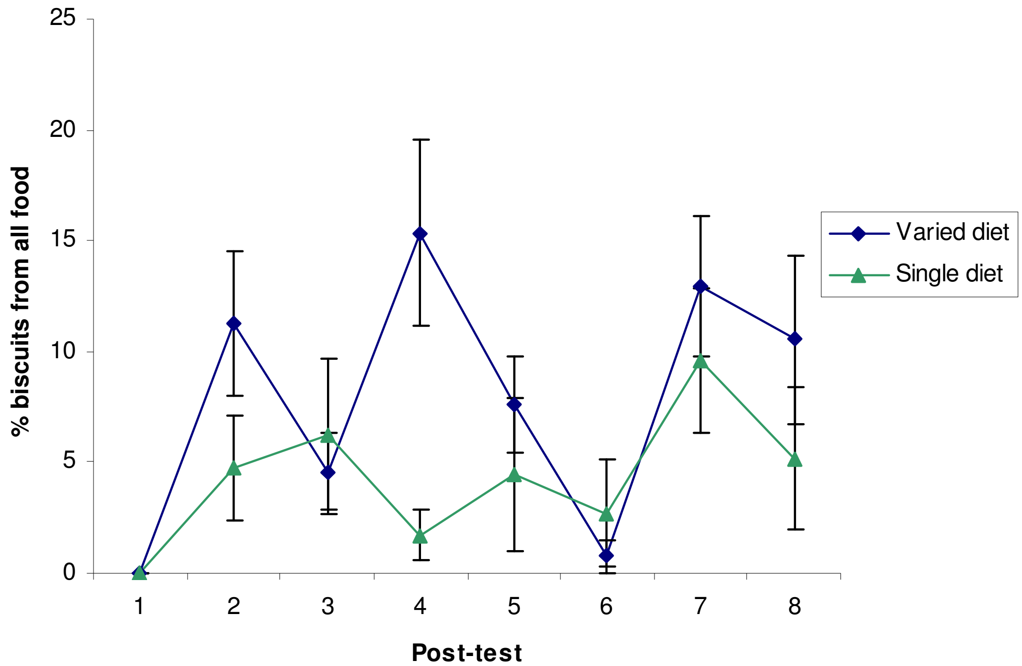

Figure 4.6: The mean percentage (± SE) of biscuit and cinnamon (biscuit) eaten by rats from total food consumed for those individuals that consumed biscuit in the varied and single diet groups in each post-treatments.

4.4 Discussion

4.4.1 Bait aversion

The lack of replication at the site level means that formal testing of site differences is not possible. Despite this, there were strong indications of differences between the rate of bait visitation and consumption at the control and treatment sites. The results show that foxes were less likely to consume treated bait from stations where a treated bait had previously been consumed than untreated bait from stations where untreated bait had been consumed. Given that levamisole induced a strong, lasting CTA after ingesting a single dose (Massei *et al.* 2003), this decrease is probably due to foxes forming an aversion to consuming treated baits. Bourne and Dorrance (1982) made a similar assumption in a field test of lithium chloride baits in targeting coyotes; they suggested that the number of baits consumed should decline markedly if resident coyotes formed an aversion. However, when untreated baits were presented at stations post-treatment, the trend of these baits being consumed returned to higher levels (see Figure 4.1). This indicates that after consumption of treated bait, foxes differentiated between treated and untreated baits, and discriminated against treated bait. Although there was evidence of a decline in consumption of untreated bait on the treatment site, the continued high rate of consumption post-treatment suggests that the aversion was associated to the presence of levamisole rather than the bait substrate.

CTA is successful when initial full consumption is followed by sudden and dramatic suppression of consumption of referent food, whether treated or not (Dimmick and Nicolaus 1990). On the treatment site, treated bait was avoided following treatment but there was no significant decline in untreated bait consumption following treatment. The avoidance of treated food only is a typical symptom for a repellent (Conover 1989) rather than a CTA-inducing agent. The ability to differentiate between treated and untreated bait is an obstruction to successfully inducing CTA. The chemical used to generate CTA must be undetectable by taste when mixed with the bait for consumption (Cowan *et al.* 2000). Detectability is problematic in the use of lithium chloride (LiCl) as an aversive conditioning chemical (e.g. Conover *et al.* 1977) since aversions will be formed to the distinctive salty flavour (Gustavson *et al.* 1976). Microencapsulation can reduce the odour and flavour cues of LiCl, and enhance the potential for bait aversion (Burns 1983). Levamisole is odourless and tasteless to humans (Remington 1975) and unlikely to be detected in moderate doses in foxes. Massei *et al.* (2003) reported that caged foxes failed to discriminate between levamisole-treated and untreated beef-flavoured turkey meat, and presented an identical dose and similar concentration (11.7g kg^{-1}) of levamisole to this study (9 g kg^{-1}). However, bland-flavoured food may have inferior masking ability than stronger flavoured meats (Nicolaus *et al.* 1989a), making levamisole more detectable in day-old chicken than in flavoured turkey meat. Wild foxes may also be more sensitive in detecting novel flavours than caged foxes, which are habituated to consuming a variety of processed food items (such as dog biscuits). Alternatively, there may be other cues that wild foxes use to distinguish levamisole-treated bait. More work is needed to identify the cues responsible to determine whether the bait substrate (bland vs. strong flavour) or levamisole formulation (liquid vs. microencapsulated) can be altered to reduce levamisole detectability to wild foxes.

Additionally, the results highlight deficiencies in establishing CTA and quantifying the response in wild fox populations. In a study inducing CTA in wild bird populations, Nicolaus *et al.* (1989a) concluded that the spatial and temporal bait distribution should match the distribution of birds in a way that most efficiently affects the population. Bait stations that are spaced at 400 m intervals would allow individual foxes access to several stations during the experimental period. However, since not all stations had treated bait during the treatment period it is possible that some individuals did not consume treated bait during this period. Any strong CTA effect on individual foxes may have been difficult to quantify since other foxes may have been responsible for consumption of baits presented following treatment. This temporal distribution problem may be somewhat overcome by presenting treated baits for sufficient duration to ensure that all foxes within the area have the opportunity to visit and consume treated bait. Typical poison baiting operations continue for between 14 and 21 days, or until bait take is depleted (Saunders *et al.* 1995). Given the lack of independence of stations, the spatial distribution of the treatment would be improved by each station undergoing pre-treatment, treatment and post-treatment during the same periods regardless of prior consumption. This would ensure that few individuals within the population escape treatment, improving the likelihood of obtaining a population response.

Despite these shortcomings, levamisole was successful in reducing the percentage of baits consumed on the treatment site to almost half that of the control site. One practical use of these findings may be to reduce the uptake of rabies vaccine baits by individual foxes. Trewhella *et al.* (1991) suggest that dominant foxes may monopolise rabies vaccine baits, denying other individuals access. CTA could be used to reduce monopolisation and allow other foxes exposure to bait, thus improving the efficacy and efficiency of the technique. However, the use of CTA for such a purpose would not be straightforward. The successful oral vaccination of a fox depends on it consuming sufficient bait material (and enclosed vaccine) to gain the appropriate immune response. Therefore, utilising CTA to reduce bait monopolisation, without reducing the efficacy of the immunisation campaign, would be successful only where sufficient bait is consumed to achieve such an immune response *prior* to the development of a CTA. Inducing CTA to bait before achieving the desired level of bait consumption would act to *reduce* the efficacy of oral vaccination campaigns. Additionally, oral vaccination of foxes against rabies may need to be repeated in subsequent years, and individuals may have to be supplemented with the vaccine to gain the appropriate immune response. Given that the persistence of the aversion is related to the strength of illness (Garcia *et al.* 1974), the formulation or concentration of the CTA agent could be changed to influence the effective period of bait aversion. Reducing the persistence of aversion would allow others to access bait in the immediate baiting campaign, but not influence the effectiveness between campaigns. Clearly, further refinement of CTA would be necessary before applying the technique to vaccination campaigns to account for the potentially detrimental effects on bait uptake.

Similarly, the technique may assist in simulating poisoning trials. Adding levamisole to bait may act to effectively remove the individual from the susceptible population, simulating the death of a poisoned animal. If added to non-toxic bait with a biomarker such as Rhodamine-B (Fisher 1999) to measure the proportion of the population that is susceptible to consuming bait, the results will more accurately represent the results of a poisoning campaign. The technique would not completely simulate the effect of poisoning, since residents that have been made averse to consuming bait will remain able to exclude others from their territories.

The results are promising enough to warrant further investigation of CTA as a strategy to reduce multiple bait uptake and simulate poisoning trials; furthermore, the technique may be an important means of non-lethal predation management. Egg predation by foxes can significantly reduce recruitment and threaten the viability of ground-nesting birds (e.g. Tapper *et al.* 1996), and reptiles such as the Murray River turtle (*Emydura macquarrii*) (Spencer 2000) and loggerhead turtle (*Caretta caretta*) (Yerli *et al.* 1997). Given the results of this trial, and the recent success in reducing egg predation by rats using CTA (Massei *et al.* 2002), there is potential for CTA to reduce egg predation by foxes. However, further replicated field trials are required to refine this technique.

4.4.2 Diet diversity and CTA

A larger proportion of rats in the varied diet group ate biscuits than the single diet group at the second post-treatment test and across all post-treatment tests, although there was no difference between the mean amount of biscuits eaten per group during these tests. Both groups readily consumed wheat, the alternative food present during test sessions. This shows that the aversion shown by both groups is a true CTA and not simply an aversion against novel foods or novelty *per se*. Secondly, it indicates that CTA was stronger and more persistent in the single-diet group since a lower proportion of rats in this group consumed biscuits when initially presented post-conditioning and again across all subsequent post-treatments. Previous studies have reported inconsistent results; Braveman and Jarvis (1978) and Miller and Holzman (1981) found that prior exposure to different flavours did not influence the acquisition or persistence of CTA in adult rats, whereas Tarpy and McIntosh (1977) found a reduction in the attenuation of CTA in adult rats that had been exposed to multiple flavours. These inconsistencies may be explained by differences in methodology between experiments. Braveman and Jarvis (1978) and Miller and Holzman (1981) used fewer flavours (three to five) during pre-exposure than Tarpy and McIntosh (1977) and this study (nine and eight respectively). This suggests that the number of foods exposed to before conditioning may be important in influencing the strength and persistence of CTA. CTA may only be weakened by exposure to diverse foods when the level of exposure exceeds a threshold.

In addition, when testing the ability of rats to accept novel flavours, Capretta *et al.* (1975) found that juveniles were influenced by prior exposure to a varied diet (three to four foods) but adults were not. Capretta *et al.* (1975) suggested that an individual's previous experience may influence its behaviour to unfamiliar stimuli only if the experiences are during a (probably age-dependent) learning period. These findings, together with those from this study and others (Tarpy and McIntosh 1977; Braveman and Jarvis 1978; Miller and Holzman 1981) suggest that the threshold level of exposure to food diversity required to influence CTA may be age-dependent. However, Braveman and Jarvis (1978) and Miller and Holzman (1981) also used one-choice tests, which are less sensitive in measuring the strength and persistence of CTA than two choice-tests (Batsell and Best 1993) employed by Tarpy and McIntosh (1977) and this study. Further experiments are required using two-choice tests to determine whether the level of exposure to diverse foods influences CTA, and if there is an age-dependent relationship between CTA behaviour and prior exposure to novel foods.

During conditioning, the single diet group ate significantly more biscuits than the varied diet group. Laboratory rats are generally neophilic, showing a strong attraction towards new objects (Barnett and Cowan 1976). The single diet group was maintained exclusively on SDS until the initial presentation of biscuits. SDS appeared to be less preferred relative to some foods given to the varied diet group (Gentle, unpublished data). This continuous, exclusive availability of SDS may have prompted 'boredom', making the novel food presented more attractive to the single diet group. This deprivation probably increased their consumption of biscuits relative to the varied diet group that were accustomed to diversity. A heightened response towards novel foods has been noted during palatability trials with SDS versus different bait formulations (R. Quy, Central Science Laboratory, pers. comm. 2003).

These results are in contrast to those of Capretta *et al.* (1975) who found that immature rats pre-exposed to several distinctive flavours would be more likely to accept a novel flavour than those with a less varied diet. This may again be due to differences in methodology, specifically the length of test sessions used to measure consumption. Capretta *et al.* (1975) measured novel food consumption after 24 hours compared to 15 minutes in this study. Longer test sessions would disguise any initial haste to consume the novel food as shown by the single-diet group. Any comparison between studies should therefore consider the length of the test session.

Previous studies have found a positive relationship between the amount of food eaten during conditioning and the strength of the aversion (Barker 1976; Bond and Westbrook 1982). In the present study there was no evidence of a relationship between the amount of biscuits eaten during conditioning and the number of presentations before biscuits were eaten. These results, like the weak negative relationship reported by Massei and Cowan (2002), appear to be influenced by marked individual variation in behaviour. Some rats that consumed large amounts of biscuits during conditioning continued to consume biscuits throughout subsequent presentations, albeit in smaller quantities. Other individuals consumed small amounts of biscuits during conditioning and did not resume eating during the remainder of the trial. Additionally, eight post-conditioning presentations used in this experiment may have been insufficient to determine any relationship.

This study has found that immature rats raised on a single diet will have a lower probability of consuming the food conditioned against in their second encounter, and in subsequent encounters, relative to rats raised on a varied diet. Applying this to field situations, juvenile wild rats exposed to a variety of novel foods should show a weaker and less persistent CTA than those exposed to low diversity. If CTA is to be used as a means to reduce predation then the level of protection will be reduced in conditions where the predators have been exposed to diverse foods as juveniles. Maximising the benefit of a CTA strategy may thus rely on targeting environments with low diversity, or modifying environments to decrease diversity.

These results have important implications for the use of rodenticides, particularly in baits, which is the mainstay of control programs in urban and agricultural environments (Caughley *et al.* 1998). Bait shyness is a common problem associated with sustained baiting programs. Bait shyness occurs when individuals that survive poisoning through ingesting sub-lethal doses of bait may become averse to consuming bait in subsequent presentations (Prakash 1988). Such aversion can last for long periods, significantly reducing the effectiveness of control programs. Bait shyness and CTA are forms of learned aversion and are induced by similar behavioural mechanisms (Prakash 1988), therefore, bait shyness should be reduced in populations exposed to diverse foods. Additionally, surviving animals from populations in highly diverse environments will resume eating bait earlier than animals in relatively constant environments. A reduction in bait shyness will increase the effectiveness of baiting campaigns by improving the likelihood of individuals consuming bait.

There is some evidence from baiting programs that support these findings. Quy *et al.* (1992) found that baiting wild *R. novegicus* was generally less successful on arable farms where there was stored cereal present. Such farms offer an environment with a continuous and stable food supply, but with low diversity (Quy *et al.* 1992). In contrast, farms rearing livestock exclusively are a dynamic environment where rats are exposed to a diverse range of seasonal foods. This suggests that rodenticide applications may be improved by either targeting environments where food diversity is high, or manipulating the environment to increase food diversity. These findings in turn support Quy *et al.* (1994) who recommended that reducing habitat predictability by means such as increasing the turnover of feeds or changing distribution of food supply, may be sufficient to turn a predicted poor treatment into a successful one. The success of baiting campaigns could be improved by accounting for the diversity of food within environments.

Despite this experiment being designed to simulate food diversity that is likely to be encountered in the field, caution must be heeded in extrapolating the results from one species tested (rats) to another (fox). Other factors, such as social interaction and learning (e.g. (Schrijver *et al.* 2002; Fernandez-Vidal and Molina 2004) may interact with the results and alter them completely. Further research on foxes in field situations is required to examine the potential of dietary diversity and CTA, and the ability of other factors to impact upon them.

A decline in the strength and persistence of CTA through exposure to a varied diet suggests caution when extrapolating the results from laboratory CTA studies to field applications. If laboratory studies measure CTA with animals raised on a monotonous diet (e.g. Massei and Cowan 2002) and the results are applied to field situations (diverse food environments), the strength and persistence of CTA will be significantly overestimated. Overestimation will decrease the expected effectiveness of CTA both in terms of the absolute level of protection offered and the period of protection. The effect of dietary diversity on CTA must be considered in the design and/or interpretation of laboratory studies for field applications.

4.5 Conclusion

The strength and persistence of CTA in laboratory *R. norvegicus* was attenuated by previous exposure to a diverse diet. This suggests that other dietary generalists, such as foxes, will also show a reduced CTA response when they are previously exposed to a diverse range of foods. Furthermore, it suggests that the results from laboratory studies where animals have been raised on single food diet will overestimate the effectiveness of CTA. However, these findings have only been tested on laboratory rats, and may be influenced by other factors not measured in this study (e.g. social, environmental).

The results from the field experiment indicated that levamisole failed to induce CTA in wild foxes most probably due to the ability of foxes to detect levamisole, but did suggest that consumption of illness-inducing bait reduced multiple bait uptake by individuals. If consumption of illness-inducing bait reduces the probability that subsequent presented bait will be eaten, then bait aversion may occur as a result of consumption of sub-lethal doses from bait in current poisoning campaigns. However, the results do not indicate the likelihood for bait aversion to occur as a result of 1080 poisoning practices. To determine this, the time until baits degrade to sub-lethal levels (Chapter 2) and the probability that foxes will find and consume baits within this time (Chapter 3) need to be investigated. This will be examined later in the thesis (Chapter 8.)

CHAPTER 5

LANDHOLDER BAITING COORDINATION CASE STUDY- MOLONG RURAL LANDS PROTECTION BOARD

5.1 Introduction

Fox control is undertaken on agricultural and conservation lands for the control of fox impacts, commonly for reducing unwanted predation on domestic stock and native species. A variety of techniques is utilised for fox control in Australia (see Chapter 1), but the most common method is poisoning with 1080-impregnated baits. Baiting for foxes is encouraged by various State government agencies (including NSW Department of Primary Industries (NSW DPI), NSW Department of Environment and Conservation (DEC), and Rural Lands Protection Boards) and is often presented as an effective means of reducing fox-associated damage on lands where baiting is undertaken. However, for reasons including bait caching (Chapter 3) and bait degradation (Chapter 2), current baiting methods may suffer from some inefficiencies. Additionally, insufficient spatial or temporal coverage of baits at a landscape scale is likely to reduce the effectiveness of baiting campaigns.

Fox populations are not static; births, deaths and seasonal patterns of dispersal result in constant changes in dynamics (Harris and Trewhella 1988). Most dispersal occurs in juvenile males from late summer until early winter (Saunders *et al.* 1995), although adults are also known to undertake long range movements to establish or extend territories (Zimen 1984). Such movements result in the rapid recolonisation of areas where foxes have been removed (e.g. Bogel *et al.* 1974; Kinnear *et al.* 1988; Saunders *et al.* 1995) through the creation of a 'dispersal sink'. Undertaking more frequent control and/or targeting a greater control area are possible strategies that could increase the effectiveness of baiting, and reduce the potential for immigration into critical areas. Undertaking further control in an additional area or buffer surrounding the area to be protected has also been shown to be effective in reducing wild dog and fox immigration into central core areas (Thomson *et al.* 1992; Thomson *et al.* 2000). Coordinating baiting campaigns with a number of landholders is also recommended to increase the effective baited area through greater participation and peer pressure. This in turn increases the effectiveness of baiting through reductions in fox density over a greater area, reducing ‘edge-effects’ and immigration into core areas.

Undertaking baiting outside a landholders cadastral (property) boundary requires unconditional cooperation with neighbours, which may not always be possible. Many landholders will not use 1080 due to a perceived lack of need to bait (e.g. cattle producers), or concern over possible impacts on not-target species such as wildlife or working dogs. To confront these perceptions, and attempt to encourage greater coordination of and participation in fox baiting programs, the ‘Outfox the Fox’ program (Outfox) was initiated by NSW DPI in 1999 (Balogh *et al.* 2001).

‘Outfox’ is the largest strategic group baiting program in New South Wales with landholders from six Rural Lands Protection Boards (RLPBs) (Young, Condobolin, Forbes, Central Tablelands, Molong and Dubbo) participating (Balogh *et al.* 2001). The program promotes the use of best practice management including replacement baiting, baiting at least twice per year and synchronising baiting with adjoining landholders (Balogh *et al.* 2001). As part of ‘Outfox’, landholders are encouraged to undertake fox baiting during two critical periods – autumn and spring. These periods target juveniles during dispersal (March) and vixens when searching for additional food whilst young are in the den (September) (Balogh *et al.* 2001). These periods also generally coincide with the autumn and spring lambing peaks to provide protection for flocks when they are most susceptible (Bailey 1996; Armstrong 1997).

The ‘Outfox’ program was initiated and then actively promoted through media releases, radio and television interviews and personal meetings between RLPB staff and landholders during 1999 and 2000. Since 2000, promotion by RLPB staff has been the only vehicle to encourage participation in the program. Early landholder surveys in 2001 suggest that the program was effectively increasing the number of landholders who were undertaking cooperative baiting (Balogh *et al.* 2001); however no subsequent assessments have been undertaken.

There are 48 RLPB districts in New South Wales as established under the *Rural Lands Protection* Act (1998). The core functions of the RLPB system are to protect the community from exotic and endemic animal disease, support and regulate the control of pest animals and insects, and manage and maintain travelling stock reserves (Lane 1998). Each board is funded by rural rate-payers through an annual fee to support these activities. Regulation of the pest animal control activities undertaken by rate-payers is an important RLPB function. Each RLPB is responsible for regulating the supply and use of 1080 baits for pest animal control undertaken on lands within their jurisdiction. This ensures that each RLPB can offer sound assistance and advice based on local knowledge, and facilitates monitoring and regulation of which control activities are undertaken. Therefore, the RLPB system provides a source of records for the tracing of 1080 use for fox control within each RLPB area. NSW DPI, as the 1080 permit holding authority for New South Wales, is responsible for auditing the use of 1080 to ensure that it is used responsibly.

This chapter assesses the spatial and temporal coverage of fox baiting in the Molong RLPB area to demonstrate the perceived effectiveness of current cooperative fox management practices. Molong RLPB was chosen as a case study since it was a key RLPB involved in the 'Outfox' program, and previous fox ecological studies undertaken in the area provide data allowing fox dispersal and potential for immigration to be estimated (Saunders *et al.* 2002a). One of the principal aims of this chapter is to demonstrate the effectiveness of current fox management using scientific method. Currently, the effectiveness is only demonstrated through perception; the number of baits laid, number of landholders undertaking baiting and area of land baited. Such perceptions may not necessarily correlate with the number of foxes killed. Nevertheless the spatial assessment of fox control within a RLPB provides a valuable estimate of the effectiveness of fox control strategies on a landscape rather than individual property scale. This chapter investigates trends in baiting practices, reports levels of coordination amongst landholders and models the effect of fox immigration into baited areas.

5.2 Methods

5.2.1 Study area

The Molong RLPB area is situated on the western side of the central tablelands of New South Wales, encompassing an area approximately 189 km long and between 20 km and 83 km wide at the narrowest and widest points respectively (see Figure 5.1). The area totals 815,382 ha which is divided into 49,149 individual parcels of land within the Orange, Cabonne and Parkes local government areas. The Molong RLPB services a total of 2403 ratepayers (as at 2002) within its boundaries.

The climate is typically temperate with cool to cold winters and warm to hot summers (Saunders *et al.* 2002b). Rainfall is neither winter nor summer dominant but average annual rainfall and reliability declines along an east-west gradient. (see Chapters 1 and 2).

The area produces a diverse range of agricultural goods with the eastern, higher altitude regions predominantly associated with horticultural enterprises such as apple, pear, cherry and wine-grape production with wool, sheep and cattle production and winter cereal cropping more common in the central and western regions (Dwyer 1978; Australian Bureau of Statistics 2003). Most suitable farming and grazing country has been cleared, although some remnant patches of dry sclerophyll forest and woodland remain (Saunders *et al.* 2002b).

5.2.2 Data collection and collation

When land managers are issued with products containing 1080 the details of each transaction must be recorded in the 1080 poison register which is audited by NSW DPI. Each record specifies details including name and property address of the land manager, the number and type of baits purchased, and the area to be poisoned. All records of the landholders undertaking fox control within the Molong RLPB from January 1998 until December 2002 were collated and entered into an Access (Microsoft®) database. Records were checked to ensure that property boundaries and ownership details were accurate through consultation with Molong RLPB and the NSW Department of Lands. The name and property address from the 1080 register were then matched to the property details from the Rural Lands Protection

Board database (TFS2®), and in turn matched to unique property identifiers (comprising either Parish and Portion, Lot and Deposit Plan (DP), or Property identity) through select queries in Valnet®, the cadastral database of the New South Wales Valuer General's Department. The unique property identifiers are spatially referenced to cadastral data, which identifies the appropriate polygon within New South Wales. The cadastral data were then imported into a GIS application (Arcview®) to facilitate spatial analyses.

Landholder enterprise information was collated from land and stock returns collected by Molong RLPB. This information quantifies livestock production for each landholder. New South Wales Department of Environment and Conservation and State Forests provided information on the timing and location of baiting campaigns undertaken on conservation and forest reserves respectively.

5.2.3 Spatial coverage and gaps

Data from individual land parcels were assessed spatially in Arcview® to determine whether each landholder was undertaking fox control individually or in coordination with surrounding neighbours. Landholders were considered to have undertaken coordinated baiting if a neighbouring landholder (a landholder whose block of land was situated not greater than 500m from the boundary) completed a baiting campaign within the same month. A coded Arcview® extension (ID Within Distance®, Jenness Enterprises, August 2003) was used to identify neighbouring properties that had undertaken baiting within the same month. The area of properties baiting within each specified period was calculated using functions in the extension Xtools® (M. Delaune, September 2003).

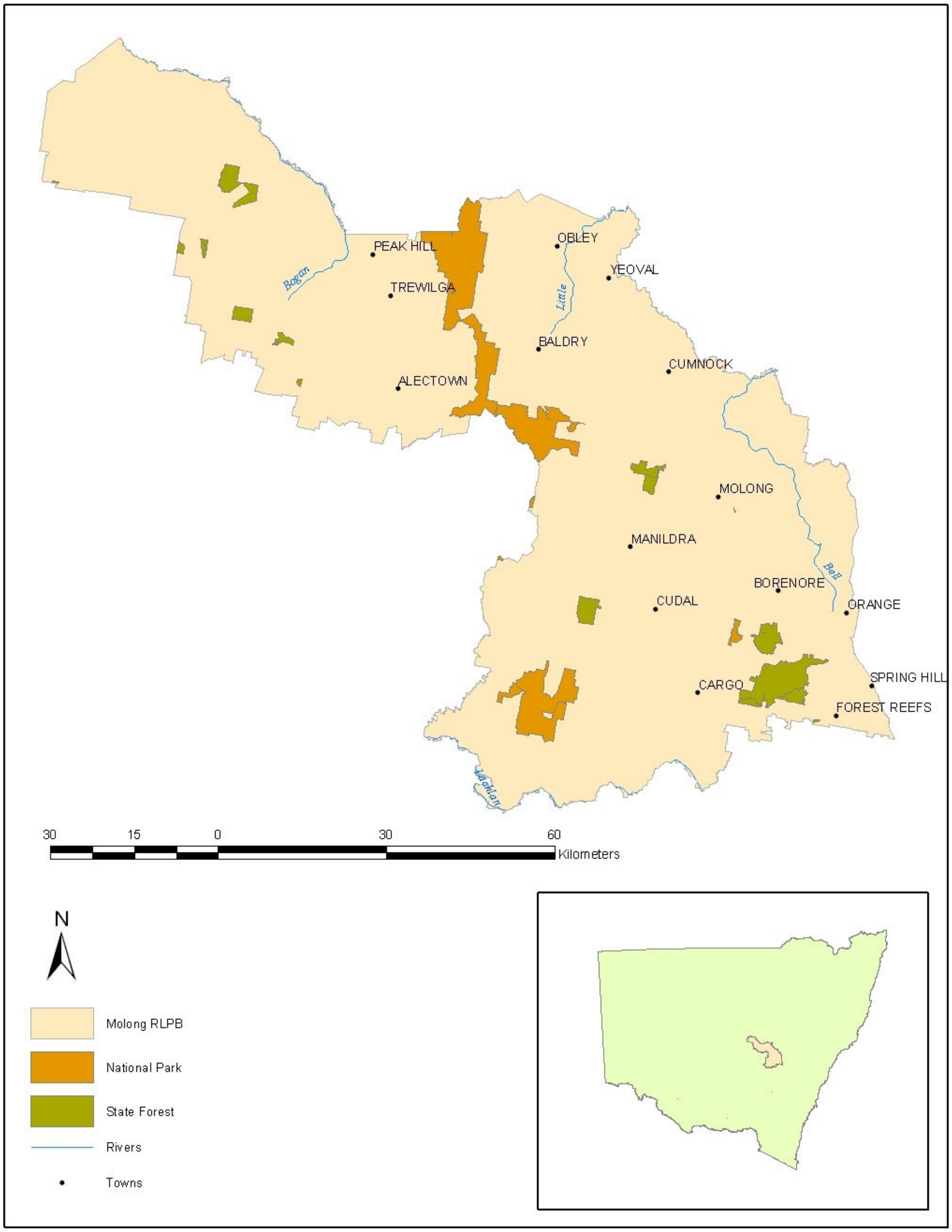

Figure 5.1: Location of the Molong Rural Lands Protection Board within New South Wales (inset)

5.2.4 Bait type and baiting frequency

Landholders purchased either fresh chicken heads or the commercially manufactured Foxoff® from Molong RLPB. Landholders could use fresh meat but had to supply the meat to the RLPB for injection.

A baiting campaign was defined by the supply of baits to a landholder during a month. Baits supplied to a landholder on multiple occasions within the same month were considered to be part of the same baiting campaign; a reasonable assumption given that landholders will often purchase baits to replace those baits that are removed or degraded during a baiting campaign.

5.2.5 Fox immigration into baited areas

The likely effectiveness of fox control for reducing immigration was explored for each continuous baited area by investigating the potential for fox immigration. For modelling purposes it was assumed that areas where fox control had been undertaken were fox-free, and areas where no control was undertaken contained foxes. The potential for immigration is a function of fox density, home range size and distance from the perimeter of the baited area (Trewhella *et al.* 1988). The shape of each land parcel is important; parcels with a high area to perimeter ratio will be less susceptible to immigration. The ability of a baited area to protect a core area was modelled here using the known relationship between dispersal and movement distances and fox home range size.

Trewhella *et al.* (1988) reviewed studies worldwide and quantified the relationship between fox home range size, fox density and recovery and dispersal distances. Dispersal is defined as the movement of an individual from its origin to the place where it reproduces or potentially could have reproduced (Howard 1960; Harris and Trewhella 1988). Dispersal distances (*a, b*) are those derived from juveniles known to have dispersed from their natal home. Fox recovery distances (*c, d*) are those derived from juvenile foxes that move and are subsequently recovered; regardless of whether individuals had completed dispersal or not. For this study, dispersal distances are used to estimate the distance that foxes immigrate into baited areas during the normal, juvenile dispersal period. Recovery distances are used in a similar manner but provide a more conservative estimate of likely dispersal distances. The regression equations derived by Trewhella *et al.* (1988) were specifically:

a. Mean dispersal distance (male) = 2.778 + 4.038(Home range size (km^2))

b. Mean dispersal distance (female) = 3.853 + 2.659(Home range size (km^2))

c. Mean recovery distance (male) = 0.084 + 3.580(Home range size (km^2))

d. Mean recovery distance (female) = 0.745 + 1.422(Home range size (km^2))

Home range sizes were derived from an earlier study at properties located within the Molong RLPB area (Saunders *et al.* 2002a). Based on the 95% Minimum Convex Polygon (MCP) home range estimates of male (3.09 km^2) and female (5.23 km^2) foxes, the recovery distances were calculated as 10.98 km and 8.18 km and dispersal distances as 15.26 km and 17.76 km respectively. Assuming a 1:1 sex ratio, (Saunders *et al.* 2002b) the means of male and female recovery (9.58 km) and dispersal distances (16.51 km) were used to create recovery and dispersal internal buffers within the perimeter of each baited area. Each buffer represents the estimated distance from the baited area boundary that foxes would recolonise during the dispersal period (December-March) within one year; the area remaining is the core area protected from annual immigration. The perimeters of baited areas were defined as the outermost boundary of continuous areas in which baiting was undertaken within the same month.

5.2.6 Built-up area boundaries

The Pesticide Control (1080 Fox Bait) Order 2002 under Section 38 of the Pesticides Act 1999, specifies the conditions of use for 1080 fox baits (Environment Protection Authority 2002). Landholders must handle, use and dispose of baits as per the instructions on the permit. One such restriction specifies that 1080 baits must not be laid within close proximity to urban areas (within 4 km of a village or street with a 70 km/h speed limit) unless the baiting program is planned and agreed to by an Authorised Control Officer (ACO). These restrictions are due to the combination of high non-target susceptibility (domestic dogs) and the wandering habits of many domestic pets (e.g. Barrett 1995).

An assessment of whether landholders were complying with this distance restriction was undertaken by identifying the built-up areas (defined by areas within a 70 km/hr speed limit) within the Molong RLPB and adding an external 4 km buffer to the built-up area perimeter. Baited properties where any part of the property fell within a 4 km radius were identified and counted. An additional external buffer was added at a 2 km radius to investigate the potential risk to domestic pets from cached baits.

5.2.7. Type of enterprise undertaking baiting

Chi-squared analyses were used to compare the proportion of ratepayers from each enterprise (sheep, beef cattle, other stock) that were undertaking fox baiting.

Caveats

Difficulties with linking landholder details from the 1080 register to property identifiers were evident during the matching process. The actual baiting location, not the landholder's residential address is required as part of completing the 1080 register. Despite this, many landholders were providing their residential address rather than the property location where baits were laid. To overcome this, it was assumed that all properties (excluding those within built-up areas) owned by a landholder were baited. This is not an unreasonable assumption but probably results in an overestimate of the area baited.

5.3 Results

5.3.1 Baiting campaigns

A total of 510 individual landholders (representing 21.2% of all ratepayers) carried out fox baiting during the period 1st January 1998 until 31st December 2002. These comprised 508 individual ratepayers and two government agencies, the Department of Environment and Conservation and State Forests. A total of 470 landholders (92.2% of baiters) was successfully linked to the cadastral information while the remaining ratepayers provided insufficient details for their adequate identification.

The number of ratepayers (excluding Government agencies) that baited annually fluctuated during the investigated period from a minimum of 152 in 2001 to 262 in 1999 (Table 5.1). Fluctuations within years were also considerable but the number of landholders baiting generally peaked in autumn and late winter/early spring (Figures 5.2 and 5.3). Similarly, the total number of baits used by landholders during baiting campaigns was highly variable, ranging from 0 baits in October 1998 and November 1999 to over 6,300 in March 2002 (Figure 5.2). The mean number of baits per landholder was reasonably consistent (Table 5.1) indicating little change in number of baits laid per landholder throughout the five-year period (Figure 5.2 and Table 5.1).

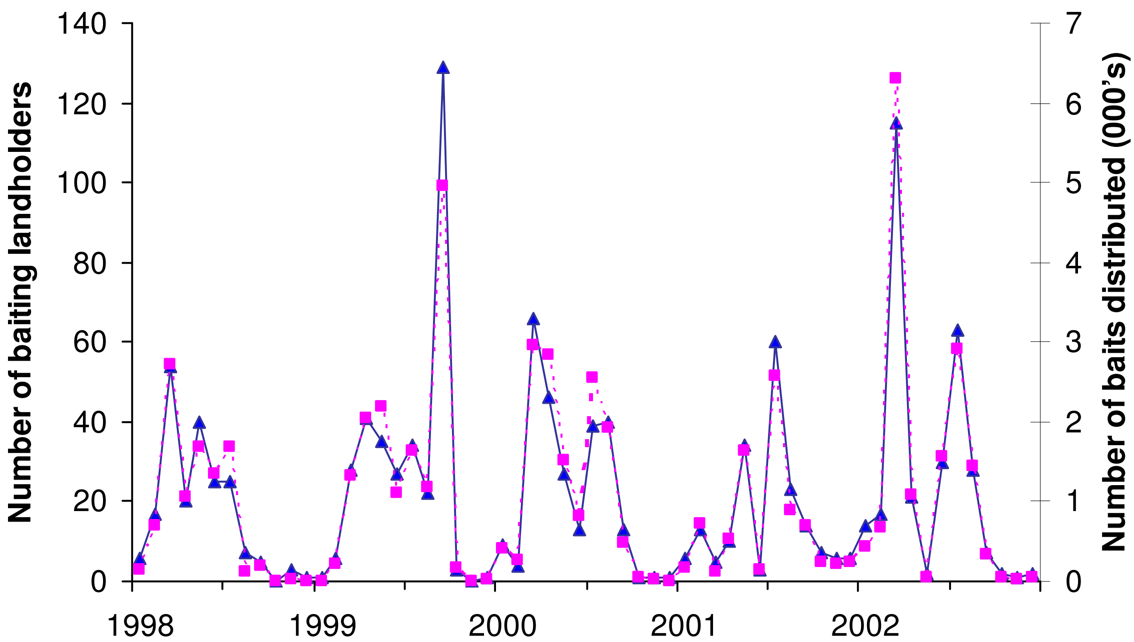

Figure 5.2: Number of landholders baiting (▲) and number of baits distributed to ratepayers (■) within the Molong RLPB area between January 1998 and December 2002.

Table 5.1: The number of landholders baiting, number of baits issued to landholders, area baited and number of baits used per baiting campaign for the Molong RLPB between 1998 – 2002. The area baited represents the area baited at least once during that year. Data relating to Government agencies are shown in parentheses.

Year	1998	1999	2000	2001	2002	Total
Number of landholders baiting	168	262	208	152 (1)	232 (2)	510
Number of baiting campaigns	203	327	260	187 (1)	302 (4)	1279
Number of baits issued	9669	14839	13865	8182	14934	61489
Mean number baits per baiting campaign (±SD)	43.6 (±49.3)	40.9 (±36.0)	47.0 (±40.4)	40.1 (±27.3)	42.9 (±37.1)	42.9 (±38.5)
Hectares baited by ratepayers	119284	191531	156237	115248	160308	742610
Hectares baited by Government agencies	-	-	-	26440	28332	54773

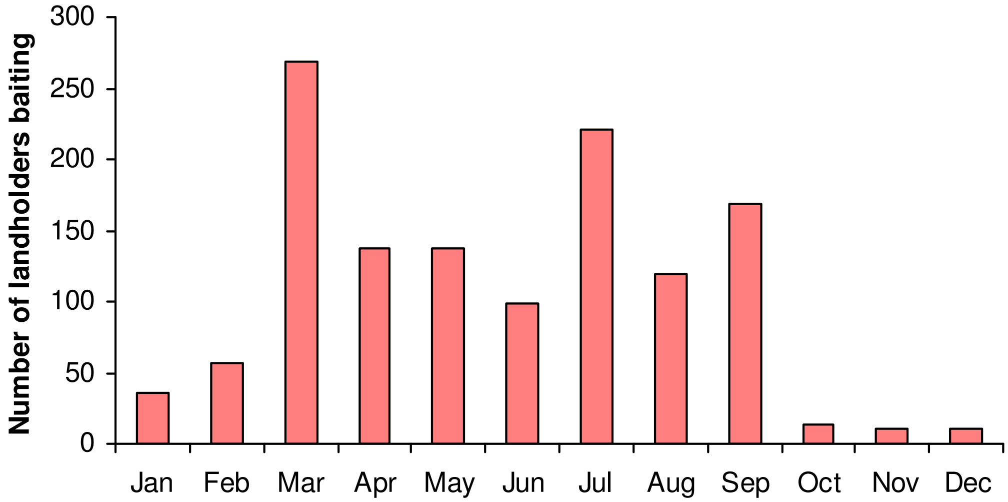

Figure 5.3: The average number of landholders undertaking fox baiting in each month within the Molong RLPB pooled for the period January 1998 until December 2002.

5.3.2 Bait type

Foxoff® were first used by the Molong RLPB in 1998 and soon became popular (Figure 5.4). However, chicken heads are still used in high numbers by the ratepayers of Molong RLPB, despite some concerns regarding their use (see Chapter 4). The majority of landholders purchased only one bait type per baiting program, but some alternated between bait types in subsequent programs.

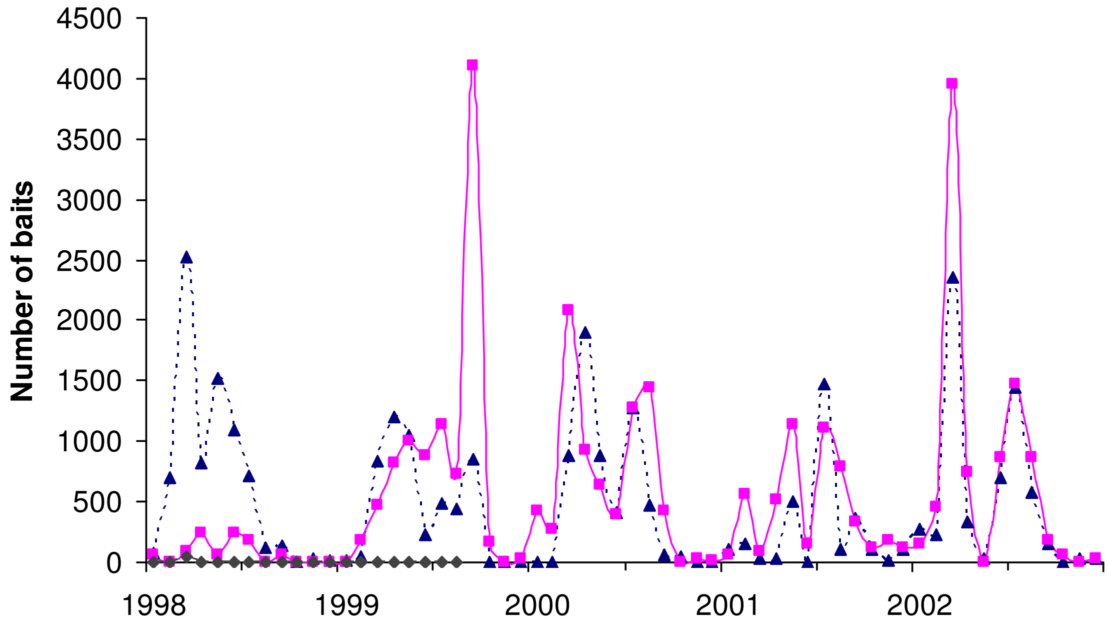

Figure 5.4: Number of Foxoff® (■), chicken head (▲) and meat baits (♦) distributed by Molong RLPB between January 1998 and December 2002.

5.3.3 Baiting coverage

The spatial coverage of baiting in the RLPB area was patchy with large, continuous areas remaining unbaited each year, and from year to year (Figures 5.5 to 5.9).

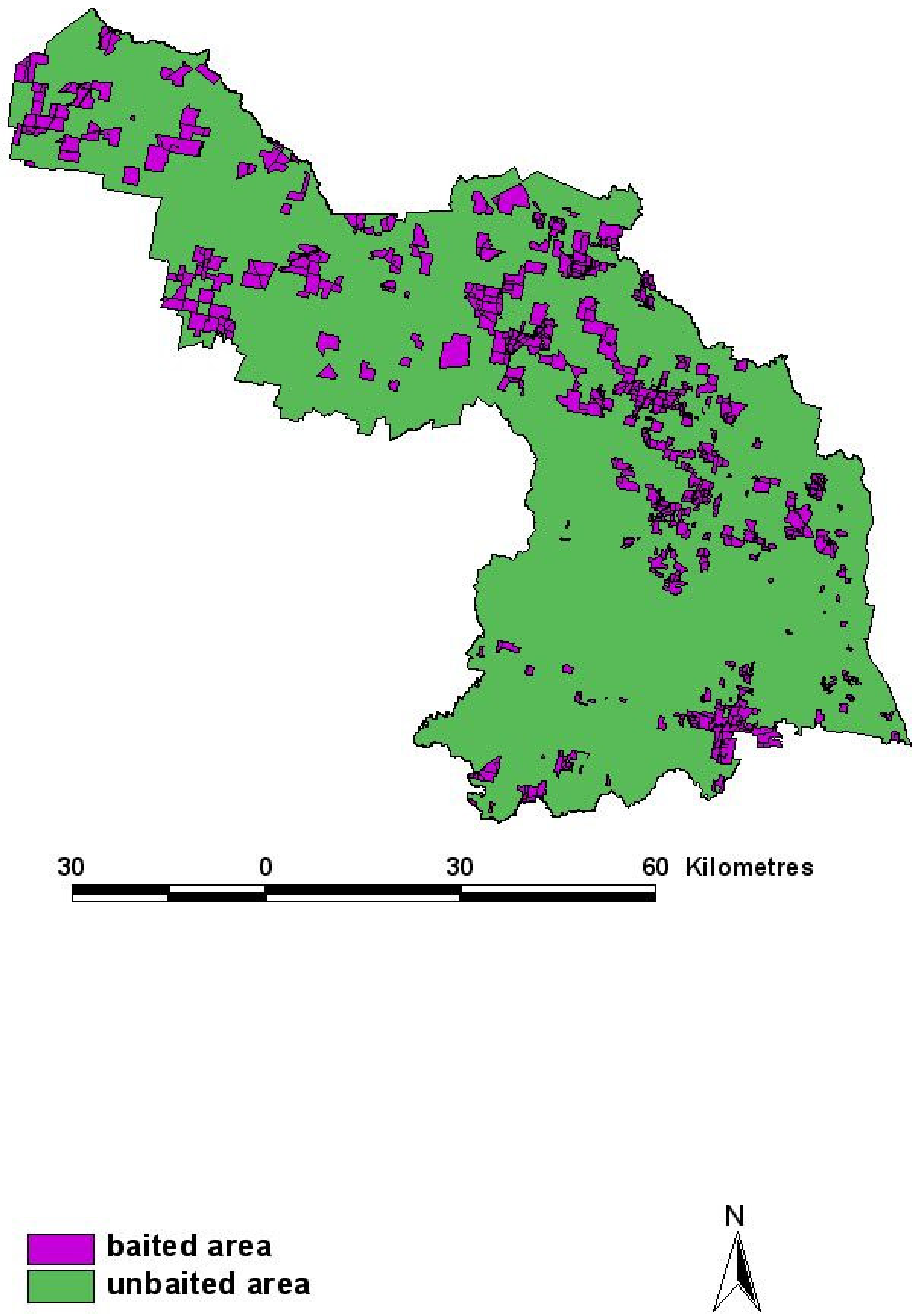

Figure 5.5: The total area of the Molong RLPB baited during 1998

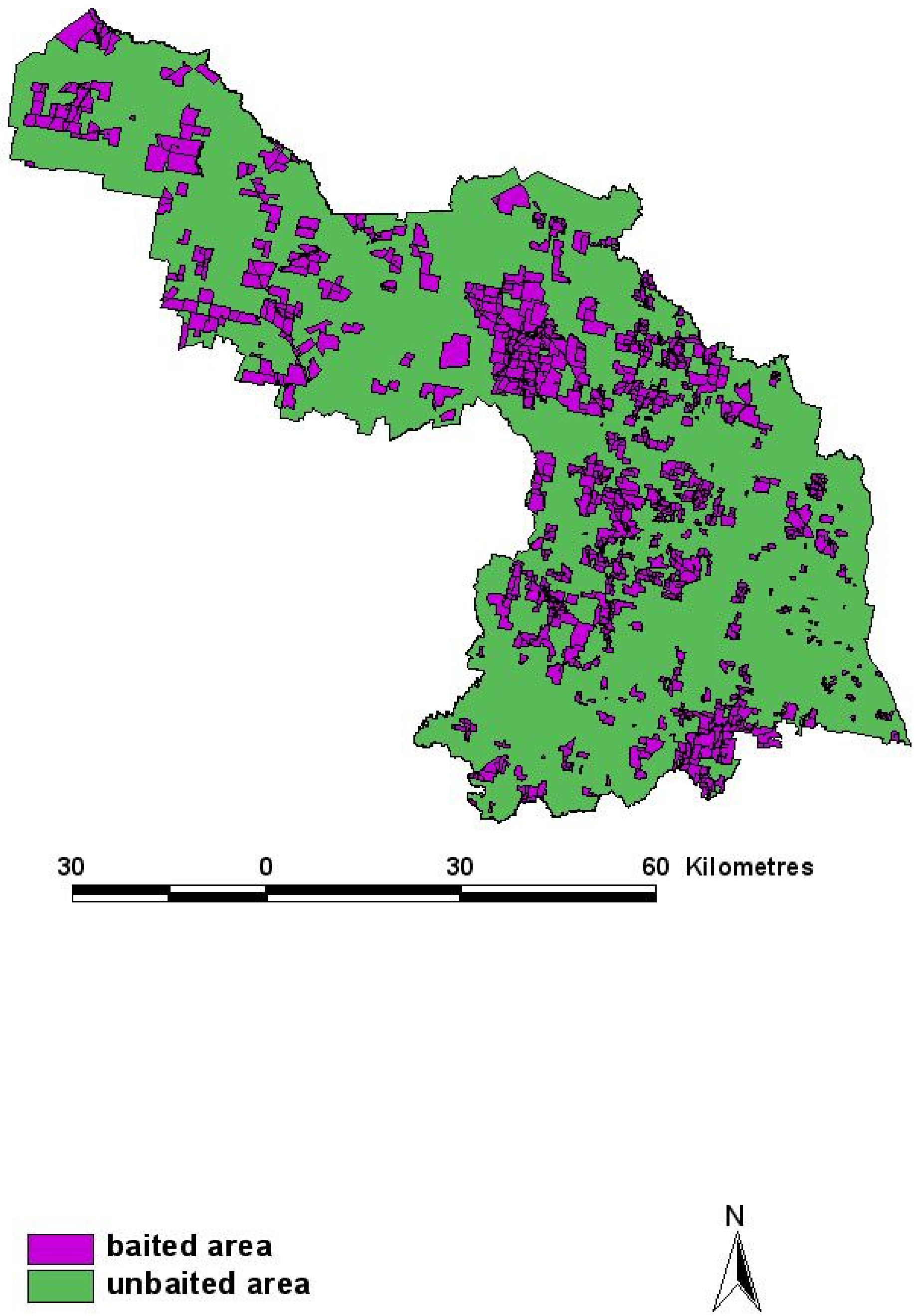

Figure 5.6: The total area of the Molong RLPB baited during 1999

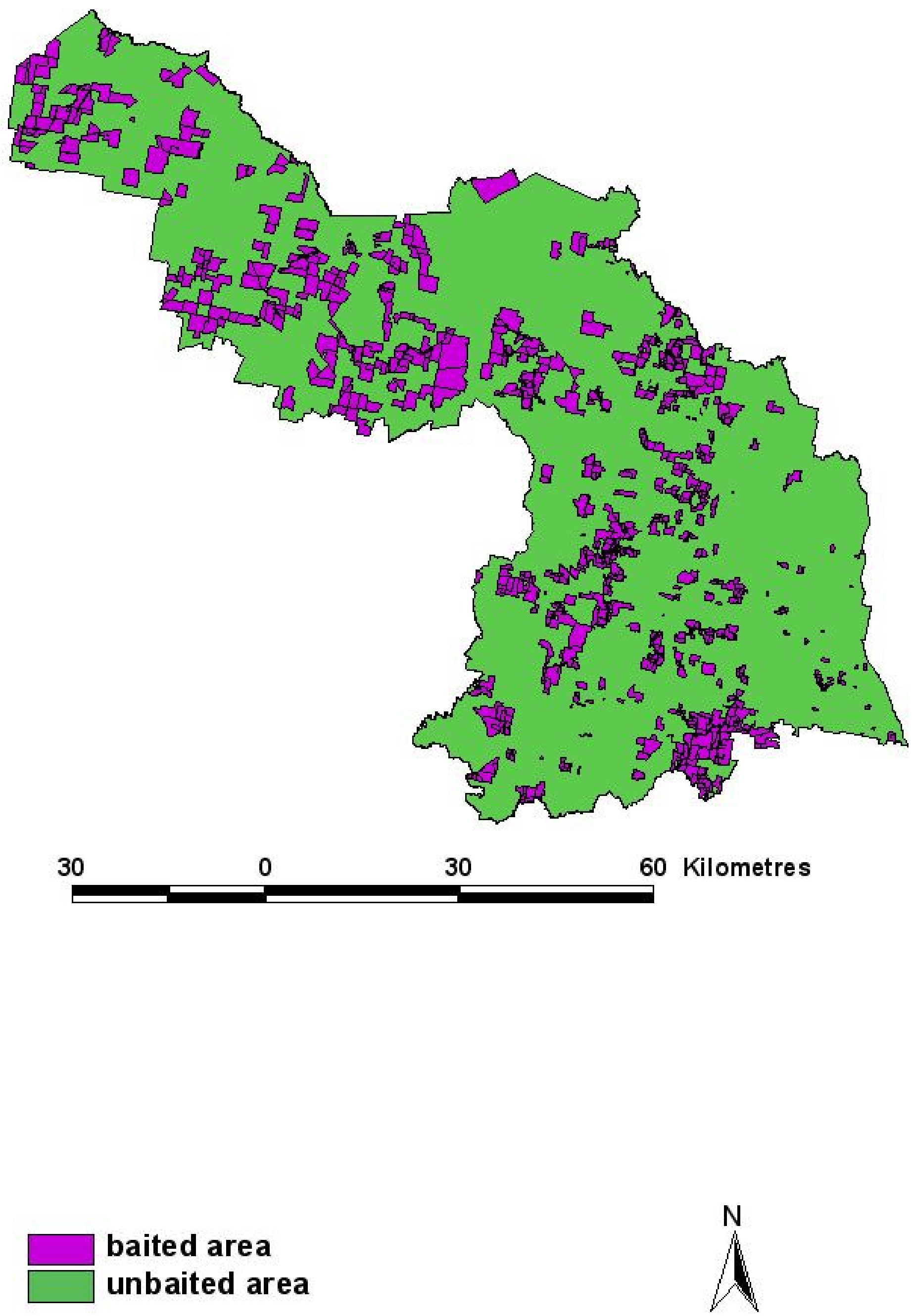

Figure 5.7: The total area of the Molong RLPB baited during 2000

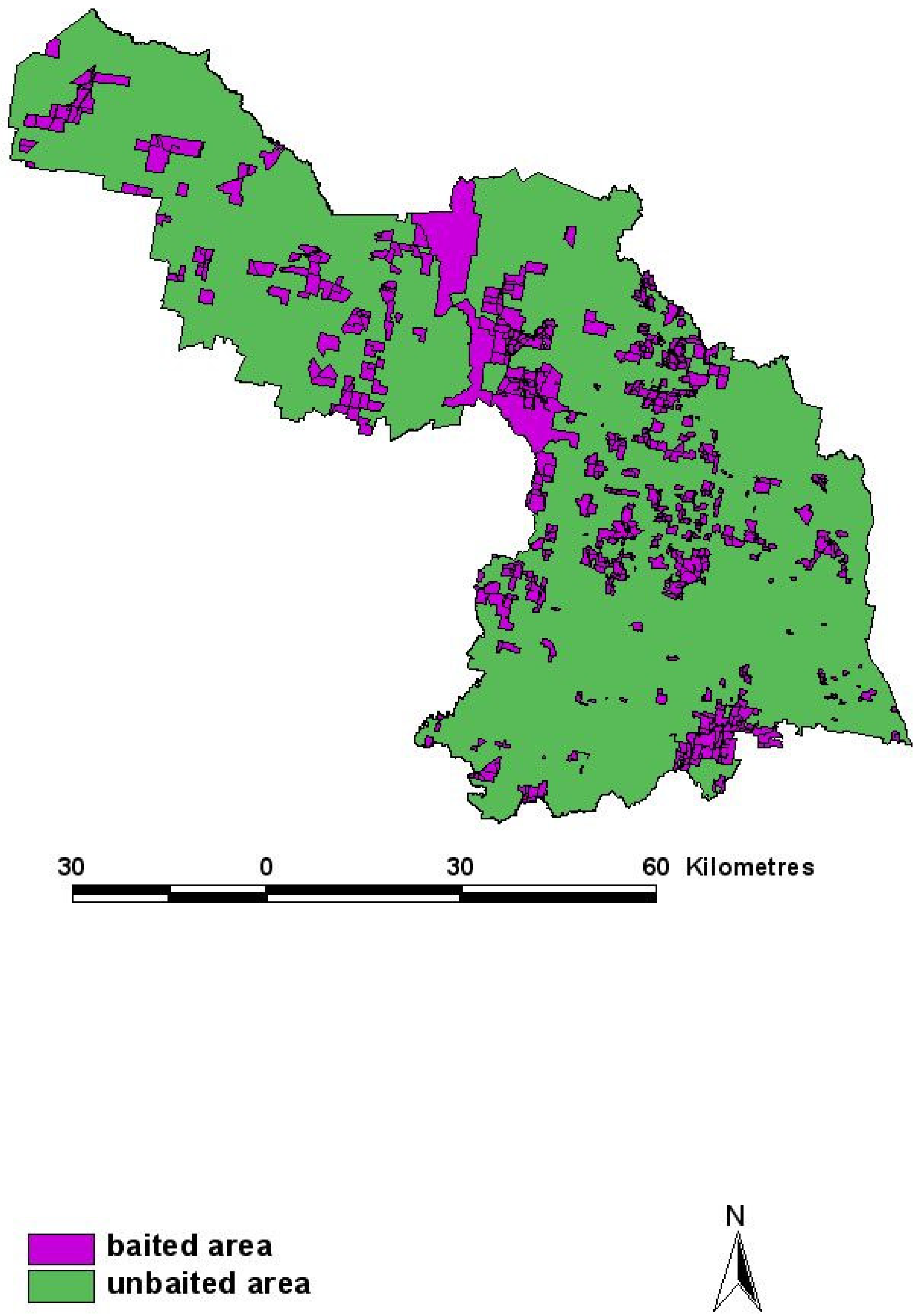

Figure 5.8: The total area of the Molong RLPB baited during 2001

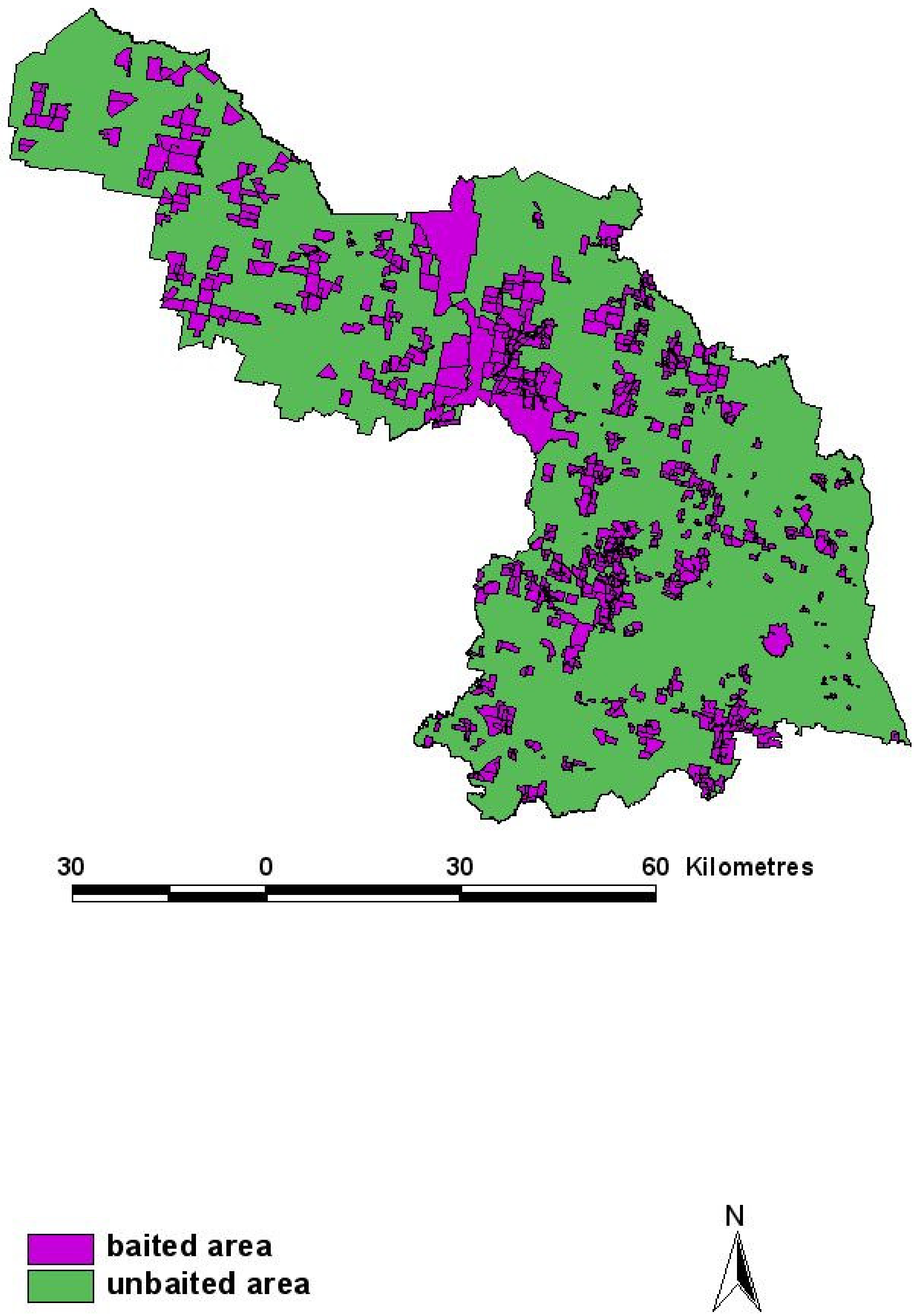

Figure 5.9: The total area of the Molong RLPB baited during 2002

5.3.3.1 Area baited

The area baited by ratepayers fluctuated widely, peaking at 102,896 ha in September 1999 (Figure 5.10). Minimal fox baiting was undertaken by Government agencies during this time, with Goobang National Park (26,400 ha) being baited during April 2001, and February, July and October 2002 and Glenwood State Forest (1,892 ha) being baited in July 2002.

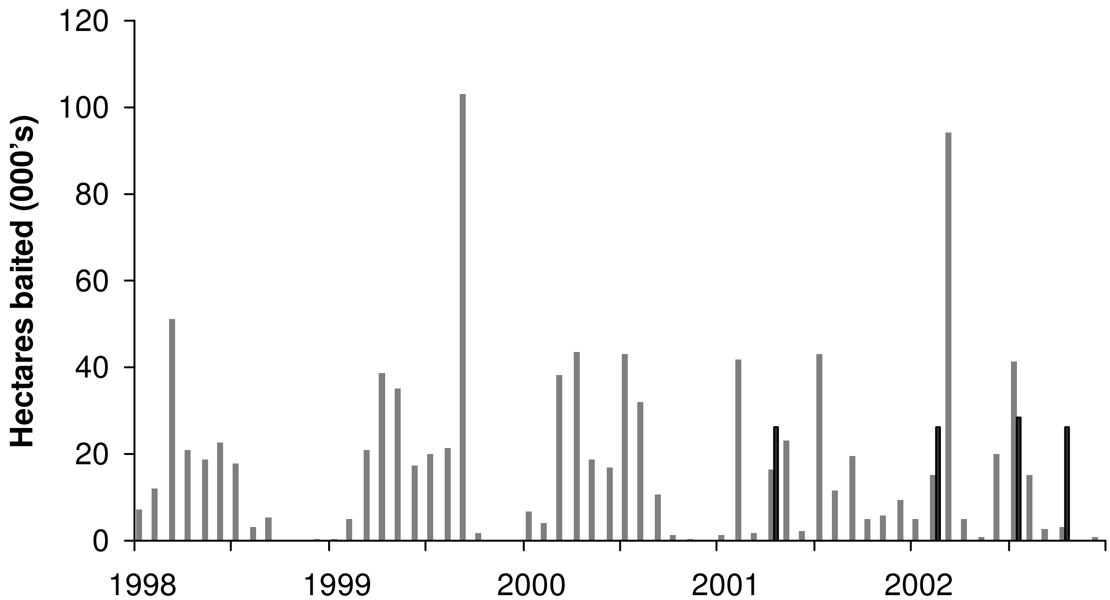

Figure 5.10: Number of hectares baited by ratepayers (grey) and government agencies (black) in the Molong RLPB between January 1998 and December 2002

5.3.3.2 Frequency of baiting

The number of landholders baiting once, twice or ≥ 3 times per year did not vary between years (χ^2= 6 .7114, d.f. = 8, P = 0.57). The majority (>80%) of landholders baited only once per year, with less than 16% baiting twice, and only 3.3% baiting three times or more in the same year (Figure 5.11).

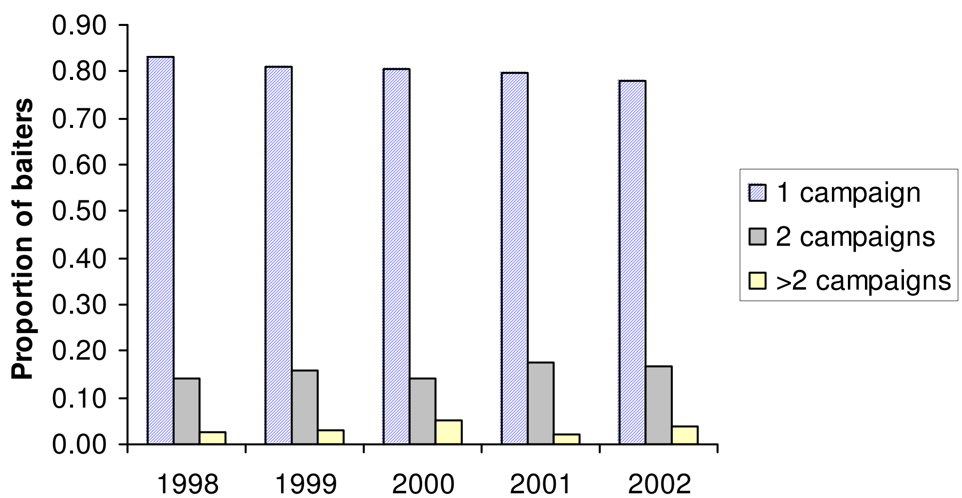

Figure 5.11: The proportion of landholders that completed one, two or greater than two baiting campaigns per annum in the Molong RLPB for the period January 1998 – December 2002.

5.3.3.3 Baiting cooperation

The proportion of ratepayers undertaking baiting in conjunction with their neighbours was generally low between January 1998 and December 2002 (Figure 5.12). Overall, less than half (45%) of baiters had at least one neighbouring landholder undertaking baiting during the same month. When there was coordination between neighbours, the level of coordination was low, the mean number of participants generally ranging between one and two (Figure 5.13). Over half (55%) of those with neighbours participating had only one neighbour, and 25% had two, and only 19% had three or more neighbours.

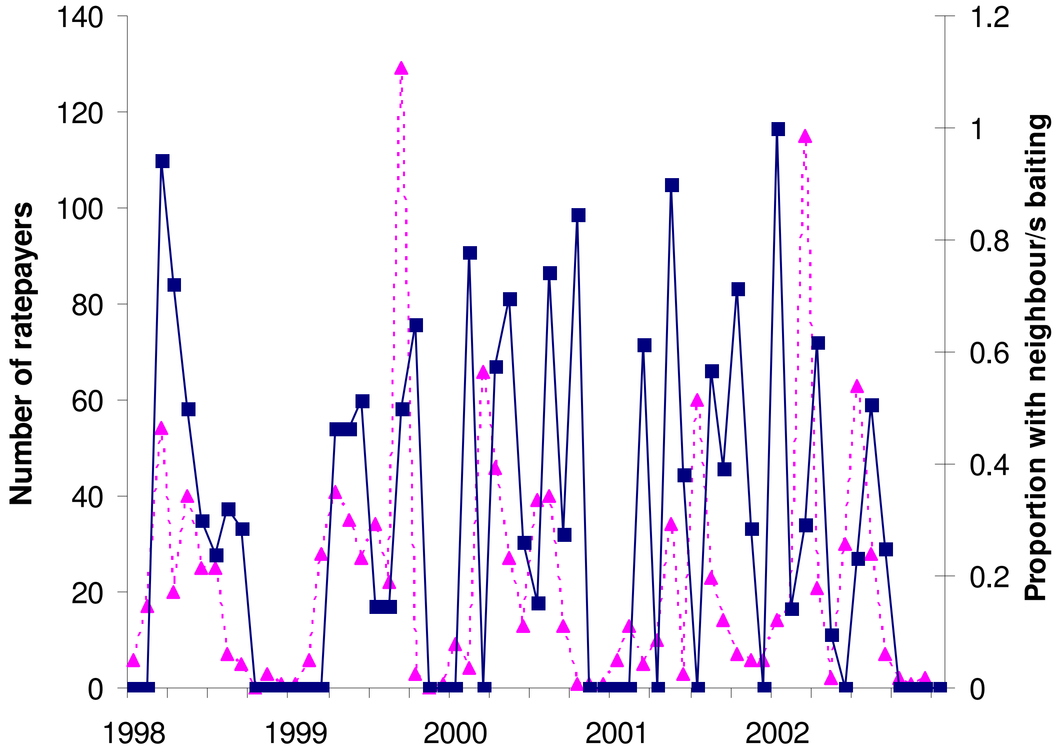

Figure 5.12: The number of ratepayers undertaking baiting (▲) in the Molong RLPB and the proportion of these with neighbours baiting (■) during the 1998 – 2002 period.

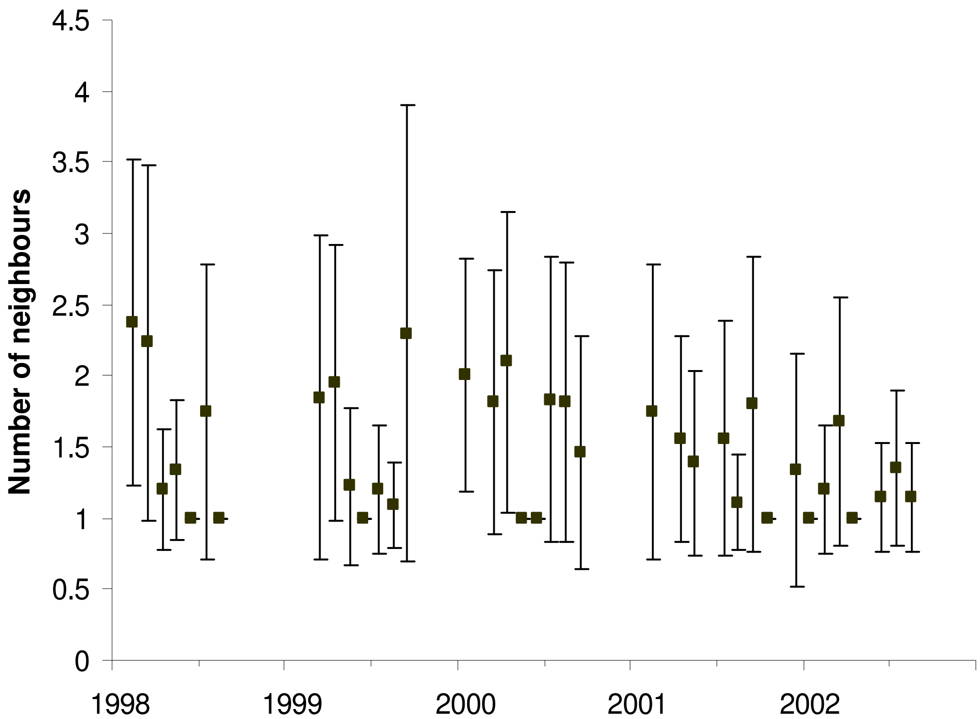

Figure 5.13: The mean number of neighbouring landholders undertaking fox baiting in coordinated baiting campaigns in the Molong RLPB. Error bars indicate standard deviation.

5.3.3.4 Fox immigration

Using the home range estimates from Saunders *et al.* (2002a), the mean dispersal and recovery distances were calculated as 16.51 km and 9.58 km respectively. This indicates that foxes would move and disperse into areas that were situated within 16.51 km of areas harbouring foxes. Assuming that baiting removed all foxes within the baited area, the 'core' areas remaining that were protected from annual juvenile dispersal were estimated as those located greater than 16.51 km from an unbaited area respectively. The recovery distance (9.58 km) was also used to provide a more conservative estimate of fox dispersal distance.

Internal buffers at 16.51 km were added to the perimeter of each continuous baited area for each month, each year and pooled over the five-year study period. No part of any area that had been baited was located greater than 16.51 km from an unbaited area. Similarly, when internal buffers were made using the recovery distance, no part of any area that had been baited was located greater than 9.58 km from an unbaited area. This indicates that there were no baited areas within the Molong RLPB large enough to prevent dispersing juveniles recolonising following baiting operations.

5.3.3.5 Built-up area boundaries

A total of 222 properties had at least part of their properties within a 4 km radius of a built-up area during the period January 1998 until December 2002. Less than one-third of these properties (71) were entirely situated within this 4 km radius. However, 96 properties had at least part of their property within 2 km of a built-up area, with 25 properties entirely situated within 2 km of the boundaries. Figure 5.14 shows the built-up areas with respective 2.0 and 4.0 km radii and the areas that were baited during the study period.

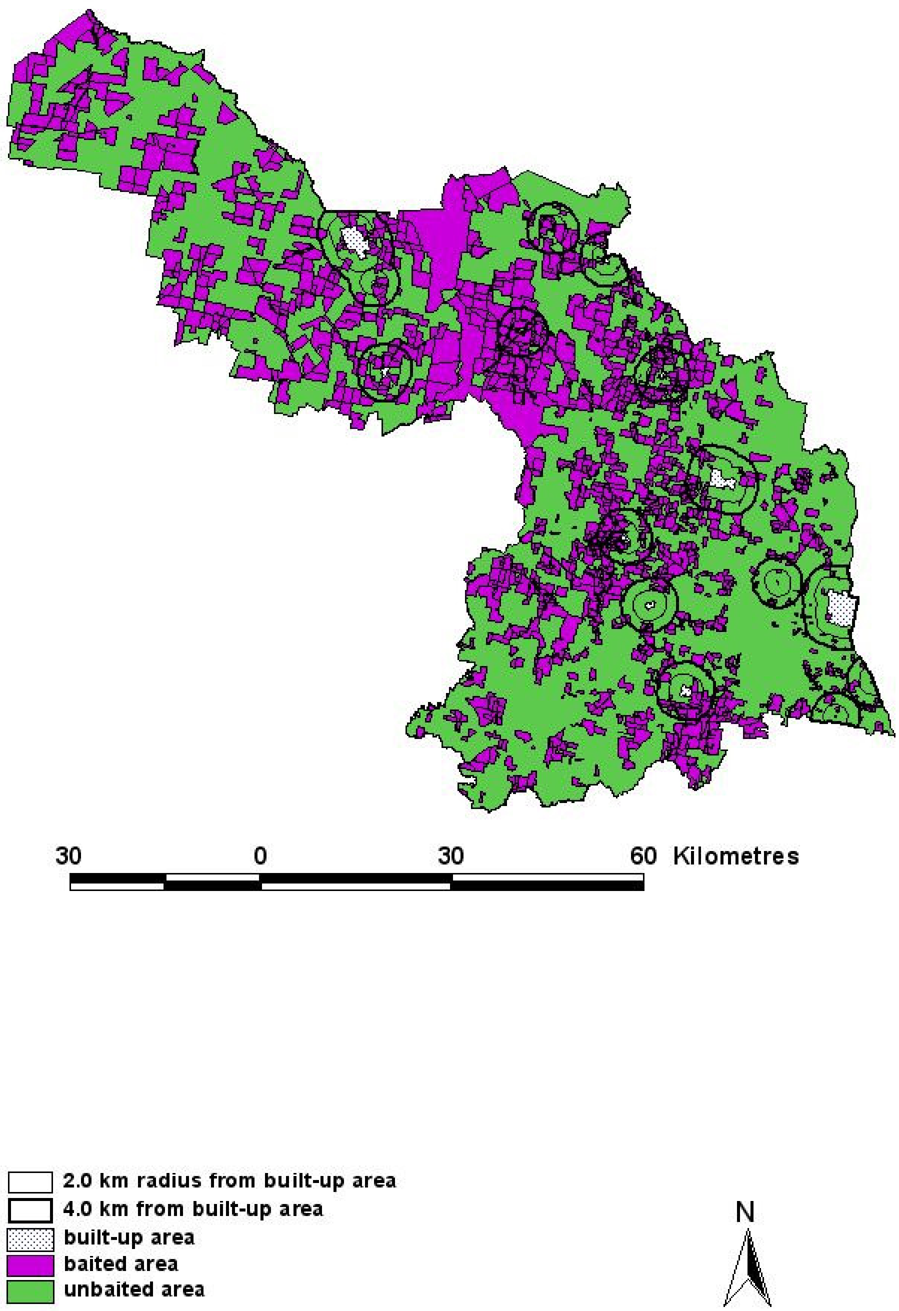

Figure 5.14: The built-up area boundaries, areas within a 2.0 km and 4.0 km radius of these boundaries, and baited areas within the Molong RLPB.

5.3.3.6 Type of enterprise undertaking baiting

Of the 2403 ratepayers within the Molong Rural Lands Protection Board, 581 (24.2%) stock only sheep, 574 (23.9%) beef cattle only, 495 (20.6%) sheep and beef cattle, 22 beef cattle and other species (0.9%), 14 sheep and other species (0.6%). The remaining 717 (29.8%) ratepayers have other stock, such as dairy cattle, undertake other agricultural or horticultural enterprises or undertake no commercial agricultural activities (Figure 5.15).

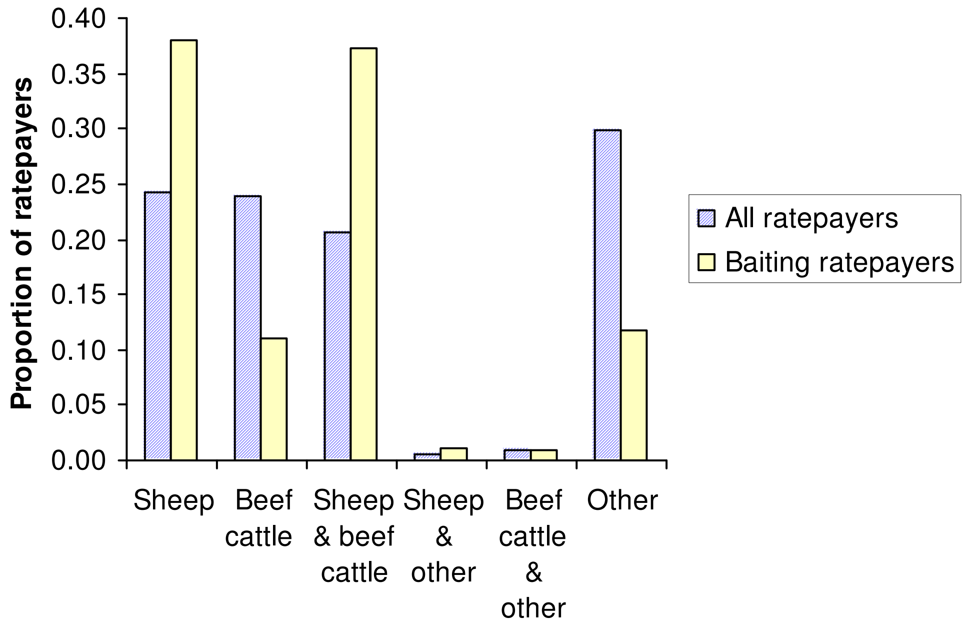

Figure 5.15: The proportion of Molong RLPB ratepayers in each enterprise and the proportion of ratepayers in each enterprise who undertook fox baiting from 1998-2002.

The stock species maintained by ratepayers significantly affected whether they would undertake fox baiting (χ^2 = 326.07, d.f. = 6, P <0.001). A significantly higher proportion of sole sheep producers undertook fox baiting than sole beef cattle producers (χ^2 = 109.70, d.f. = 1, P <0.001) and other enterprises (χ^2= 148.10, d.f. = 1, P< 0.001). These patterns remained highly significant (P <0.001) even after BonFerroni adjustment to correct for multiple comparisons within the same data set. However, there was no significant difference between ratepayers that ran only sheep and those with both sheep and cattle (χ^2= 3.2141, d.f. = 1, P =

0.073). Other comparisons were not undertaken since the sample size was too small for rigorous analyses.

There was no significant difference between the type of enterprise and the season of baiting (χ^2 = 12.25, d.f. = 9, P = 0.20).

5.4 Discussion

The results of this chapter suggest that many landholders within the Molong RLPB are concerned about fox problems and bait regularly with 1080-baits. However, a much larger proportion (78.8%) do not. In this section, I review the factors affecting the success of baiting in the Molong RLPB, and assess whether the present strategy is effective.

5.4.1 Missing records

The data collation and validation process highlighted many deficiencies in the information in the 1080 register. Forty landholders that purchased baits from the Molong RLPB, representing 8% of the total purchasers, could not be identified, despite intensive searches in the Molong RLPB database, Valnet® and communications with staff from Molong and neighbouring RLPBs. Although their details were entered correctly into the 1080 register, these details were insufficient to link with the cadastral property information and hence could not be included in the analyses. This may be due to a number of reasons. For example, the register specifies only that the name and the property address that the poison is supplied to be given, not where the poison is actually laid. An 'agent' can act on behalf of other landholders and only the agents details may be entered into the register. Additionally, landholders may be from other RLPB areas or ownership details may have changed. This lack of consistency in the details entered into the register has serious implications for auditing 1080 baiting operations throughout New South Wales, since, in the event of any audit, there will be many properties that cannot be identified. For auditing purposes, a unique property identifier, such as a Property Identification number (from Valnet®) or an Assessment number (a RLPB identification number), should be presented at the point of sale to allow for the identification of baiting locations. The identity of the purchaser should also be verified through an adequate form of identification, such as a current drivers licence, to check their identity. In Queensland, each landholder must provide an adequate cadastral identifier (usually Lot/Deposit Plan number) at the point of sale. Supplying this cadastral information forms the basis of the Queensland Department of Natural Resources and Mines "PestInfo®" system which is used to monitor bait distribution (P. Paping, Department of Natural Resources and Mines, pers. comm. 2004).

5.4.2 "Outfox the Fox"

Despite concerted efforts to publicise the 'Outfox the fox' program, it appears not to have had sufficient impact to radically improve baiting practices. The general aims of the 'Outfox' program include synchronised baiting within groups, baiting at least twice per year, undertaking baiting when foxes are most susceptible, regularly checking and replacing baits when they are taken, and continued baiting until take declines (Balogh *et al.* 2001). Since the initiation of the 'Outfox' program in early 1999, there has been no obvious increase in the number of landholders, or coordination between landholders, participating in fox baiting. Similarly, there has been no change in the frequency of baiting nor the number of baits used per baiting occasion. This strongly suggests that there is inertia amongst landholders to adopt or change baiting practices. Landholders have been known to resist change, especially when practices have been established and undertaken for long periods. Many landholders, including historical non-baiters, would have been made aware of the program. In addition to some local and regional media coverage, landholders would have been notified through the addition of a brochure attached to the RLPB rates notice and personal communications with RLPB staff or other landholders. Landholders purchasing fox baits were told of the program and asked to encourage surrounding landholders. Further opportunity exists since all neighbours within 1 km of any baited area must be contacted to notify them (>72 hours before) that fox baits will be laid. Alternative strategies, such as undertaking seminars at field days, and liasing with existing groups (e.g. Landcare, Australian Wool Innovation) have been successful in fostering the support and involvement of landholders in coordinated baiting for fox control (Croft *et al.* 2002). Such approaches should be attempted if authorities are serious about improving baiting coordination and practices.

This study demonstrates the importance of planning and undertaking pest management strategically. Such thinking is not new: Braysher (1991, 1993) highlighted the importance of undertaking the strategic approach to pest animal management. The strategic approach relies on planning and undertaking pest control programs to target goals using best practice techniques. This is achieved through defining the problem in terms of pest animal impact, developing and implementing a management plan to reduce the impact, and monitoring and evaluating the outcomes to ensure that they are meeting the required objectives. Pivotal to such adaptive management is the ability to be adaptive when new information is found. Applying such principles to 'Outfox' would mean that the current coordinated approach is not achieving the desired results, and should be modified. The guidelines to such an approach are given in PESTPLAN, a guide to undertaking strategic pest management (Braysher and Saunders 2003).

The 'Outfox' program could be viewed as effective in terms of the number of landholders involved and number of baits laid, but when the baiting coverage, temporal coordination between landholders and likely impact on immigration are taken into account it is probably not achieving the desired objectives. This case study demonstrates the importance of monitoring the performance of pest management programs rather than simply assuming that they are having an effect.

Foxes are well known pests on agricultural and conservation lands, but the extent of the problem they cause is both variable and difficult to measure, especially predation on domestic stock (e.g. Saunders *et al.* 1997a). It is difficult to improve the participation in control programs without being able to demonstrate the benefits of undertaking control through objective scientific studies. Therefore, improving our knowledge of the relationship between density, damage and the impact of control may be the key to increasing participation in baiting programs.

5.4.3 Bait type

Both Foxoff® and chicken heads are commonly used by landholders in Molong RLPB, but very few landholders use fresh meat bait. The popularity of Foxoff® is probably due to its ease of handling and distribution and long shelf life. Molong RLPB encourages the use of Foxoff® since the handling cost is reduced compared to the traditional injection technique necessary for preparation of fresh baits (C. Somerset, Molong RLPB, pers. comm. 2003). Fresh meat baits also spoil more rapidly (see Chapter 3). For this reason, DEC and State Forests exclusively use Foxoff® within the Molong RLPB since its long shelf life makes it ideal for replacement baiting, allowing baiting campaigns to continue for longer periods (J. Neville, Department of Environment and Conservation, and R. Finlay, State Forests, pers. comm. 2003). However, the reduced palatability of Foxoff® compared to other bait types (see Chapter 3) may reduce the effectiveness of these campaigns relative to those utilising other bait types. A compromise may be to encourage landholders to initially lay a fresh bait type, then replace taken or degraded baits with Foxoff®. This would allow campaigns to offer a highly palatable bait initially but continue for longer with the less palatable but degradation-resistant Foxoff®. Additional work should be done to identify and assess the relationship between the handling and distribution cost and palatability of different bait types. For example, a bait type that is highly palatable to foxes may not necessarily be more cost-effective than less palatable bait due to increased handling cost. Improving our understanding of the payoff between bait palatability, handling cost and other considerations are important in improving the cost-effectiveness of fox baiting programs.

5.4.4 Type of enterprise undertaking baiting

The results of this chapter indicate that ratepayers who produce sheep, whether exclusively or in conjunction with other stock, are more likely to undertake fox baiting than those without sheep. This is not surprising, given that foxes are a recognised predator of lambs (Lugton 1987; Greentree *et al.* 2000) thus providing the necessary incentive to undertake control. Conventional sheep joining usually occurs during March-April and December-January resulting in lambs being born in winter/spring or autumn respectively (Lloyd Davies and Devauld 1988; Balogh *et al.* 2001). Lambs are most susceptible to predation during their first few weeks, and landholders appear to concentrate baiting efforts before and during lambing periods (Figures 5.2 and 5.3). However, many ratepayers who exclusively stock cattle, and those without registered stock also still bait, suggesting that foxes are perceived as pests to enterprises other than sheep production. This is supported by a recent survey of primary producers in Queensland that found that landholders from all producer categories surveyed (including beef cattle, horticultural, cropping and dairy) recognised foxes as a significant pest animal (Oliver and Walton 2004). Foxes may injure cattle, particularly calves or birthing cows and damage infrastructure such as watering systems in commercial orchards or vineyards (S. Balogh, NSW Department of Primary Industries, pers comm. 2002). Alternatively, ratepayers may bait to simply cooperate with neighbouring sheep producers or reduce impacts on native wildlife. Many landholders are aware of the environmental damage caused by pest animals (Oliver and Walton 2004) and wildlife conservation may be an important driver for increasing involvement of non-sheep producers in fox baiting campaigns. Regardless, these observations confirm that landholders other than sheep producers are willing to undertake fox baiting, potentially allowing larger areas of land to be baited. A greater understanding of what motivates non-sheep producers to undertake fox baiting may lead to improved strategies to increase participation in fox baiting programs.

Government agencies, especially DEC and State Forests baited only sporadically during the study period, with Glenwood State Forest and Goobang National Park baited on one and three occasions respectively. Fox management by DEC is primarily undertaken under the New South Wales Threat Abatement Plan for predation by the Red Fox (Fox TAP) (NSW National Parks and Wildlife Service 2001). The Fox TAP identifies which threatened species within New South Wales are at greatest risk from fox predation and the sites where fox control is most critical for these species. The plan identifies 81 priority sites for fox control on all types of public and private land across New South Wales, and provides recovery actions for 34 threatened species (11 mammals, 15 birds and eight reptiles) (NSW National Parks and Wildlife Service 2001). The plan relies on collaboration with other agencies, community groups and private landholders to undertake fox control campaigns and/or monitoring of threatened species populations. Within the Molong RLPB, DEC undertake baiting in areas for the benefit of no particular species but rather for the broad aim of biodiversity conservation as recognised by the Fox TAP (J. Neville, Department of Environment and Conservation, pers. comm. 2003). Their campaigns are generally timed to coincide with periods when foxes are most susceptible, which also overlap with the periods when landholders undertake baiting. State Forests have no official agreement to undertake fox baiting within the region but will bait in conjunction with surrounding neighbours if approached (R. Finlay, State Forests, pers. comm. 2003).

5.4.5 Built-up area boundaries

Over 43% of baited properties were at least partly within four kilometres of a built-up area, so that most bait would have been laid on parts of the property outside the 4 km exclusion zone. However, baited properties located within four kilometres (13.9%), and two kilometres (4.9%) of a built-up area may still be exposing domestic animals to unnecessary risk. This is of concern since foxes will cache baits considerable distances from where originally laid (see Chapter 3), and in this situation could potentially move baits even closer to residential areas. Even if campaigns were planned in coordination with an ACO there still lies an inherent risk that domestic animals may be exposed to 1080 bait. Very few 1080 poisonings of domestic dogs are reported, although anecdotal evidence suggests that it is not uncommon (A. Litchfield, Orange Veterinary hospital, pers. comm. 2003). To reduce the potential for non-target deaths, and retain public support for the continued use of 1080, greater care is needed to ensure that ratepayers are baiting as specified by the restrictions on the permit.

5.4.6 Fox immigration

The dispersal models of Trewhella *et al.* (1988) have been used to develop robust spatial models of fox dispersal behaviour (Trewhella and Harris 1988). However, the models are relatively simple and do not account for non-homogenous habitats (such as unfavourable patches) or mortality of resident foxes, which may affect fox dispersal and consequent colonisation. There are few hard barriers to fox dispersal (Harris and Trewhella 1988), and there are none obvious within the Molong RLPB area. The estimated recovery distance (9.58 km) was used rather than the dispersal distance to allow for such variations and provide a more conservative estimate of the likely immigration distance. This estimate is comparable to the mean 11 km dispersal distance measured by Coman *et al.* (1991) in Central Victoria where fox home ranges are similar to those within the Molong RLPB.

A buffer of 10-15 km wide was considered sufficient to reduce fox immigration into baited areas in Western Australia (Thomson *et al.* 2000). But buffers are likely to be narrower where fox density is high given the inverse relationship between population density and recovery/dispersal distances (Trewhella *et al.* 1988). In this study, based on mean recovery distance, no properties involved in fox control, both singularly or in conjunction with neighbours, had any 'core' areas that offered relative protection from fox reinvasion. Even using the more conservative recovery distance (and subsequent immigration estimate), and pooling baited areas across months and years, no baited areas within the Molong RLPB were large enough to have had adequate protection from reinvasion. In addition, buffer areas should undergo constant baiting to ensure that fox density is maintained at low levels, to ensure an effective 'dispersal sink' (Thomson *et al.* 2000). In the Molong RLPB, the majority of landholders bait once per year, with less than 22% baiting on two or more occasions. This suggests that the spatial coverage and frequency of baiting is inadequate to prevent annual immigration into core areas within the Molong RLPB.

The immigration problem may be at least partly due to the small size of properties and hence, a large number of landholders would be required to undertake baiting effectively. Given the average property covers 299.2 ha (SD = 435.0, n = 2403), it would require approximately 108 neighbouring landholders to act as a buffer to protect a 'core' area of one average size property. This level of coordination is logistically very difficult, especially when some landholders refuse to lay 1080 fox baits, due to misconceptions about the toxicity of 1080, perception that foxes are not a problem or fear of non-target deaths, especially of working dogs (C. Somerset, Molong RLPB, pers. comm. 2002). Also, lambing periods are typically not discrete within areas (e.g. Lloyd Davies and Devauld 1988; Balogh *et al.* 2001), varying in timing or length. Lack of synchronisation between landholders may reduce the likelihood that involved parties will agree to a period when baiting should be undertaken (Saunders *et al.* 1997a). This is a problem in the Molong RLPB since there is considerable variation in timing of baiting campaigns across each year, and from year to year (Figures 5.1 and 5.2).

This study supports Thomson *et al.* (2000) in concluding that buffer zones would be impractical where small parcels of land are to be protected. An alternative strategy for these areas could include baiting more frequently (or more prolonged baiting) to counter immigration. Such a strategy is applied in many smaller nature reserves in Western Australia where ground-based fox baiting is undertaken 4 times per year (R. Armstrong, Conservation and Land Management, pers. comm. 2002) as part of the Western Shield program (Armstrong 1997). The current frequency of baiting in the Molong RLPB is well below this level, but given the relatively small average property size, it may be easier to increase the frequency of baiting rather than attempting to control foxes over a surrounding area.

Baiting coverage and frequency may be insufficient presently in the Molong RLPB to reduce fox density for extended periods, but seasonal reductions in fox density may be all that is required to reduce predation on domestic stock. Lambs and goat kids are known to be at greatest risk from fox predation in the first weeks after birth up until marking. Landholders within the Molong RLPB appear to be undertaking baiting to reduce fox density when prey is most susceptible, which may be a more efficient strategy to reduce damage than widespread and frequent control campaigns. This strategy may be more applicable to agricultural enterprises where young animals are most at risk than conservation areas where many species are susceptible as juveniles and adults. However, if ‘one shot’ or short-term campaigns are to be successful at reducing predation upon susceptible prey, then the program should be of sufficient duration to ensure that fox density remains low while prey remain susceptible. However, immigration by foxes may be instantaneous once baiting campaigns are completed (see Molsher 1999). Typically campaigns continue for periods of one to two weeks (Saunders *et al.* 1995); where immigration may be virtually instantaneous, baiting campaigns lasting up to two weeks may be insufficient to reduce fox density for long enough to effectively reduce predation on lambs and goat kids. More investigation is required to determine whether seasonal reductions of fox density are as efficient and effective at reducing agricultural damage than intensive control campaigns.

Other studies support the suggestion that current baiting techniques may be deficient in reducing fox density and associated impacts for long periods. For example, Greentree *et al.* (2000) experimentally tested the relationship between lamb predation and fox control in south-eastern Australia. Three levels of fox control were undertaken (nil control, once per year and three times per year) and the associated rates of lamb predation and fox density were measured. No significant difference was found in the lamb predation rates between the three levels of control, and there was no significant difference in fox abundance between control and treatment sites. Immigration of foxes into the baited area was suggested as a possible cause (Greentree *et al.* 2000), despite a large area comprising of both core and surrounding buffer zones being baited (300 km^2). However, despite the involvement of many landholders, buffer zones only extended up to 3 km from the perimeter of the core areas, which may have been insufficient to adequately reduce fox immigration. Fox home ranges within the Greentree *et al.* (2000) study area are similar to those in the Molong RLPB area (Berghout 2001; Saunders *et al.* 2002a), and hence immigration potential would be similar. Results from this study and those of Greentree *et al.* (2000) and Thomson *et al.* (2000) suggest that immigration is an important factor in reducing the effectiveness of baiting.

Recent evidence from Western Australian research indicates that fox populations have some capacity to respond to decreases in density through compensatory mechanisms such as increased litter size and rates of juvenile survival (Marlow *et al.* submitted). This suggests that populations would recover to original (pre-control) densities within 2 years. Foxes appear to compensate for population control through both immigration into, and compensatory responses within, baited areas.

5.5 Conclusion

If such a large effort is required to make broadscale baiting effective, then the use of buffer zones may not be an appropriate strategy. This supports the conclusions of Thomson *et al.* (2000) that buffer zones may be more appropriate for situations where a large 'core' is to be protected (perhaps where endangered prey is to be protected), since the ratio of core area to buffer decreases disproportionately with the core area. Therefore, the use of buffer zones may be inappropriate to protect properties typical of central-western New South Wales; in these circumstances it may be more appropriate to bait smaller areas more frequently. Despite this, co-coordinating baiting programs with neighbouring landholders should still be encouraged, especially where block sizes are small, to reduce 'edge effects' between baited and non-baited areas.

The current strategy of disseminating information through RLPBs is not resulting in changing baiting practices. It appears that greater or more effective publicity and communication is required to initiate change to current landholder baiting practices.

This study is unique because it investigates the effectiveness of current baiting campaigns scientifically through assessing the spatial coverage and timing of baiting campaigns and their likely affect at reducing fox immigration. In doing so it demonstrates how important it is to improve our understanding of the way that baiting programs are implemented. This is important since typical measures of the success of baiting campaigns rely on easily quantifiable terms, such as the number of people involved or the number of baits laid rather than a scientific assessment based on how the project is achieving its objectives. Such an approach should be undertaken in our strategies for pest management in Australia.

CHAPTER 6

FOX DENSITY AND DEN PREFERENCES

6.1 Introduction

Estimates of abundance of animal populations often form the cornerstone of ecological and wildlife management studies (Caughley 1977; Krebs 1989). Accurate and reliable estimates are especially important for the planning and assessment of pest management programs where the objective is to reduce population size (Wilson and Delahay 2001). Abundance may be either estimated in relative or absolute terms (Caughley 1977) using direct (counts of animals) or indirect methods (counts of field signs) (Sadlier *et al.* 2004; Webbon *et al.* 2004). Most fox management programs only seek to obtain indices that relate to true abundance, since it is usually the direction (increase or decrease) and magnitude of the change (percentage) that is required. However, absolute estimates of abundance are inherently more useful for determining the need for and magnitude of management, especially for containment of exotic diseases or zoonotics, and to assist in the planning, cost and choice of strategies employed by management programs.

In Australia, actual density estimates are essential for determining the likelihood of spread and persistence of rabies in fox populations. Rabies is present on every continent except Australia and Antarctica (Blancou 1988) and would be a major concern if it ever became established here (Saunders *et al.* 1995). Rabies has two major epidemiological cycles; urban rabies with the dog as primary host, and sylvatic rabies with at least one wildlife vector involved (Saunders 1999). In Europe and North America foxes are the major host of sylvatic rabies (Geering 1992) and, as a result, considerable effort is made annually to reduce the density of susceptible individuals by immunisation of wild foxes against the disease (Wandeler 1988; Stohr and Meslin 1996; MacInnes *et al.* 2001; Vos 2003). Accurate estimates of fox density in Australian environments are needed to determine whether density is greater than the threshold required for sylvatic rabies to persist here (Marks and Bloomfield 1999a). Where the threshold is exceeded, these estimates would be invaluable for calculating the reduction in susceptible individuals required to stop this persistence.

There are many problems associated with estimating the actual density of foxes (Harris 1981). The use of direct counts to estimate the absolute abundance of foxes is limited, given the largely cryptic, nocturnal activity and relatively low density of the species compared to other animals (e.g. Newsome and Catling 1992). Estimates from distance techniques using line and point (spotlight) transect counts are promising but violations of sampling assumptions (particularly reduced encounter rates on the transect) suggest that additional refinement of the technique is necessary (Ruette *et al.* 2003). Additionally, the distribution of foxes in a variety of habitats worldwide means that many direct count techniques, including distance sampling methods (Ruette *et al.* 2003), cannot be applied consistently across different habitats and landscapes (Wilson and Delahay 2001). Counts of field signs are becoming favoured due to the greater cost, effort and observer skill required for direct counts of animals (Sadlier *et al.* 2004). A well-chosen field sign index, such as faecal counts may be applicable across a range of habitats; early assessments of the technique suggest that it is an efficient means of estimating relative density across landscapes (Sadlier *et al.* 2004; Webbon *et al.* 2004). The technique has the potential to yield estimates of absolute fox density (see Webbon *et al.* 2004) but requires further validation with reliable estimates of actual density (Sadlier *et al.* 2004; Webbon *et al.* 2004).

Counts of natal den sites during spring are generally regarded as being the most reliable method to determine fox density (Trewhella *et al.* 1988). With knowledge of typical sex ratios, family group organisation, and litter size it is possible to determine the population size (Harris and Smith 1987). These estimates are normally labour-intensive and may require large areas to be searched to find sufficient dens. Since areas are often too large to survey completely, a representative sub-sample may be searched and the results extrapolated to a greater area (Krebs 1989; Wilson and Delahay 2001). With counts of natal den sites, developing an appropriate sampling strategy requires knowledge of the likely distribution of dens to determine the probability of detection (Wilson and Delahay 2001). Improving our knowledge of where dens are likely to be located should increase the search efficiency and therefore the use of the den-count technique for estimating density.

Understanding the factors that determine the location of fox dens is useful not only for estimating fox density, but may lead to improvements in fumigation and baiting programs. Fumigation with carbon-monoxide can be an efficient control technique (Anonymous 1995), but it again relies on being able to locate natal dens. If baiting campaigns are undertaken while the nightly ranging area of juveniles is small, animals may not be susceptible unless baits are distributed within these ranging areas (Robertson *et al.* 2000). During the whelping and initial cub-raising period den sites are a 'focal point' for fox activity, and may provide ideal sites for distributing bait (Robertson *et al.* 2000). This is confirmed by Bugnon *et al.* (2004) who found that presenting bait at dens increased the uptake of anti-rabies bait and resulted in high levels of vaccination in young foxes. Distribution of baits dosed with an abortifacient (cabergoline) at known den sites was shown to be effective in reducing the reproductive success of urban foxes (Marks *et al.* 1996). Spring baiting campaigns undertaken on agricultural lands are often timed to precede or coincide with periods of high prey susceptibility (see Chapter 5); these periods may be ineffective for targeting juveniles if bait is not laid within activity centres. Improving our understanding of where den sites are likely to be found should, therefore, improve the efficiency of spring baiting campaigns.

This chapter assesses the distribution and density of fox dens on one agricultural property on the central tablelands of New South Wales. The density and distribution of dens is used to estimate fox density and to determine if there are preferences shown by foxes in locating den sites. The implications of these findings for density estimation, rabies contingency planning and current fox management strategies, particularly poison baiting, are discussed.

6.2 Methods

6.2.1 Study site

This study was conducted on "Larras Lake North", a mixed farming and grazing property on the central tablelands of New South Wales. This property was chosen because it was representative of a typical central tablelands agricultural enterprise with associated remnants of natural habitats and likely to undertake fox baiting (see Chapter 5). The 9.6 km^2 property is used primarily for sheep (wool) and cattle production but cereal (including wheat and oats) and pasture crops (lucerne, forage sorghum) are also sown. The site is composed primarily of open pasture, with patches of open woodland and timbered riverbanks. The Bell River and adjacent habitat form part of the south-eastern boundary. Plant community associations are given in Chapter 5.

6.2.2 Den searches

An intensive search of the site was undertaken between August and early November in the years 2000, 2001 and 2002 by systematically traversing transects over the entire site. Dens are only usually active during the breeding season and searches were undertaken during the peak cubbing period (August to November) for eastern Australia (McIntosh 1963b; Ryan 1976; McIlroy *et al.* 2001). A four-wheeled motorcycle was used to search those habitats that could be easily traversed, with the remaining areas searched on foot. The distance separating each driven or walked transect depended on the sighting probability, which in turn reflected such factors as topography, habitat, and pasture height. Transects were spaced up to 40 m apart where visibility was high but decreased to be almost overlapping where habitat or terrain reduced visibility. The distance between transects therefore varied based on the judgement of the observer to ensure that the probability of sighting dens was high at all times.

All structures (e.g. tree stumps, tree bases, logs, rock piles, shrubs, fence posts, sheds) encountered were thoroughly checked for the presence of dens. Sites were considered to be dens when they showed obvious signs of construction and/or use by foxes. Dens were classified as natal if they showed obvious signs that cubs were present, such as the presence of adult and cub scats, hair or prey remains, digging and/or scratching, and fresh scent. This was confirmed in most cases by the visual sighting of cubs either during the day or at dusk/early evening. Active dens were those that showed signs of recent (i.e. the current season) preparation or use, including digging, the presence of scats and scent, but were not currently occupied. Inactive dens were older dens that had not been prepared for use in the current breeding season and showed no signs of being used. The location (GPS grid reference), habitat, den habit and form, evidence of activity, and number of entrances were recorded for each den.

6.2.3 Data collation and analyses

All data relating to den locations were collated and entered into a Microsoft Access® database, and location data then imported into ArcView® to facilitate spatial analyses. Once imported, den locations were plotted and checked for accuracy and the location and/or datum (AGD66, AGD84 or WGS84) modified if necessary.

A habitat map of the study site was constructed through selecting areas of each habitat from satellite imagery (Landsat) supplied by the New South Wales Department of Primary Industries. Areas were selected based on a combination of canopy intensity and density and were extensively ground-truthed during the den searches. Three habitat types were defined: open, open woodland and riverine. Open habitat consisted of areas of open grassland and crop areas with no canopy layer of trees or tall shrubs. Open woodland areas were those with a canopy of trees apart from those situated along the river. Areas immediately adjacent to the river (<10m) were classified as riverine and may or may not have had a canopy layer of trees or shrubs.

A Digital Elevation Model (DEM) was then constructed using ArcView® Spatial Analyst (ESRI, California USA) to derive slope and aspect surfaces. Slope class increments were chosen at 5 degrees, allowing for 7 classes ranging between 0 and 35 degrees. Eight aspect classes were chosen to represent the 360 degree aspect spectrum.

Each den location was then classified by aspect, stratum, and habitat through a spatial join of the respective data layers in ArcView®. These were then modified if necessary through comparison with the recorded details and/or ground-truthing. The area of each class within each stratum was calculated using functions in the extension Xtools® (M. Delaune, September 2003) to provide habitat availability. A chi-squared test of heterogeneity (Pearson's) with Yates' correction for continuity (Sokal and Rohlf 1995) was used to compare whether there was any preference in selecting den sites for habitat, slope and aspect and whether these were different for natal and active dens. A Students *t*-test was used to compare the number of entrances between active and inactive dens.

6.2.4 Den distribution

The nearest neighbour distances between the active and natal dens were calculated for each year to determine whether dens were distributed in an aggregated, regular or random pattern at P<0.05 (Clark and Evans 1954; Krebs 1989; Berghout 2001). This was done using the index of aggregation,

$$R = \frac{ro}{re}$$

where:

ro is the mean nearest neighbour distance

re is the expected nearest neighbour distance.

This index is computed by comparing the distance to the nearest den (i.e. nearest neighbour distance) with the expected nearest neighbour distance (the Clark and Evans test: Clark and Evans 1954). The expected nearest neighbour difference is the distance between neighbouring dens assuming a random distribution of dens across the study site. The ratio (index of aggregation or *R*) of the mean observed nearest neighbour distance to the expected distance indicates den dispersion. If $R = 1.0$ the distribution is random, if $R<1.0$ dens are clumped or aggregated. A regular pattern is evidenced by an *R* value exceeding 1.0. A *z*-test (Clark and Evans 1954) was used to indicate whether *R* significantly deviated (P<0.05) from random:

$$z = \frac{ro - re}{se[ro]}$$

where:

z = standard normal deviate

$se[ro]$ = standard error of expected distance to nearest neighbour

= $0.26136/\sqrt{nD}$

n = number of individuals in search area

D = density of individuals in search area

(Clark and Evans 1954; Krebs 1989).

The coded ArcView® extension ID Within Distance® (Jenness Enterprises, August 2003) was used to calculate the distance between the nearest neighbouring dens and the edge of the search area. Dens that were located closer to the edge of the search area than to another den were excluded from the analyses. This addition of a 'boundary strip' reduces the potential for bias in the Clark and Evans test towards a regular pattern by not including outermost dens that may have nearest neighbours outside the search area (Krebs 1989).

A low density of natal dens would potentially mean that use of a boundary strip to exclude outermost dens would drastically reduce the sample size and hence ability to determine den dispersion. Therefore, a correction of the expected nearest neighbour distance and standard error in the Clark and Evans (1954) test proposed by Donnelly (1978) was applied to reduce bias arising from including dens in the boundary strip in the analyses.

The corrected distance is re_c, where:

$$re_c = re + (0.051 + 0.041/\sqrt{n})(L/n)$$

$$se[ro] = (\sqrt{(0.07A + 0.037L\sqrt{A}/n)})/n$$

A = search area
L = length of search area perimeter
n = number of individuals in search area
(Krebs 1989).

This shall be referred to as the Donnelly (1978) test.

6.2.5 Fox density

To estimate fox density accurately from natal den counts the social organisation of the population must be known (Trewhella *et al.* 1988). In Australia, the predominant social group consists of a pair of breeding adults with dependent and then dispersing juveniles (Saunders *et al.* 1995; McIlroy *et al.* 2001). However, social groups may contain additional non-reproducing vixens and/or males; failing to account for these will underestimate true density (Sadlier *et al.* 2004). Previous studies on the central tablelands suggest that the proportion of non-reproducing vixens in the population is low (McIlroy *et al.* 2001; Saunders *et al.* 2002b). Given that the sex ratio of foxes does not differ from parity (Saunders *et al.* 2002b), there would also be few non-reproducing males.

Assuming monogamous pairing, each natal den will have a male and female fox with a litter of cubs (Harris 1981). Only a few litters were directly and accurately observed, so the mean litter size (4.0) estimated using placental scar counts from vixens collected on the central tablelands (Saunders *et al.* 2002b) was used.

Family groups may prepare and use several dens (classified here as active) during the breeding season. Each family group may use several active dens during the cub-raising period (Berghout 2001), such that, active dens only represent *potential* natal den sites. As a result, only active dens confirmed to contain litters (classified here as natal dens) each year were used to estimate the number of family groups, and hence estimate fox density.

An additional density estimate was calculated by dividing the total number of active dens located each year by the mean number of active dens used by vixens (estimated by radio-tracking) on the central tablelands of New South Wales (Berghout 2001).

6.2.6 Potential for persistence of rabies

To control a rabies outbreak, it is critical to reduce the number of susceptible individuals to below the threshold density needed to maintain rabies in the wild population (Saunders 1999). The density of susceptibles may be reduced either through vaccination or through the use of lethal control measures to reduce population density. The proportion of animals that must be immunised or killed to stop persistence of rabies is therefore determined by comparing the density of susceptible animals to the critical threshold density (Anderson 1986; Marks and Bloomfield 1999b). Adopting the approach of Marks and Bloomfield (1999b), published K_t values were compared to pre and post-whelping fox density estimates using the formula below to estimate whether fox density was sufficient to support the persistence of rabies and estimate the proportion of the population that needed to be immunised to stop persistence.

$\underline{P} > 1 - (K_t/K_{pr})$

or

$\underline{P} > 1 - (K_t/K_{po})$

where:
$\underline{P}$ = proportion of the population to be immunised
K_t = critical threshold density of animals to support rabies persistence
K_{pr} = pre-breeding density of susceptible animals
K_{po} = post-breeding density of susceptible animals
(Anderson 1986; Marks and Bloomfield 1999b).

Pre-breeding density estimates were calculated from the number of breeding adults; post-breeding estimates are calculated from the number of breeding adult pairs plus the mean number of cubs in each litter.

6.3 Results

6.3.1 Den locations

Totals of 79, 119 and 84 fox dens were found in the 9.6 km^2 search area in the years 2000, 2001 and 2002 respectively (Table 6.1 and Figures 6.1, 6.2, 6.3 and 6.4 respectively). The combined total of 282 dens recorded over this period included 231 individual dens comprising 19 natal, 112 active and 100 inactive dens.

Table 6.1: The number of inactive, natal and active fox dens located each year on "Larras Lake North".

Den activity	*Number of dens*		
	2000	*2001*	*2002*
Inactive	34	56	38
Active	36	54	40
Natal	9	9	6
Total	79	119	84

6.3.2 Den persistence

The use of dens varied markedly from year to year with some dens used constantly while others were abandoned. The numbers of dens that were active or natal in each year that continued to be used in the following years are shown in Table 6.2.

Table 6.2: The numbers of active or natal dens in 2001 and 2002 that were active or natal in the previous year (Year -1) or two years prior (Year-2).

Habitat	Active		Natal	
	2001	2002	2001	2002
Number dens located	54	40	9	6
Number active Year – 1	9	4	2	4
Number active Year – 2	-	3	-	-
Number natal Year – 1	3	3	2	4
Number natal Year – 2		3	-	-

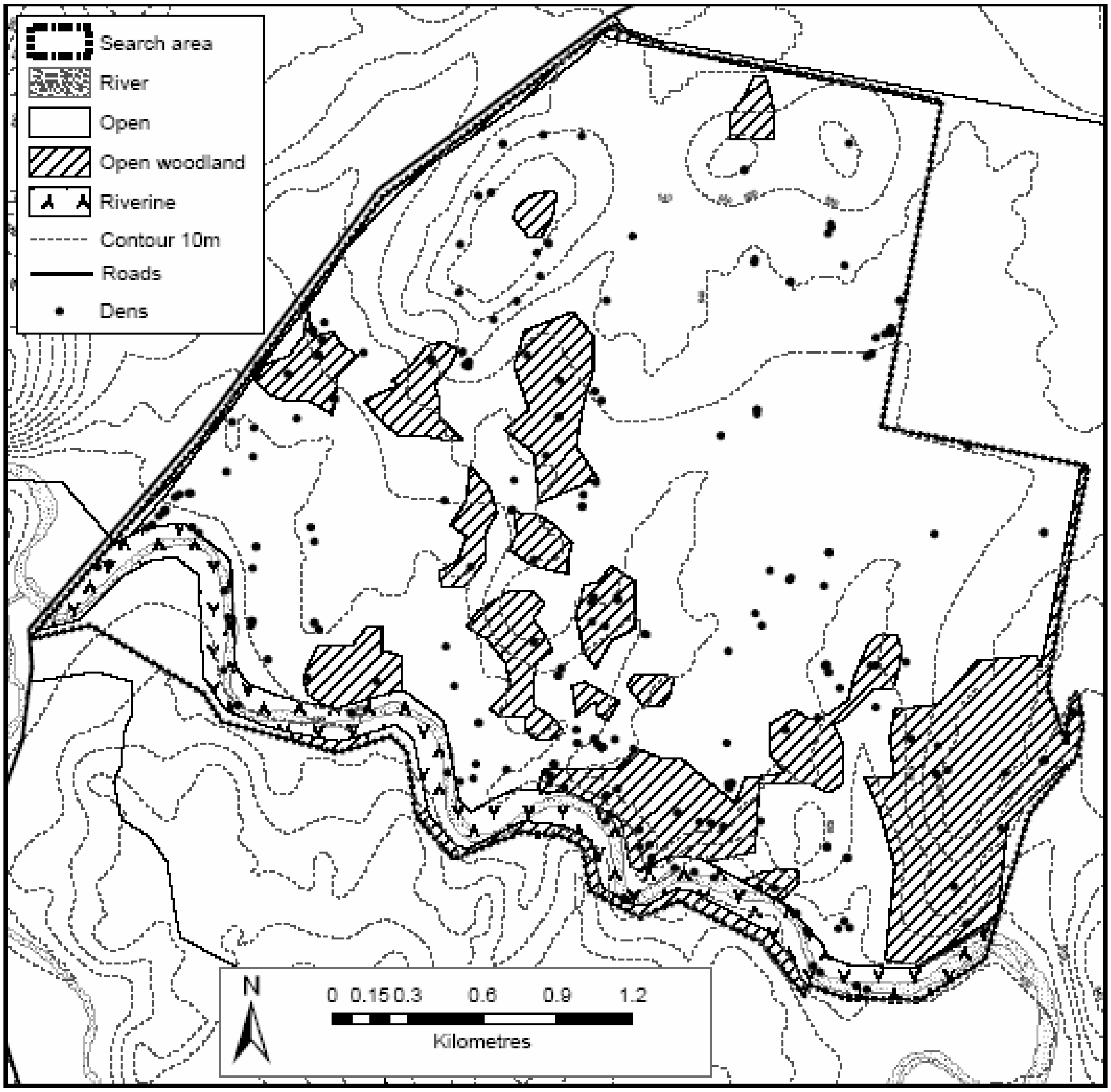

Figure 6.1: The locations of all active, inactive and natal fox dens found on the study site over the 3 year study period.

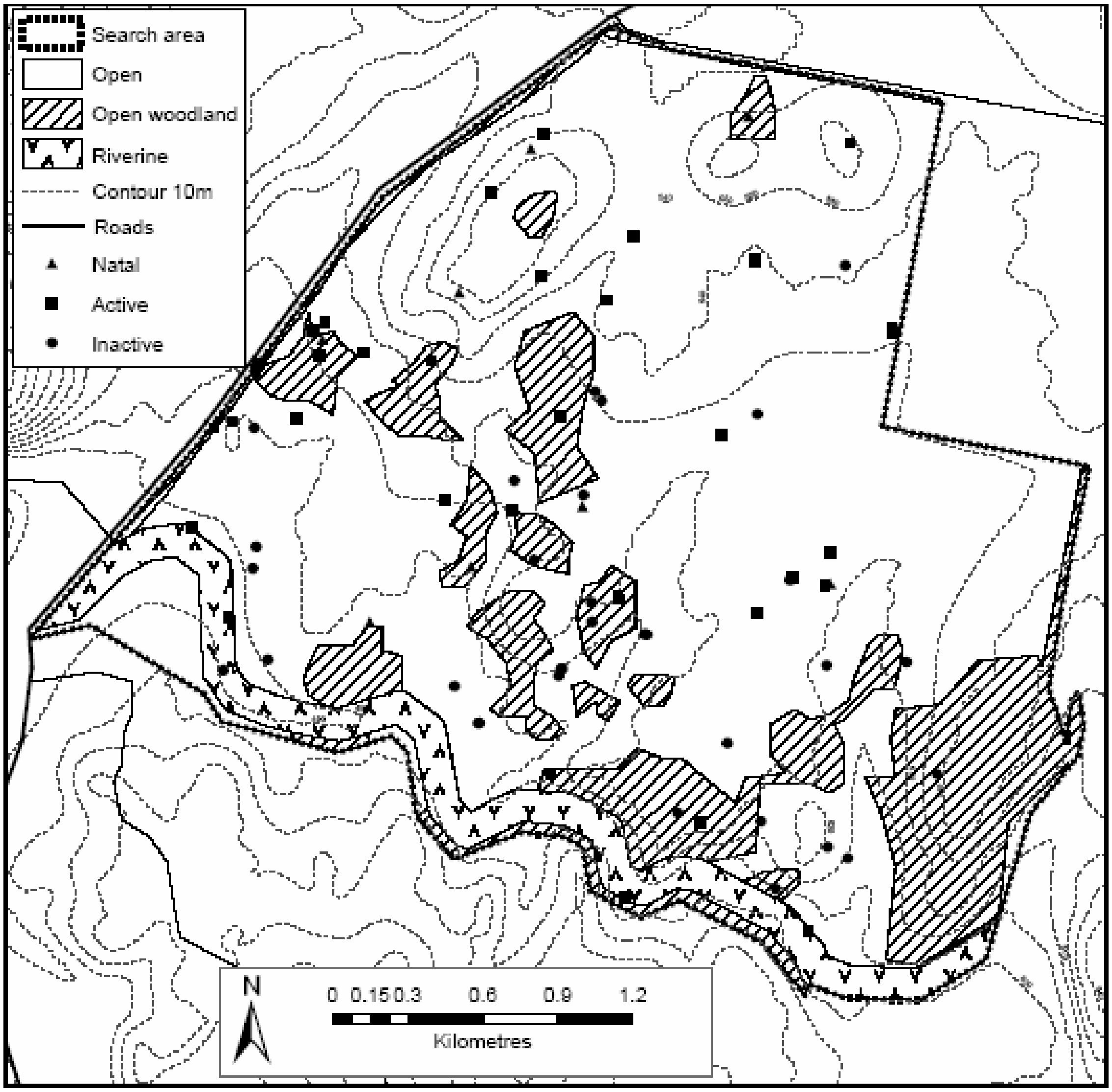

Figure 6.2: The locations of all natal, active and inactive fox dens found during 2000.

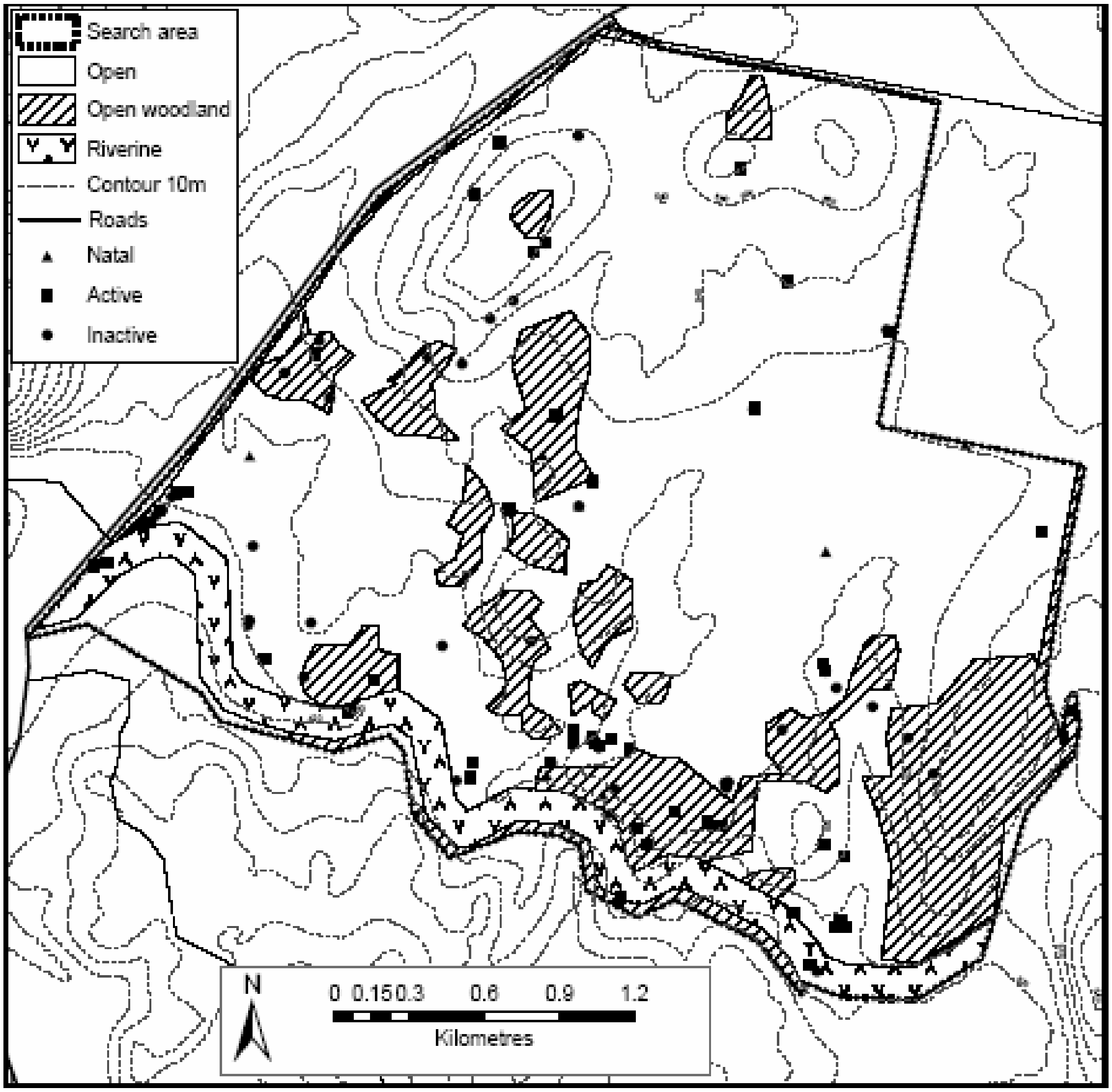

Figure 6.3: The locations of all natal, active and inactive fox dens found during 2001.

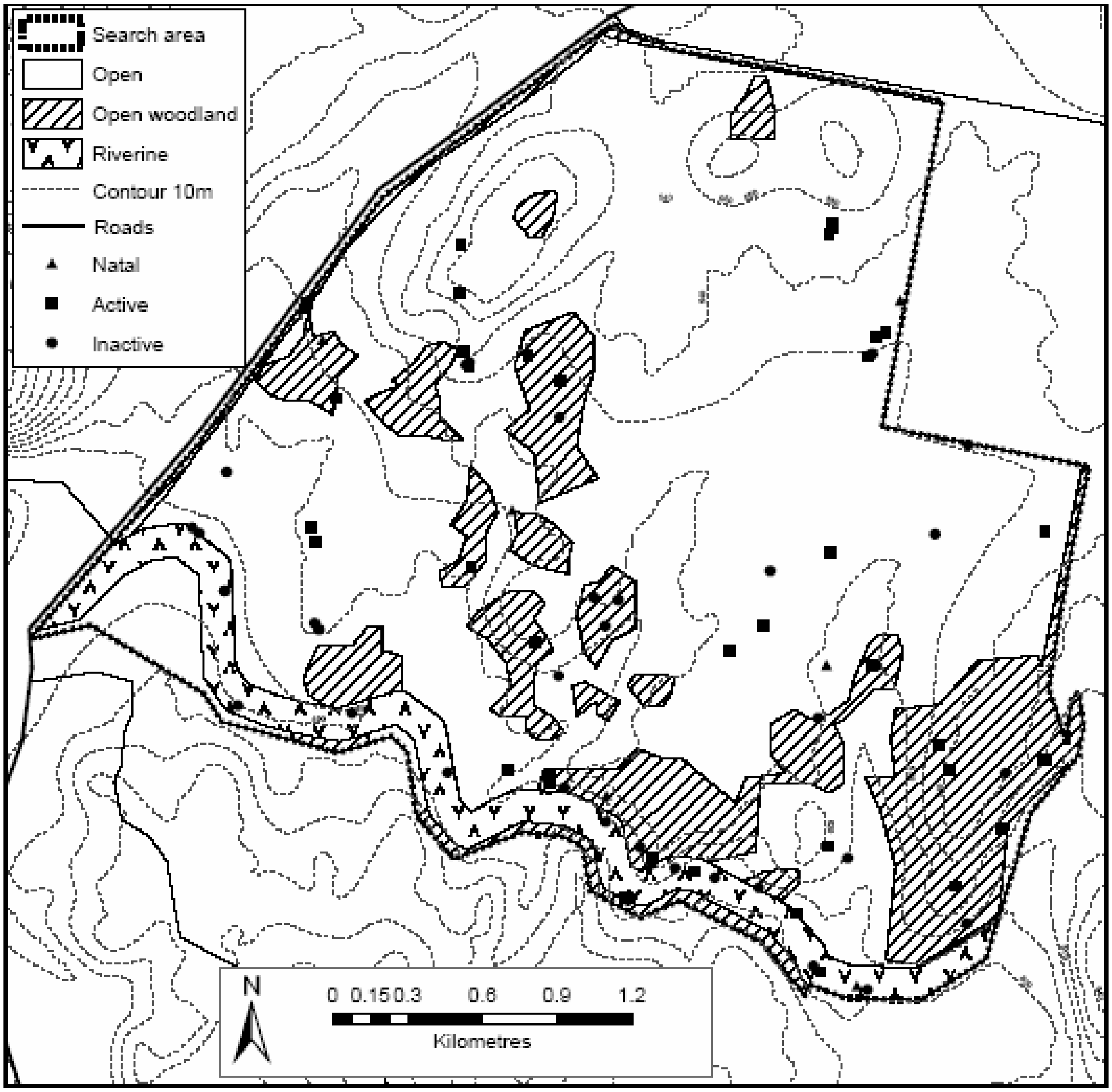

Figure 6.4: The locations of all natal, active and inactive fox dens found during 2002.

6.3.3 Den microhabitat and form

Most dens were dug into the ground (85.7%) with the remainder being located in logs (9.1%) or in the base of trees and/or between rocks (5.2%). The majority of dens (70.6%) were located adjacent to or within a physical structure, whether natural or man-made. Of these dens, 38% were predominantly under or near trees, 31.7% were in or near logs, 26.4% adjacent to or under rocks, and 3.9% were under or adjacent to a fence.

Due to the small number of natal dens located, both natal and active dens were pooled for comparisons against inactive dens. Relatively more active/natal dens were located within or adjacent to cover (0.771, 101/131) (χ^2 = 5.51, d.f. = 1, P = 0.018) than inactive dens (0.62, 62/100). There was no significant difference between the proportion of active/natal dens and inactive dens situated above ground (24/131 and 9/100 respectively) (χ^2 = 3.29, d.f. = 1, P = 0.07), although a slightly larger sample size may have returned a significant difference.

The mean number of entrances for each den was 1.9 ($\pm$ 1.3SD, n = 231). There was no difference in the number of entrances to natal dens (2.4 $\pm$ 2.1SD, n = 19) compared to active dens (2.0$\pm$ 1.2SD, n = 112) (t = 0.81, P>0.05). However, the number of entrances of inactive dens (1.8$\pm$ 1.1SD, n = 100) was significantly less than those dens showing obvious signs of activity (active and natal dens pooled) (2.0$\pm$ 1.4SD, n = 131) (t = -1.67, P = 0.046).

Habitat

The 960 ha search area consisted of 699.8 ha of open habitat (72.9%), 194.9 ha of open woodland (20.3%), and 65.3 ha of riverine habitat (6.8%) (Figure 6.5 and Table 6.3). From the total of 231 individual dens that were located, the majority (64.5%) were found in open habitat, 26.0% were found in open woodland, and the remainder were within riverine habitat (9.5%). When active, natal or inactive dens were pooled, foxes did not show a significant habitat preference for den locations (χ^2 = 3.84, d.f. = 2, P = 0.15) despite proportionally more dens found in both riverine and open woodland habitats (Figure 6.5).

For active dens, there was no significant preference shown for locating dens within habitats (χ^2 = 2.33, d.f. = 2, P = 0.31). Similarly, foxes did not show any habitat preference for the location of natal dens (χ^2 = 1.68, d.f. =2, P = 0.43), nor active and natal dens pooled (χ^2 = 3.66, d.f. = 2, P = 0.16).

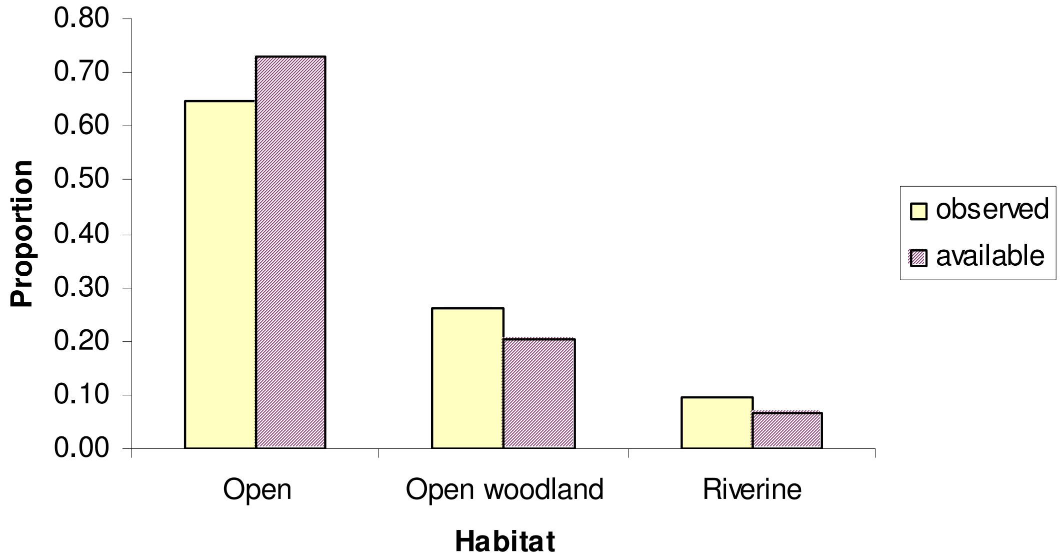

Figure 6.5: The proportion of all fox dens (n = 231) located in each habitat (observed) and the proportion of each habitat available within the search area (available).

Table 6.3: The percentage availability of habitat strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive 2000	Inactive 2001	Inactive 2002	Active 2000	Active 2001	Active 2002	Natal 2000	Natal 2001	Natal 2002	Total
Open	72.9	27	43	14	23	38	20	5	5	3	178
Open woodland	20.3	6	11	12	10	10	17	3	4	2	75
Riverine	6.8	1	2	12	3	6	3	1	-	1	29
Total	100.0	34	56	38	36	54	40	9	9	6	282

There was a significant difference in the location of dens within habitats between years (χ^2 = 20.84, d.f. = 4, P <0.001). Foxes did not show any preference for locating dens within habitats in 2000 (χ^2 = 0.32, d.f. = 2, P = 0.85) and 2001 (χ^2 = 0.02, d.f. = 2, P = 0.99). In 2002, foxes showed a significant preference for habitat (χ^2 = 15.00, d.f. = 2, P <0.001), with a greater percentage of observed dens located in open woodland (36.9%) and riverine habitats (19%) relative to open areas (45%).

Slope

The majority of the study area was gently undulating, with over 90% of the site on slopes of 0-10 degrees. Dens appeared to be located within the slope classes (Figure 6.6). No significant preference for slope was detected (χ^2 = 0.305, d.f. = 2, P = 0.86: Figure 6.6).

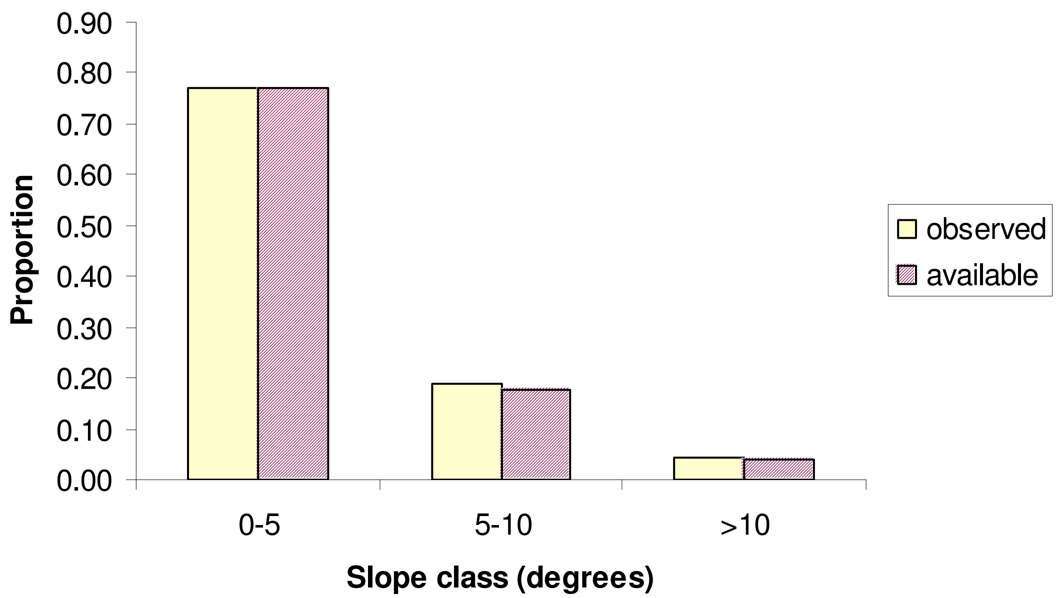

Figure 6.6: The proportion of all fox dens located (n = 231) in each slope class (observed) and the proportion of each slope class available within the search area (available).

Those dens that were active at some stage during the study period were assessed further. There was no evidence to suggest that these active dens were preferentially located in any particular slope class (χ^2 = 1.98, d.f. = 2, P = 0.37). Similarly, foxes did not show any preferences for locating active (χ^2 = 2.70, d.f. = 3, P = 0.26) or natal dens (χ^2 = 0.39, d.f. = 2, P = 0.82).

Table 6.4: The percentage availability of slope strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive 2000	Inactive 2001	Inactive 2002	Active 2000	Active 2001	Active 2002	Natal 2000	Natal 2001	Natal 2002	Total
0-5	77.1	31	38	27	31	41	31	6	8	5	218
5-10	17.5	3	15	6	5	13	8	3	-	-	53
>10	5.4	-	3	5	-	-	1	-	1	1	11
Total	100.0	34	56	38	36	54	40	9	9	6	282

Aspect

The study area has a predominant southern to western aspect, with over 75% of the area facing this general direction (Figure 6.7).

There was no significant relationship between den location and aspect (χ^2 = 12.48, d.f. = 8, P = 0.13). Similarly, active (χ^2 = 10.7, d.f. = 8, P = 0.22) and natal dens (χ^2 = 6.02, d.f. = 8, P = 0.64) were not preferentially located to face any particular aspect. Those dens that were active at some stage during the study period (active and natal pooled) were assessed, but there was no evidence that these dens were located in any particular aspect class (χ^2 = 10.22, d.f. = 8, P = 0.25).

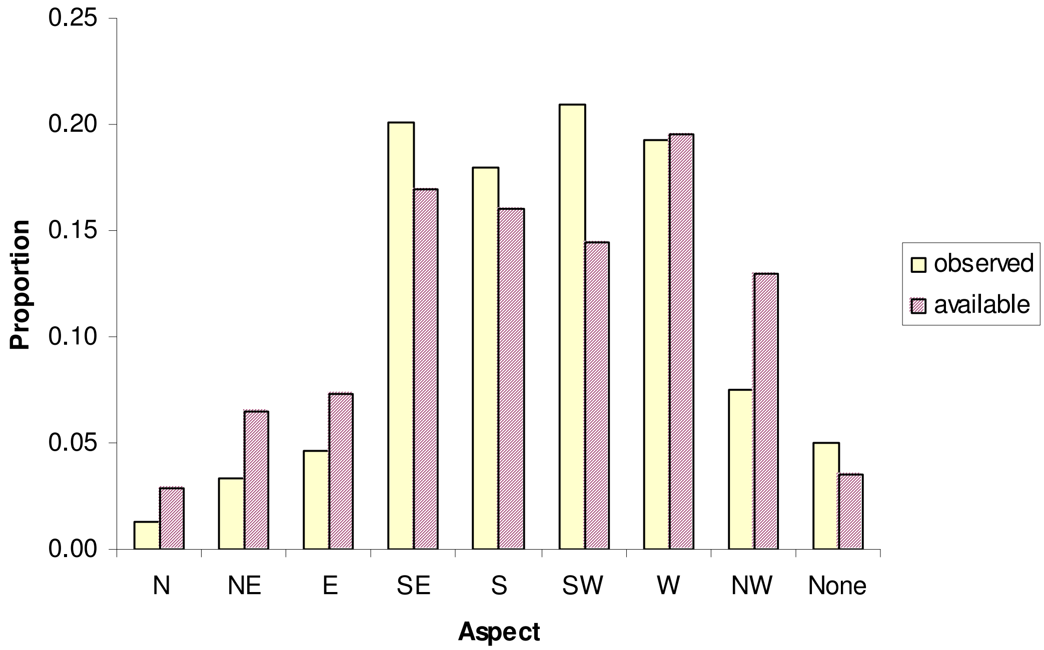

Figure 6.7: The proportion of all fox dens located in each aspect class (observed) and the proportion of each habitat class available within the search area (available) (n=231).

Table 6.5: The percentage availability of aspect strata within the search area and the number of inactive, natal and active fox dens within each stratum.

Habitat	% available	Inactive			Active			Natal			Total
		2000	2001	2002	2000	2001	2002	2000	2001	2002	
N	2.9	-	1	-	-	-	-	1	-	1	3
NE	6.5	-	1	5	2	3	2	1	-	-	14
E	7.3	2	6	1	1	1	-	-	-	-	11
SE	16.9	10	9	7	8	8	10	2	2	2	58
S	16.0	4	8	11	6	11	7	1	3	-	51
SW	14.4	6	11	6	9	10	10	2	4	1	59
W	19.5	11	10	7	8	8	7	1	-	2	54
NW	13.0	1	4	-	1	10	4	-	-	-	20
No aspect	3.5	-	6	1	1	3	-	1	-	-	12
Total	100.0	34	56	38	36	54	40	9	9	6	282

6.3.4 Den dispersion

Removal of dens that were situated closer to the edge of the search area than the nearest neighbour den resulted in 11, 15 and 10 active dens being excluded from dispersion analyses in 2000, 2001 and 2002, respectively. The mean distance between neighbouring active dens was generally short, ranging between 89 m and 164 m, and analyses of nearest neighbour distances indicated that active dens in all years were significantly clumped or aggregated (Table 6.6).

Natal dens were spaced further apart than active dens, as expected due to their overall low density (<1.0 km^{-1}). The mean nearest neighbour distances ranged between 375 m and 1140 m in 2001 and 2002, respectively (Table 6.6). The index of aggregation calculated for natal dens in 2000 and 2002 suggested that these dens were dispersed in a regular pattern, but only the distribution of natal 2002 dens was statistically significant different from random ($P<0.05$). The aggregation index for 2001 natal dens was less than 1 (0.59), suggesting that dens were aggregated, but this did not deviate significantly from random ($P>0.05$).

6.3.5 Fox density

A total of 9 natal dens was located in the search area in 2000 and 2001, but only 6 were located in 2002. Assuming that each den represents 2 adult foxes and the population sex ratio is 1:1, this equates to a pre-whelping population size of 18 foxes in 2000 and 2001, and 12 in 2002. Given that the mean number of cubs *in utero* is 4.0 (Saunders *et al.* 2002b) the post-whelping population size was calculated as 54 (18 adults and 36 cubs) in 2000 and 2001, and 36 (12 adults and 24 cubs) in 2002. These estimates equate to a pre-whelping density of 1.90 foxes km^2 for 2000 and 2001, and 1.25 foxes/km^2 for 2002. Post-whelping density would be 5.60 foxes km^2 in 2000 and 2001 and 3.75 foxes/km^2 in 2002.

Fox population size and density can also be calculated by using the number of active dens and an estimate of the number of active dens utilised by vixens. Berghout (2001) observed through radio tracking that each vixen utilised an average of 2.4 active dens (n = 10). In the current study, this translates to estimates of pre and post-whelping densities between 3.1 and 15.4 foxes/km^2 (Table 6.7).

Table 6.6: The mean nearest neighbour distance (NND, km), expected nearest neighbour distance (NND, km), index of aggregation (*R*), deviation from randomness (*z*), test used, and significance (* P<0.05; ^{NS} P>0.05) for active and natal fox dens located during each search period.

Den class	*n*	*Den density (no/km^2)*	*Mean NND (km)*	*Expected NND (km)*	*R*	*z*	*Suggested dispersion*	*Test and significance*
Active 2000	25	3.75	0.164	0.258	0.638	-4.15	Clumped	Clark and Evans*
Active 2001	39	5.63	0.089	0.211	0.422	-8.12	Clumped	Clark and Evans*
Active 2002	30	4.17	0.14	0.245	0.522	-5.41	Clumped	Clark and Evans*
Natal 2000	9	0.94	0.736	0.632	1.14	1.19	Regular	Donnelly ^{NS}
Natal 2001	9	0.94	0.375	0.632	0.59	-1.75	Clumped	Donnelly ^{NS}
Natal 2002	6	0.63	1.14	0.781	1.44	2.16	Regular	Donnelly*

Table 6.7: The number and density of active and natal fox dens during 2000, 2001 and 2002 and resultant estimates of pre- and post-whelping fox density (foxes/km^2).

Year	Active dens (density per km^2)	Natal dens (density per km^2)	Pre-breeding - post-breeding fox density (foxes/km^2) from active dens	Pre-breeding - post-breeding fox density (foxes/km^2) from natal dens
2000	36 (3.8)	9 (0.94)	3.1 – 9.4	1.90 - 5.60
2001	59 (6.1)	9 (0.94)	5.1 – 15.4	1.90 - 5.60
2002	40 (4.2)	6 (0.63)	3.5 – 10.4	1.25 - 3.75

6.3.6 Potential for persistence of rabies

The most conservative estimate of K_t, or the threshold density required for rabies to persist in Australia, equals 1.0 (i.e. 1.0 foxes/km^2) (Pech and Hone 1992). All the density estimates from natal den counts both pre and post-breeding for each year exceeded this minimum by at least 0.25 foxes/km^2. This suggests that fox populations on the central tablelands of New South Wales are at a sufficient density year-round to support the persistence of rabies.

The use of either pre or post-breeding density influences $\underline{P}$, the critical proportion of population reduction or immunisation required to prevent rabies persisting (Table 6.8). For the years 2000 and 2001 it was estimated that >80% reduction would be required post-breeding as compared to less than 50% reduction before breeding. Similarly, only a 20% reduction would be required before breeding, compared to >70% following breeding in 2002. However, these values will vary since the mortality of yearlings is cumulative rather than instantaneous.

Table 6.8: Estimates of the critical proportion ($\underline{P}$) of the fox population required to be immunised or made non-susceptible to prevent persistence of rabies both pre- (K_{pr}) and post-breeding (K_{po}) densities for each year of the study period. K_t values represent the minimum and maximum from the literature (Pech and Hone 1992).

Year	Pre-breeding (K_{pr}) - post-breeding (K_{po}) fox density (foxes/km^2) from natal den density	P (K_t = 0.2)	P (K_t = 1.0)
2000 / 2001	1.9 - 5.6	0.895 – 0.964	0.474 – 0.821
2002	1.25 - 3.75	0.84 – 0.947	0.2 – 0.733

The minimum K_t value of 0.2 proposed by Pech and Hone (1992) probably too low for rabies to persist and levels of reduction required to reduce the population to this density would be difficult. The K_t of 1.0 is probably the more realistic value; other assessments for Australian agricultural areas suggest that reducing fox density to <1.0 foxes/km^2 would be sufficient (Coman *et al.* 1991; Thompson and Fleming 1994).

6.4 Discussion

6.4.1 Caveat

Identifying fox dens was simplified in the study area since other animals likely to make similar burrows (e.g. common wombat (*Vombatus ursinus*) and the European rabbit (*Oryctolagus cuniculus*)) were not present. Where these and other burrowing species are present, additional care should be taken to confirm that the burrows are indeed fox dens. Foxes leave characteristic signs of occupation making this relatively straightforward. These should be checked to confirm their identification, especially where den destruction and fumigation is used as a management tool.

6.4.2 Den location and habit

The majority of the study site was open habitat, with less than 30% of the area open woodland and riverine habitats. Foxes located dens in all habitats, but did not show any consistent preference for locating dens in any specific habitat. However, in 2002 foxes showed preference for locating dens in open woodland and riverine habitats. Previous studies are also conflicting; Storm *et al.* (1976) found a significant preference for dens located in wooded areas, whereas other studies report that open areas are preferred (Henry 1986; Hewson 1986; Nakazono and Ono 1987). The results from the current study suggest that typical agricultural lands such as those on the central tablelands are suitable for dens, but preferences for locating dens within habitats may change from year to year.

This is most likely in response to seasonal conditions. A severe rainfall deficit occurred at the study site during winter and spring 2002 (see Figure 4.1) which severely reduced the growth, and subsequent coverage and density of pasture. During this period, visibility at ground level in open areas increased dramatically, particularly where grazed by stock. These areas may have become less preferred by foxes during this period since den sites would have been more visible, offering less protection from predators and/or the elements. This would explain the preference shown for riverine and open woodland areas, where visibility would have been relatively greater during this period.

Berghout (2001) suggested that this change in preference may be due to bias in the technique used to locate dens; Storm *et al.* (1976) radio-tracked foxes to locate dens, whilst the remainder of the studies relied on visual searches. It is unlikely that the visual searches undertaken in the current study resulted in a bias towards finding dens in open areas (due to greater sightability). Less dens were located in open habitats when sightability was high (i.e. 2002), suggesting that preferences at this time were not due to any visibility bias. Additionally, where sightability was reduced, the searching protocol was increased to ensure that the search effort expended while locating dens was directly related to the sightability within each habitat. Therefore, it is unlikely that the results were significantly affected through a bias towards any particular habitat or topography in the searching protocol.

There was no preference shown for den site selection on the basis of slope or aspect. This lack of preference is in contrast with the findings of other den studies. Eide *et al.* (2001) found that arctic foxes (*Alopex lagopus*) select steeper terrain for den sites. They also preferred a southerly aspect, which provides protection from winds and thermoregulation and microclimatic advantages (Arjo *et al.* 2003). No such preference was found in this study. In colder, arctic climates these sites may offer improved microclimate conditions suitable for raising cubs. The central tablelands does not suffer from extremes of temperature (see Chapter 3) like those found in the arctic (Prestrud 1992) or desert environments (Arjo *et al.* 2003) and therefore there may be little advantage in selecting sites to improve microclimatic conditions in 'milder' environments.

Swift foxes (*Vulpes velox*) preferentially select den sites on the top of hills, probably to assist in detecting the approach of predators such as the coyote (*Canis latrans*) or to avoid flooding in lower areas (Pruss 1999). Foxes in Australia generally lack a top-order predator, although raptors may take cubs (Corbet and Harris 1991) and the wild dog/dingo (*Canis familiaris*) is known to kill both cubs and adults (Saunders *et al.* 1995). Wild dogs/dingoes are not present on the study site and likely raptorial predators, such as the wedge-tailed eagle (*Aquila audax*) are sighted only occasionally (S. Brown, "Larras Lake North", pers comm. 2003). Additionally, foxes are not actively managed through either hunting or baiting on "Larras Lake North" so pressure from predators or man is unlikely to have been a major determinant of den site location. The location of several dens close to roads, including a minor highway, also suggests that foxes appear to tolerate disturbance.

6.4.3 Den microhabitat and form

Despite there being no consistent preference for any specific habitat, slope or aspect by foxes in locating their dens, there were differences in where dens were located within habitats. Relatively more active and natal dens were situated within or adjacent to cover, such as fencelines, logs and rocks, than inactive dens. This is similar to the results of Meia and Weber (1992) who did not locate any breeding dens (n = 14) in bare earth alone, but found that all were located within root systems, rocks, or man-made dumping grounds. Other studies have noted a preference for covered areas that offer some protection from the elements (Storm *et al.* 1976; Weber 1982; Iokem 1985; Paqout and Libois 1986). Foxes may prefer to use dens that offer such protection; these sites may also be inherently more persistent and less prone to disturbance and/or destruction than those situated away from structures. Greater persistence would mean greater security and protection for the den-dwellers and an increased potential for the den to develop (i.e. through increased size, depth or complexity) into a more suitable environment for raising young.

Natal dens generally had more entrances than active or inactive dens, but this was not statistically significant. However, when pooled with active dens, natal and active dens had more entrances on average than inactive dens. Natal dens usually have more entrances than other dens (Weber 1983; Nakazono and Ono 1987). Dens with more entrances may offer cubs greater means of 'escape' into shelter (Meia and Weber 1992), may assist with ventilation and thermoregulation (Berghout 2001), or may simply be correlated to den size or age, and therefore suitability for raising cubs.

6.4.4 Fox density

The calculated densities of between 1.25 and 5.6 foxes/km^2 are similar to estimates from other den count studies undertaken in temperate grazing lands in Australia. Coman *et al.* (1991) recorded densities between 1.2 and 3.0 foxes/km^2 in temperate grazing land in central Victoria, and J. Tracey (NSW Department of Primary Industries, unpublished data) recorded

1.7 – 4.3 foxes/km^2 on the New South Wales central tablelands. It is also comparable to density estimates from similar habitats calculated by other methods; on the New South Wales northern tablelands (Thompson and Fleming 1994) visitation to sandplots both pre and post baiting (index-manipulation-index) yielded estimates of 4.6-7.2 foxes/km^2. All these estimates are generally greater than those found in other Australian habitats apart from some urban areas (e.g. city of Melbourne, 3.0-16.2 foxes/km^2: Marks and Bloomfield 1999b). However, estimates from the current study are considerably greater than those from Berghout (2001) who calculated density at between 0.55 - 1.34 foxes/km^2 and 0.52 – 1.26 foxes/km^2 in 1995 and 1996 respectively on agricultural lands at Murringo, on the southern central tablelands of New South Wales. Despite enterprise (mixed grazing) and habitat (predominantly open) being similar to this study, fewer fox dens were located by Berghout (2001). This may, simply, have been a result of overall lower fox density during the period of the searches. Spotlight counts undertaken on both sites between 1995 and 1997 show that densities are broadly similar at Murringo and Larras, although they appear to fluctuate across years (see Saunders *et al.* 2002a). The relatively higher density of foxes on agricultural lands is also supported by studies in other countries; for example density of fox breeding dens in Scotland was greater on agricultural land compared to hill forest and heathland moorland (Hewson 1986). Since fox density is related to the productivity of the environment (Saunders *et al.* 1995), the relatively high densities found on temperate agricultural lands indicate that such habitats are highly productive and capable of sustaining high density fox populations.

Nine breeding dens were found in 2000 and 2001, declining to six in 2002. Variation in pregnancy rates appears to be the primary source of changes in reproductive output of carnivores (Clark and Fritzell 1992). Therefore, the number of breeding vixens, and hence natal dens should be consistent in a stable population (Nakazono and Ono 1987), suggesting that the population at the study site is fluctuating. The decrease may be due to a decline in food abundance or prey availability (Hewson 1986; Meia and Weber 1992). A severe rainfall deficit occurred at the study site during winter and spring 2002 (see Figure 4.1), and this may have reduced the abundance of food resources, and hence reproductive performance (e.g. McIlroy *et al.* 2001). There is little evidence that mean litter size is dependent on food supply (see review by Newsome 1995), indicating that the methodology is likely to be robust in detecting changes in density even without estimates of litter size for the consecutive breeding seasons.

6.4.5 Den dispersion

Analyses of den dispersion using nearest neighbour distances revealed that natal dens were regularly distributed across the study site in 2002, but were not significantly different from random in 2000 and 2001. This generally supports the findings of other studies; natal dens in the southern central tablelands of New South Wales (Berghout 2001), urban Melbourne (Victoria) (Marks and Bloomfield 1999b) Scotland (Hewson 1986) and Japan (Nakazono and Ono 1987) were all regularly distributed. However, natal dens in a mountainous area of Switzerland were randomly distributed, probably as a result of the limited number and random dispersion of suitable sites (Meia and Weber 1992). In the current study there was no preference shown for locating dens for any habitat or terrain features (slope and aspect), suggesting that suitable sites were available across the study site. The regular spacing of natal dens is probably a result of the territorial nature of foxes (Hewson 1986), and may act to ensure resource security and/or to avoid neighbouring foxes encountering cubs (Berghout 2001).

Active dens in all years were distributed in clusters. Foxes often prepare multiple dens for use (Berghout 2001) and it is likely that the clumping of active dens represents dens sustained by each vixen for this purpose. The lack of differences between natal and active dens in this study is not surprising given the similarities of the habitats across the study site. Additionally, the potential for active dens to be used at some stage during the whelping season means that these sites, like natal dens, would be suitable for raising cubs and therefore would be likely to have similar characteristics. The likelihood that cubs were shifted between dens is unlikely to be a confounding factor for estimating density and determining habitat differences given that large areas were searched within short periods, minimising the likelihood that litters were encountered multiple times. Regardless, it indicates that a large number of den sites in the study area are suitable for raising cubs, providing further evidence that agricultural lands on the New South Wales central tablelands are highly suitable for foxes.

6.4.6 Management implications

Results from this study and others indicate that temperate agricultural lands like those on the central tablelands are highly suitable for foxes and support high-density populations. The lack of consistent preference by foxes for locating dens in any particular habitat and the dispersion of dens suggest that most habitats in these areas would be suitable for foxes to locate dens. Preferences shown by foxes for locating active and natal dens in proximity to cover means that particular attention should be paid to structures such as logs, rock piles and fencelines during searches within all habitats. Despite this, many dens, including both active and natal dens were located in open areas with no structure nearby. Therefore, undertaking searches for natal dens as a means of estimating fox density or to undertake fumigation /destruction should be done systematically to encompass all available habitats and landforms. This will ensure that the probability of detecting dens is greatest and will be less prone to under or over-estimation.

The regular distribution of natal dens on the study site suggests that there would be no benefit in laying bait in any specific habitat to 'target' natal dens sites. Rather it suggests that, to increase the probability of targeting potential activity 'focal points', baits should be laid systematically across all habitats.

The clumped dispersion of active dens indicates that, once an active den is located, the likelihood of locating additional active den/s nearby is increased. Since foxes may prepare multiple active dens for use during the cub-raising period, these dens represent likely areas to raise cubs. The mean nearest neighbour distance between active dens ranged between 86 and 164 m. Therefore, once an active den is located, searches for subsequent active dens should be concentrated in the area relatively close (less than a few hundred metres) to the location of the active den.

Foxes have been recognised as a potentially important host of rabies in southern Australia (Geering and Forman 1987; Pech and Hone 1992; Saunders 1999). If rabies were ever to be introduced into Australia, fox density on the central tablelands of New South Wales at any time of year (i.e. pre and post-breeding) appears sufficient for rabies to be maintained within the populations. Therefore, operations to reduce the proportion of susceptible individuals in the population would be required to halt the persistence of the disease.

The estimated proportion of the population to be either vaccinated or killed to stop rabies persisting (at $K_t = 1.0$) ranged from 0.2 to 0.82 depending on the year (2000/2001 and 2002), and density estimate (pre or post-breeding). A lethal rabies control strategy is probably oversimplified since it fails to account for any compensatory changes in fox reproduction, behaviour or movements that are likely to occur following culling operations (e.g. Marlow *et al.* submitted). Regardless, these figures demonstrate that a considerably smaller proportion of the population needs to be targeted to reduce the persistence of rabies pre-breeding (i.e. winter) than post-breeding (spring). Therefore, strategies to reduce the persistence of rabies in the fox population may prove to be more efficient when they are timed to coincide with pre-breeding compared to post-breeding.

Greater understanding of fox density, such as that provided in the current study may assist in understanding the impact of foxes on prey. Knowledge of fox diet (e.g. Coman 1973; Croft and Hone 1978; Palmer 1995) and nutritional requirements (see Winstanley *et al.* 2003) can be used to provide estimates of the quantity of food consumed per individual. Knowing the density of individuals can therefore assist in providing estimates of fox predation through calculating the amount of prey consumed (e.g. McLeod 2004). This technique is likely to significantly underestimate the true cost of fox predation since it fails account for surplus killing of prey (see Kruuk 1972; Chapter 3). Regardless, such assessments are valuable in highlighting the relative impact of foxes since they provide a means to quantify, economically assess, and compare the damage caused by foxes and other pests.

Assessments of fox density can be used to improve the efficiency of fox management strategies through determining if/where management is required and the appropriate level needed through objective means such as cost-benefit analyses. This is critical for the responsible and strategic management of pest animals (Braysher 1993). Accurate estimates of abundance are required for pest management programs where the progress and ultimately success or failure of the program is measured in reductions of population size (Wilson and Delahay 2001). Such measures are also important in developing strategies that are sensitive to changes in the abundance of the species to be managed (e.g. baiting strategies – see Chapter 3). Additionally, evaluating the success of such strategies in terms of the prey response relies on understanding predator-prey interactions, especially the relationship between species abundance and damage (Hone 1994; Moberly *et al.* 2004). This is difficult for species such as the fox due to deficiencies in the techniques for monitoring fox abundance. Spotlight counts are inherently inaccurate but still remain widely used (see Ruette *et al.* 2003); new techniques such as genetic fingerprinting show potential (see Kohn *et al.* 1999) but remain relatively inefficient and expensive (M. Piggott, Monash University, pers. comm. 2002). Density estimates from den counts are limited to the breeding season but remain an accurate and reliable means of estimating fox density (Trewhella *et al.* 1988). These estimates could be used to calibrate other techniques rather than comparing between abundance indices, which should be undertaken only with caution (Smith *et al.* 1984).

6.5 Conclusion

Estimating fox density through counts of natal den sites appears to be a successful technique to use in agricultural lands on the central tablelands of New South Wales. More importantly, the successful application of the technique may improve currently unreliable indices of abundance, critical to the improvement of fox management. However, factors including the coverage of baiting operations (Chapter 5), bait caching (Chapter 3) and bait longevity (Chapter 2) may influence the effectiveness of baiting operations. Additionally, other issues, such as the preparation, handling and the economic cost of using each bait type may be equally important and therefore should be considered in assessing baiting strategies.

CHAPTER 7

COST-EFFECTIVENESS OF BAITING OPERATIONS

7.1 Introduction

Strategies for managing pest animals are traditionally assessed for their effectiveness, with less consideration given to the efficiency or cost of achieving the desired effect (Hone 1994). However, the basic economic problem of limited resources and choosing between many viable options applies, by necessity, to pest management (Bicknell 1993). Economic analysis of competing options is therefore useful to aid in decision-making relating to pest control (Moberly *et al.* 2004).

The management of foxes on agricultural and conservation lands in Australia relies heavily on poison baiting (see Chapter 1). A survey of New South Wales Rural Lands Protection Boards (RLPBs) in 2002 indicated that baiting was the most popular control technique for foxes, amounting to 74% of control effort (West and Saunders 2003). Foxoff® was the most common bait type used in New South Wales, comprising over 48% of baits used in 2001. Ten percent of RLPBs used baited chicken wingettes by 2001, despite this bait type being introduced only in 1998. When respondents were asked to rank the most effective bait types, the perceived effectiveness of most bait types closely matched their proportional use. For example, 10% of respondents perceived wingettes to be the most effective bait type, matching the percentage of the respondents who used wingettes. However, Foxoff® was used by 48% of all respondents, but was perceived to be the most effective bait type by only 27% of respondents (West and Saunders 2003). This suggests that other factors may be important in the decision to use Foxoff®, apart from perceived effectiveness. These may include the cost-effectiveness of the bait, its extended shelf and field longevity, or the lack of costs in bait preparation and handling that are associated with the 1080 injection process required for fresh bait types.

Ideally, the costs and benefits of undertaking fox baiting should be assessed to determine if control is worthwhile; i.e do the benefits of control exceed the costs? In many cases, due largely to lack of data and inadequate modelling of density:damage relationships, the benefits from reducing fox density are not easily quantified, or cannot be reliably estimated and parameterised (see Greentree *et al.* 2000). Additionally, many outcomes from particular inputs and strategies are not always economically quantifiable (Moberly *et al.* 2004). It is therefore difficult to use cost-benefit techniques to perform an economic analysis of baiting practices. The level of input spent on management programs is generally easier to quantify than the benefit derived; where the benefits from undertaking control cannot be easily estimated, strategies should be assessed on the cost required to achieve a given level of output. Such assessments can be termed cost-effectiveness analyses.

Cost-effectiveness analysis is one measure that can be used to compare the efficiency of different methods of control (Hone 1994). Rather than using cost-benefit analysis to quantify and subsequently assess the need to undertake an objective, cost-effectiveness analysis is used primarily to determine the least expensive way to meet the objective (Bicknell 1993). Given that fox baiting is commonly undertaken on agricultural and conservation land for protection of susceptible prey (see Chapter 5), cost-effectiveness analysis would be a suitable means to economically assess the choice of baiting strategy to be used within these campaigns.

Factors such as the bait type, density, longevity and uptake together with bait placement, presentation technique, duration of placement, and replacement strategy all influence the efficiency and effectiveness of a baiting campaign. It is beyond the scope of this chapter to explore all possible combinations of these factors. However, aspects of baiting including bait longevity (Chapter 3), bait caching and palatability (Chapter 4) will influence the characteristics of baiting campaigns and ultimately their cost-effectiveness. Additionally, since the objective of baiting operations is to reduce fox density, the ultimate measure of effectiveness would be to assess the cost per fox removed.

This chapter assesses the cost-effectiveness of using different bait types in central-western New South Wales based on their relative cost, longevity and palatability. Although these data were collected in this region the analyses have obvious applications to similar regions across New South Wales and Australia. These issues are investigated to determine the most appropriate strategy for practitioners, depending on the duration of the baiting campaign and the relative importance of other issues. Such issues include the ease of use, the relative storage, handling and replacement required and non-target or environmental concerns associated with the longevity and caching of bait material. This case study approach is used to develop a preliminary decision tree model to assist practitioners to choose the most appropriate strategy for use in typical conditions encountered in the central tablelands environment.

7.2 Methods

7.2.1 Bait types - Description

Foxoff® is commercially manufactured by Animal Control Technologies Pty Ltd (Somerton, Victoria). The precise formulation is known only to the manufacturer but it appears to be a mix of meatmeal and animal fat (tallow) with some attractants. It is available in two sizes, 60 g (Foxoff®) and 35 g (Foxoff® Econobait). The Foxoff® Econobait (hereafter known as Foxoff®) is by far the most popular and is usually the type sold by RLPBs in New South Wales (C. Lane, RLPB State Council, pers. comm. 2003). Foxoff® may be purchased in any quantity from the RLPB; since it is packaged in trays containing 30 baits, purchases are usually comprised of single or multiple trays.

Day-old chicks are produced by poultry hatcheries for either layer or meat chicken production. Those that are external to requirements (usually males) are culled, as are those with deformities, poor health or general condition. Despite their name, day-old chickens may be culled up to several days after hatching. The majority of these are destroyed but some are frozen and sold for pet food, especially for feeding reptiles (e.g. snakes). Day-old chicks usually weigh between 40 and 60 g.

Chicken wingettes (hereafter known as wingettes) are the wings of meat chickens and are sold separately for the catering industry. Wingettes are the entire chicken wing with the shoulder (drummette) removed. Wingettes weigh 40-80 g, depending on the breed and condition of the processed bird.

7.2.2 Bait preparation

In NSW only licensed authorities may purchase commercially manufactured bait directly from the manufacturer. These authorities are usually RLPBs, although in certain circumstances, conservation agencies (such as NSW Department of Environment and Conservation) may have the authority to purchase Foxoff® directly from the manufacturer for use on crown land. Private landholders may purchase or receive baits only from a licensed authority, and this is usually from a RLPB.

7.2.3 Costs

The cost of bait is dependent upon whether it is purchased wholesale (i.e. by the RLPB) or retail (by the consumer, i.e. landholder). Therefore the wholesale price of bait mostly represents the actual purchase cost of the material while the retail price accounts for additional storage costs, production costs and profit associated with selling the bait. RLPBs purchase the bait (Foxoff®) or bait substrate (freshly prepared bait type) and are responsible for selling bait to landholders.

For consistency, prices used in the analyses below are all current 2004 (July) prices used by the Molong RLPB. Where Goods and Services Tax (GST) applies all costs are given inclusive of GST.

7.2.3.1 Bait type

Foxoff® costs $0.88 per bait when purchased (at wholesale prices) as part of a ‘Farmpack’. Foxoff® is purchased as a ready-to-use product and is 1080- impregnated. Foxoff® typically retails for $1.00 per bait to contribute towards the storage and distribution costs (C. Lane, RLPB State Council, pers. comm. 2003 and C. Somerset, pers. comm. Molong RLPB 2004).

Day-old chicks cost $0.20 per unit (wholesale). Wingettes are sold by weight; depending on the weight of each unit (~40-80 g) the cost of each wingette varies between $0.125 and $0.25. I used a mean cost of $0.19 per unit in the analyses here.

As fresh-prepared baits, day-old chicks and wingettes must be injected with 1080. 1080 solution is relatively cheap but the time and labour costs involved in storage, preparation and distribution of these bait types can be considerable. As a result, RLPBs typically sell wingettes for approximately $0.60 per unit to assist in covering these costs (C. Somerset, pers. comm., Molong RLPB 2004). Day-old chicks are not a registered bait type and therefore no sale prices are available. However, given that the wholesale purchase price of day-old chicks is similar to wingettes, $0.60 per unit would be a reasonable estimate.

7.2.3.2 Bait longevity - cost per day

The 1080 in bait can be lost through the contribution of one or more of the following:

- defluorination by bacteria, fungi and other microbes,
- leaching by rainfall,
- consumption by sarcophagous insects, or
- conversion to inorganic fluoride compounds

(Korn and Livanos 1986; Kramer *et al.* 1987; McIlroy and Gifford 1988; Fleming and Parker 1991; Saunders *et al.* 2000; Twigg and Socha 2001; this study).

The rate of decline or degradation of 1080 and the subsequent period that baits remain lethal to foxes vary with these factors and bait type (see Chapter 3). Bait must remain toxic for long enough to ensure that resident foxes will find and consume a lethal dose. If bait degrades too rapidly for foxes to have this opportunity, it may reduce the efficacy of the baiting program (see Chapter 2). Additionally, reduced longevity would require bait to be replaced more often in continuous baiting programs, thus reducing cost-effectiveness.

The cost-effectiveness in terms of the cost of presenting lethal bait per day is a useful comparative measure between specific bait types. With knowledge of the estimated lethal lifespan (i.e. period that bait retains at least 0.65 mg 1080, approximate LD_{50} for a 5 kg fox) (see Chapter 2) and unit cost of bait, the mean cost per day that a specific bait type would remain lethal to foxes can be estimated. Incorporating both the wholesale and retail bait prices represents the cost to conservation agencies and landholders respectively. This effectively standardises how much it costs to present lethal bait (of each bait type) per day. A comparison of this figure between bait types can determine the relative cost of using the bait types.

7.2.3.3 Baiting campaigns – bait uptake and bait replacement

Baiting campaigns are usually undertaken for 1-3 weeks (see Chapter 5), dependent on the practitioner's preferences. Bait should be retrieved or replaced before the 1080 content reaches sub-lethal doses. Results from degradation trials indicate that the longevity of bait varies with the type of bait (Chapter 3). Therefore, the type of bait used in a baiting campaign will determine the period after which it should be replaced. Taking this into account, the number of baits for each of the bait types to be replaced during baiting campaigns lasting from one to four weeks will be estimated using the degradation data.

The total purchase cost of the bait used in baiting campaigns is derived from the per unit bait price and the number of baits required. The purchase price of bait is more or less fixed by the supplier (RLPB) but it does increase periodically following the price of raw materials (C. Somerset, Molong RLPB, pers. comm. 2004). The number of baits required will depend on the number of baits initially laid, the duration of the baiting campaign, and the number of baits removed during the campaign if a replacement baiting strategy is used.

The number of baits initially laid in a baiting campaign again depends on the personal preferences of the practitioner and is usually determined by the size of the area to be protected. The mean number of baits used per campaign in the Molong RLPB between 1998 and 2002 was 42.9 but was highly variable (SD = 38.5). Regardless, the mean (43 baits) will be sufficient for the purposes of this analyses.

Replacement baiting is one practice that will influence the number of baits used per campaign. Replacement baiting is where baits are checked regularly (usually at 2-5 day intervals) and fresh bait is laid when bait is taken. If baiting programs continue for extended periods, 'old' bait is also removed and replaced with fresh bait. The rate of bait take will directly affect how many baits need to be replaced as they degrade to contain sub-lethal doses. To determine the effect that bait take and replacement baiting may have on the need to retrieve and replace bait, I simulated the number of baits that need to be replaced for a baiting campaign. Each simulation used an initial number of baits laid (43), a variable rate of bait uptake (10, 25 or 50% of available baits), checking/replacing interval of 3-4 days and variable duration of the baiting campaign (1, 2, 3 or 4 weeks) to estimate the number of baits of each bait type that need to be replaced. This allowed me to estimate the effect that these variables (bait type, bait uptake, and duration of the baiting campaign) have on the number of baits that need to be replaced and, therefore, the relative cost of the campaign using each bait type.

7.2.3.4. Bait consumption – relative cost per bait consumed

The costs of presenting lethal bait (per day) for each bait type is useful to compare the costs of presenting bait in terms of longevity, but it does not account for the palatability of the bait. Specific bait types may rank highly in terms of cost vs. longevity, but this will mean little if the bait is unpalatable to the target species. Therefore, any assessment of the relative cost-efficiency of the different bait types should also consider bait palatability.

To incorporate this aspect, it is necessary to have meaningful data on the palatability of the bait types. As palatability is related (inversely) to caching (Van Polanen Petel *et al.* 2001), the data collected as part of the caching study (Chapter 4) were used to indicate the relative palatability of the bait types. Thus the percentage of each bait type consumed from those removed in the toxic trials was compared to the purchase cost of the bait to determine the relative cost-effectiveness of the bait types on a cost per bait consumed basis.

Results from the caching trials (see Chapter 4) indicate that the bait type significantly influences whether the bait will be eaten or cached when taken. In the non-toxic bait trials, there were significant seasonal peaks in caching within study sites but the relationship was not consistent (or significant) across both sites. Since toxic caching trials were not undertaken in all seasons, the percentage of baits (of each bait type) that are consumed was assumed to be consistent across all seasons; the percentage of each bait type taken that was cached was assumed to be the mean from the toxic trials. This is a reasonable assumption given the lack of seasonal differences in caching on the non-toxic trials.

7.2.3.5 Bait procurement and distribution costs

The time (labour) and travelling (vehicle) costs associated with purchasing, laying, checking, replacing and retrieving should be considered when assessing the cost of using different bait types. To purchase bait, the landholder must travel to his/her local RLPB. This represents both a travel (vehicle) cost and time (labour cost), which is largely dependent on the distance that must be travelled. These costs are termed as off-site costs since they are incurred largely whilst travelling off the baiting site. Once the baits have been procured, the travel and time required to lay baits will depend on the placement strategy and the distance travelled whilst laying baits. Checking, replacing and retrieving baits also entail travelling and time costs on the baiting site; these are termed on-site costs.

Given that the time and labour required for laying and checking each bait type will be very similar for each bait type, I assumed that the on-site costs associated with these activities would be the same. However, there are differences in the time it may take to replace bait where there is a disproportionate number of baits of one type needing to be replaced (i.e. day-old chicks and wingettes degrade at a faster rate than Foxoff® and therefore must be replaced more frequently). Therefore, an extra labour cost was added in recognition of the additional time needed to replace degraded bait during checking/replacing occasions. Where appropriate, these differences were quantified by adding extra time (labour cost) to the on-site costs.

The slight difference between replacing a disproportionate number of degraded baits of one bait type in the on-site costs may be compounded by the additional off-site costs required to procure the replacement bait. Foxoff® bait may be legally stored for up to 4 weeks after purchase of the bait (Environmental Protection Authority 2002), enough for most baiting campaigns. But the fresh bait types can only be stored temporarily under refrigeration for a few days (<5) before bait spoils. If any additional wingette or day-old chick baits were required throughout the campaign after this period, then these must be purchased.

Here, I estimate the cumulative number of trips required for the procurement of bait (off-site costs) and the physical replacement of bait (on-site costs), together with the travelling and time costs associated with these trips. Each simulation uses the time and travelling costs estimated for typical baiting campaigns (durations of 1, 2, 3 or 4 weeks and checking/replacement interval of 3-4 days). The on-site costs of time (labour) and travelling (vehicle) for laying and checking bait (with or without replacing degraded bait) are calculated through estimating the time (in hours) and distance travelled (km) for a standard baiting campaign (43 baits). Travel costs are calculated from the total running costs per kilometre for a diesel 4WD. Labour cost are based on the gross hourly wage of an agricultural labourer. The off-site costs of time (labour) and travelling (vehicle) for procuring bait from the RLPB are largely dependent on the distance the practitioner must travel to reach the RLPB. This distance is calculated by averaging the minimum and maximum distance that practitioners must travel within the Molong RLPB to procure bait. The additional labour time required at different rates of bait uptake was not considered important since it would represent an additive cost consistent for all bait types.

7.2.3.6 Total campaign costs and cost per bait consumed

When assessing the cost-effectiveness of different strategies, it is important to account for both the cost of bait purchase and the cost of bait procurement and usage. The total costs of undertaking a baiting campaign will depend on the number of baits used, campaign duration, checking and replacement strategy and bait procurement and distribution costs. The cumulative cost of the bait used was derived from the number of baits that are removed or degraded, at given bait uptake rates (10, 25, and 50%) and campaign durations (7, 14, 21 and 28 days) (see Section 7.2.3.3). The travelling and time expenses were calculated from the total labour and vehicle cost associated with procurement and distribution/usage of bait (Section 7.2.3.5). The total of these costs were compared for the different bait types.

When the total costs of undertaking a campaign are compared to the number of baits consumed (Section 7.2.3.4), the total cost per bait consumed can be calculated. This is perhaps the most useful measure of cost-effectiveness since it accounts for the total economic costs incurred per bait consumed. These costs are calculated for given bait uptake rates and campaign durations for each bait type.

Sensitivity analyses

The results of sections *7.2.3.2* to *7.2.3.4* will vary depending on the purchase cost of the bait. Thus, sensitivity analyses were undertaken to examine how resistant the above relationships were to fluctuations in the purchase price. In each case, I evaluated the percentage increase/decrease in the purchase price of the each bait type that was required to alter the observed relationships among bait variables.

Sensitivity analyses were not undertaken for the bait procurement and distribution costs because fluctuations in these costs would only affect the absolute values and not the relationships between the variables.

7.2.4 Decision tree analyses

Decision trees provide a highly effective technique to assist in decision making processes. They present the problem in a clear, objective manner so the options and the consequences of each option can be identified and compared (Buzan 1993). Decision tree analyses are especially suited to problems that require the best alternative to be chosen quickly, while still considering all the known advantages and disadvantages (Schuyler 2001).

The basis of the decision tree presented here is to provide a conceptual model of what factors should be considered in undertaking baiting campaigns (regionally specific but with obvious application elsewhere). The following results, together with other considerations, are presented to determine the optimal baiting strategy for a given situation.

7.3 Results

7.3.1 Bait longevity - cost per day

On the NSW central tablelands and western slopes, Foxoff® baits remain lethal to foxes for an average of 2.1 weeks (14.7 days) after burial, with 95% remaining lethal for at least 1.0 weeks (7 days) and 95% degrading to below sub-lethal levels by 5.0 weeks (35 days). Wingettes degrade at a faster rate, retaining 0.65 mg 1080 for a mean of only 1.1 weeks (7.7 days), with

95% remaining lethal for 0.5 weeks (3.5 days) and 95% becoming sub-lethal after 1.8 weeks (12.6 days) (see Table 3.9, Table 7.1).

No data are currently available on the degradation rate and expected lifespan of 1080- injected day-old chicks. Given that they are the same substrate (chicken) as wingettes it is not unreasonable to assume that the expected lifespan is similar. Day-old chicks could potentially last longer as their lack of abattoir processing may reduce bacterial contamination (see Adam and Moss 1995). Alternatively, they may last for shorter periods given that bacterial processes within their contained digestive tract may accelerate breakdown. Under most trial conditions they appear to remain structurally viable for similar periods as wingettes (M. Gentle pers. obs.). Therefore, in the absence of actual estimates, data relating to wingettes will be applied here to day-old chicks. However, where cost data are indentical only data for wingettes shall be presented.

The retail cost, or the price that landholders pay when purchasing baits from the RLPB, ranges between \$0.60 and \$1.00 for each wingette and Foxoff® bait, respectively. Day-old chicks would cost an estimated \$0.60 each. Using the retail cost and the mean period that each bait type would remain lethal to foxes (rounded to the earlier whole day), the average cost per day for Foxoff® baits during the period they remain lethal is 7.1 cents (see Table 7.1). However, the cost ranges between 2.9 and 14.3 cents depending on whether the bait remains lethal for 35 or 7 days, respectively. Wingettes and day-old chicks are estimated to be more expensive, costing on average 8.6 cents for each day that they remain lethal to foxes.

Based on the wholesale purchase price, by contrast, the mean cost per day to present wingettes (2.7 cents) and day-old chicks (2.8 cents) is considerably cheaper than Foxoff® (6.3 cents).

Table 7.1: The cost per day (cents) for the period that Foxoff®, wingettes and day-old chicks remain lethal to foxes (i.e. containing >0.65 mg 1080). For comparative purposes, the cost per day ($) for a baiting program using 43 baits is shown for both retail [R] and wholesale [W] prices.

Bait type	Bait cost [retail/wholesale]	Days >0.65mg 1080 (95% CI)	Cost day^{-1} (cents) (95% CI)	Cost per day per program using 43 baits (95% CI)
Foxoff®	$1.00 [R] $0.88 [W]	14.7 (7.0 – 35.0)	7.1 (14.3-2.9) 6.3 (12.6-2.5)	$3.05 ($6.15-$1.25) $2.71 ($1.08-$5.42)
Wingette	$0.60[R] $0.19[W]	7.7 (3.5 – 12.6)	8.6 (20.0-5.0) 2.7 (6.3-1.5)	$3.70 ($8.60-$2.15) $1.16 ($2.71-$0.65)
Day-old chick	$0.60[R] $0.20[W]	7.7 (3.5 – 12.6)	8.6 (20.0-5.0) 2.8 (6.6-1.6)	$3.70 ($8.60-$2.15) $1.20 ($2.84-$0.69)

Records from Molong RLPB indicate that the average number of baits used in baiting campaigns between 1998 and 2002 was 42.9 (Table 5.1). This equates to a retail cost per day for undertaking an average baiting campaign (i.e. 43 baits) of $3.70 for wingettes and day-old chicks and $3.05 for Foxoff®. For wholesale, the price differential is reversed.

Sensitivity analyses

Using the mean cost per day, a retail price increase of 20% (to $1.20) would be required before Foxoff® became as cost-effective as the fresh bait types. Alternatively the retail price of wingettes or day-old chicks would have to fall by greater than 17% (to 49 cents) to become more cost-effective than using Foxoff.

Based on wholesale prices, Foxoff® would have to fall to 50 cents, a 43% reduction, to become equal to or more cost-effective as the fresh-bait types. Alternatively, the price of wingettes and day-old chicks would have to increase to greater than 44 cents per unit (>132% rise) to match the cost-effectiveness of Foxoff®.

7.3.2 Baiting campaigns – bait uptake and bait replacement

The number of baits needing to be retrieved and replaced before degrading to sub-lethal levels would vary depending on the bait type and the duration of the campaign (see Table 7.2). Foxoff® baits need to be replaced about every 14 days; a three-week campaign would not require bait replacement until day 14. Once replaced, these baits would remain toxic until day 28. Consequently, campaigns lasting for 1-2 weeks do not require any bait to be replaced on the basis of degradation. Replacing baits at the end of a 14 day period should suffice for both 3 week and 4 week campaigns. In contrast, wingettes and day-old chicks should be replaced every 7 days; baiting campaigns that last over one week would require baits from the previous week to be replaced. Therefore the number of wingette and day-old chick baits needs to increase in weekly increments.

Table 7.2: The cumulative number of baits required during an average baiting campaign (43 bait stations) lasting 7, 14, 21 and 28 days. The cumulative retail [R] and wholesale [W] costs of the bait material are also shown for comparative purposes.

Bait type	Mean days >0.65 mg 1080	Duration of campaign and cumulative number of baits used			
		7 days	14 days	21 days	28 days
Foxoff®	14.7	43 $43 [R] $37.84 [W]	43 $43 [R] $37.84 [W]	86 $86 [R] $75.68 [W]	86 $86 [R] $75.68 [W]
Wingette	7.7	43 $25.80 [R] $8.17 [W]	86 $51.60 [R] $16.34 [W]	129 $77.40 [R] $24.51 [W]	172 $103.20 [R] $32.68 [W]
Day-old chick	7.7	43 $25.80 [R] $8.60 [W]	86 $51.60 [R] $17.20 [W]	129 $77.40 [R] $25.80 [W]	172 $103.20 [R] $34.40 [W]

Where practitioners replace baits that are removed in addition to those that are sub-lethal the number of baits used increases (Table 7.3). As a demonstration, the number (Fig 7.1) and relative cost (Table 7.3) of using each bait type that needs to be retrieved during replacement baiting (every 3-4 days) is presented for given campaign durations (1-4 weeks) and rates of bait take (10, 25, 50%).

Table 7.3: The cumulative number of baits required to undertake baiting and replace degraded or removed baits during a baiting campaign (43 bait stations) lasting 7, 14, 21 and 28 days at 10, 25 and 50% bait uptake rates. The cumulative retail prices of the bait material are also shown for comparative purposes.

		Duration of campaign			
	Bait type	7 days	14 days	21 days	28 days
Cumulative number of baits used at bait uptake rates of (10%), {25%}, (50%) respectively and when baits are replaced every 3-4 days	Foxoff®	47.3 {53.8} (64.5)	55.9 {75.3} (107.5)	95.5 {113.8} (154.5)	109.8 {142.1} (200.2)
	Wingette	47.3 {53.8} (64.5)	94.2 {105.5} (123.6)	140.8 {156.1} (181.4)	187.2 {206.0} (238.9)
	Day-old chick	47.3 {53.8} (64.5)	94.2 {105.5} (123.6)	140.8 {156.1} (181.4)	187.2 {206.0} (238.9)
Cost of bait used – retail price = [R] *wholesale price* = [W]	Foxoff® [R] =$1 [W] = $0.88	$47.30 {$53.80} ($64.50) *$41.60* *{$47.34}* *($56.76)*	$55.90 {$75.30} ($107.50) *$49.19* *{$66.26}* *($94.60)*	$95.50 {$113.80} ($154.50) *$84.04* *{$91.04}* *($135.96)*	$109.80 {$142.10} ($200.20) *$96.62* *{$125.05}* *($177.94)*
	Wingette [R] = $0.60 [W] = $0.19	$28.38 {$32.28} ($38.70) *$8.99* *{$10.23}* *($12.25)*	$56.52 {$63.30} ($74.16) *$17.90* *{$20.05}* *($23.48)*	$84.48 {$93.66} ($108.84) *$26.75* *{$29.66}* *($34.47)*	$112.32 {$123.60} ($143.34) *$35.58* *{$39.14}* *($45.93)*
	Day-old chick [R] = $0.60 [W] = $0.20	$28.38 {$32.28} ($38.70) *$9.46* *{$10.76}* *($12.90)*	$56.52 {$63.30} ($74.16) *$18.84* *{$21.10}* *($24.72)*	$84.48 {$93.66} ($108.84) *$28.16* *{$31.22}* *($36.28)*	$112.32 {$123.60} ($143.34) *$37.44* *{$41.20}* *($47.78)*

Relatively more wingettes or day-old chicks than Foxoff® would be required during a replacement baiting program at all levels of bait uptake and campaign duration. However, as for a non-replacement baiting program over seven days the most cost-effective bait alternates every week (retail prices) (Table 7.3). Over a 7 day campaign, the cost of using Foxoff® is more expensive than the two fresh meat baits but over a 14 or 28 day campaign the difference between using these bait types is negligible. However, based on the wholesale cost of purchasing the bait substrate it is more cost-efficient to use wingettes and day-old chicks than Foxoff® over all time periods.

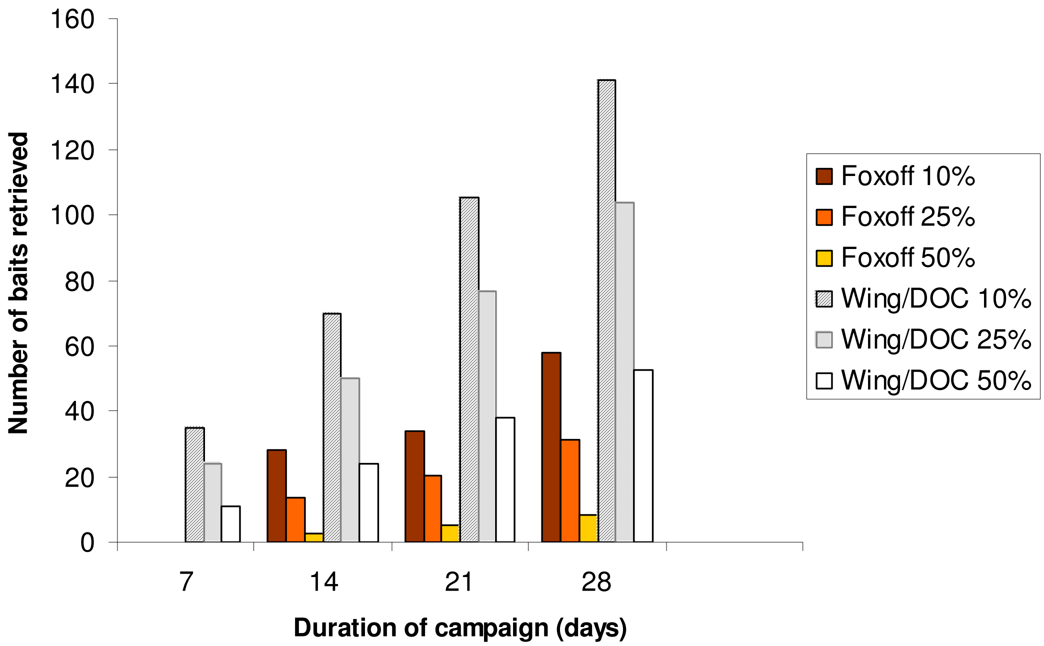

Figure 7.1: The cumulative number of baits needing to be retrieved during a replacement baiting program (43 baits laid and checked/replaced every 3-4 days) at bait uptake rates of 10, 25 and 50% (4.3, 10.75 and 21.5 baits, respectively removed every 3-4 days). DOC = day-old chick, Wing = wingette.

Sensitivity analyses

Based on retail prices, for baiting periods lasting 7 days or less, at all levels of bait uptake, it would cost an extra 66% of the fresh bait purchase price to use Foxoff®. Over a 14 day campaign Foxoff® baits are less expensive, although the margin is slim (1.1% of Foxoff® cost). This margin increases to 19% and 45% though, as the rate of bait uptake increases (25 and 50% respectively). The same relationship occurs after 21 and 28 days; the additional cost of using Foxoff® relative to the fresh bait types is 13.0, 21.5 and 42% for 10, 25 and 50% uptake levels, respectively, for a 21 day campaign. Over 28 days Foxoff® is cheaper by 2.2, 15 and 39.7% for 10, 25 and 50% uptake rates, respectively.

Regardless of campaign duration and rates of uptake it is always more cost-effective to use wingettes (>172% saving) or day-old chicks (>158% saving) than Foxoff® based on wholesale prices.

7.3.3 Bait consumption – relative cost per bait consumed

In the toxic bait caching trials, significantly more Foxoff® baits (74.3%) were cached when taken by foxes compared to day-old chicks (26.2%) and wingettes (43.1%). Given that there was no significant difference between the percentage of day-old chicks and wingettes cached, the percentages of these two bait types cached were pooled (35.5%). The percentage of toxic cached baits that was subsequently recovered averaged only 13.6% and was not significantly different between the bait types (Chapter 4). Accounting for this, the mean percentage of day-old chicks/wingette and Foxoff® baits that were eaten after being taken was 69.4% and 35.8% respectively. This equates to only one Foxoff® bait being consumed from approximately every 2.8 Foxoff® baits removed. Wingettes and day-old chicks require only 1.4 baits to be removed for every bait consumed (Table 7.4).

Table 7.4: The mean percentage of Foxoff®, wingette and day-old chick baits consumed from those taken in the toxic bait trials and the cost of each consumed bait relative to those that were taken.

Bait type	Bait cost [R = retail, W = wholesale]	Mean percentage of baits eaten (cached)	Number of baits taken for 1 to be consumed	Cost $bait^{-1}$ consumed from those taken
Foxoff®	$1.00 [R] $0.88 [W]	35.8 (64.2)	2.79	$2.79 $2.46
Wingette	$0.60[R] $0.19[W]	69.4 (30.6)	1.44	$0.86 $0.27
Day-old chick	$0.60[R] $0.20[W]	69.4 (30.6)	1.44	$0.86 $0.29

Based on the retail cost of purchasing bait, an estimated \$2.79 worth of Foxoff® baits is taken for every bait consumed. This is more than three times the cost of using wingettes or day-old chicks, which require only \$0.86 worth of bait to be taken for every bait consumed. Based on the wholesale prices, Foxoff® (\$2.46) is even more expensive relative to wingettes and day-old chicks (\$0.27 and \$0.29, respectively).

7.3.4 Baiting campaigns - cost of bait consumed

The above calculations demonstrate that differences in the purchase cost and palatability between bait types can considerably affect the cost per bait consumed. However, the duration of the baiting campaign and 'lethal longevity' of bait will affect the need to replace bait, and therefore the cost. The rate of bait uptake will also affect the number of baits that need to be replaced; high levels of bait uptake will mean that fewer degraded baits need to be replaced. In consideration of this issue, the numbers of baits that are consumed for the number of baits taken for a given campaign duration (1-4 weeks) at 10, 25 and 50% bait uptake rates (from Table 7.3) are shown in Table 7.5.

Table 7.5: The cumulative number of baits consumed during a baiting campaign (43 baits) lasting 7, 14, 21 and 28 days at 10, 25 and 50% bait uptake rates (e.g. 10% of baits consumed during each checking period). The cumulative retail and wholesale prices of the bait material are also shown for comparative purposes.

		Duration of campaign			
	Bait type	7 days	14 days	21 days	28 days
Cumulative number of baits consumed at bait uptake rates of 10%, {25%}, (50%) respectively when 43 baits are initially laid and baits are checked/replaced every 3-4 days	Foxoff®	3.16 {7.91} (15.82)	7.70 {15.39} (30.79)	11.55 {23.1} (46.18)	15.40 {30.79} (61.6)
	Wingette	5.97 {14.92} (29.84)	11.94 {29.84} (59.68)	17.91 {44.76} (89.53)	23.87 {59.68} (119.37)
	Day-old chick	5.97 {14.92} (29.84)	11.94 {29.84} (59.68)	17.91 {44.76} (89.53)	23.87 {59.68} (119.37)
Cost per bait consumed – retail price = [R] *wholesale price* = [W]	Foxoff® [R] =$1	$14.96 {$6.80} ($4.08)	$7.26 {$4.89} ($3.49)	$8.27 {$4.93} ($3.35)	$7.13 {$4.62} ($3.28)
	[W] = $0.88	$13.16 {$5.98} ($3.59)	$6.39 {$4.31} ($3.07)	$7.28 {$4.34} ($2.95)	$6.27 {$4.07} ($2.89)
	Wingette [R] = $0.60	$4.75 {$2.16} ($1.30)	$4.73 {$2.12} ($1.24)	$4.72 {$2.09} ($1.22)	$4.70 {$2.07} ($1.20)
	[W] = $0.19	$1.50 {$0.69} ($0.41)	$1.50 {$0.67} ($0.39)	$1.49 {$0.66} ($0.39)	$1.49 {$0.66} ($0.38)
	Day-old chick [R] = $0.60	$4.75 {$2.16} ($1.30)	$4.73 {$2.12} ($1.24)	$4.72 {$2.09} ($1.22)	$4.70 {$2.07} ($1.20)
	[W] = $0.20	$1.58 {$0.72} ($0.43)	$1.57 {$0.71} ($0.41)	$1.57 {$0.70} ($0.40)	$1.56 {$0.69} ($0.40)

The cost per bait consumed is calculated from the number of baits required to present lethal bait during each campaign length, considering bait longevity and replacement for the given uptake rates.

When the number of baits consumed and cost per bait consumed for a given uptake are considered, there is a major discrepancy between the fresh meat types and Foxoff®. Foxoff® baits cost more than wingettes/day-old chicks for all campaign durations and rates of bait uptake. The difference between using Foxoff® and the fresh meat baits is greater for campaigns lasting 7 days or less.

The cost per bait consumed decreases with increasing rates of bait uptake; this is simply due to increased numbers of baits being consumed and the reduced cost of replacing degraded baits that are not consumed.

7.3.5 Bait procurement and distribution costs

Each trip on-site for a baiting campaign using 43 bait stations would require travelling approximately 19 km to accommodate bait stations spaced at 200-300 m intervals, including a travelling distance to reach the baiting locations within the site. Laying bait is more labour intensive than checking (without replacing degraded) bait, with approximately 5.5 hours needed compared to 3.5 hours respectively. When checking bait, an estimated 30 minutes additional time would be needed to replace degraded bait compared with periods when only removed bait is replaced (M. Gentle pers. obs.). The cost of these parameters was then estimated from labour and total vehicle running costs (see Table 7.6).

Landholders would have to travel on average between 5 and 95 km (one-way) to obtain baits from the Molong RLPB (i.e. offices in Molong and Peak Hill) (see Figure 5.1). Given the even distribution of landholders across the board district, I chose a total travelling distance of 95 km per trip (47.5 km each way) as an appropriate compromise. The total time to travel this distance, and collect bait from the RLPB would total approximately 1.5 hours. The costs estimated from these parameters are estimated in Table 7.6.

Table 7.6: Cost of parameters associated with one trip for either procurement (off-site) or use (on-site) of baits for a baiting program (43 baits).

		Travelling cost			Labour cost			
Task	Cost class	Vehicle cost (per km)	Distance travelled (km)	Total	Time (h)	Hourly rate	Total	Total cost
Laying bait	On-site	$0.7196	19	$13.67	5.5	$14.44	$79.42	$93.09
Procuring bait	Off-site	$0.7196	95	$68.36	1.5	$14.44	$21.66	$90.02
Checking (replace degraded)	On-site	$0.7196	19	$13.67	4.0	$14.44	$57.76	$71.43
Checking (degraded not replaced)	On-site	$0.7196	19	$13.67	3.5	$14.44	$50.54	$64.21

Sources: Vehicle costs based on the total average running cost for a diesel 4WD (Nissan Patrol) (National Road and Motoring Association 2004). The labour cost hourly rate is based on that of an agricultural/horticultural labourer (Australian Bureau of Statistics 2002).

The costs of each task based on the labour and travel costs (from Table 7.6) were assessed based on the cumulative tasks required for each bait type when undertaking baiting campaigns for 7, 14, 21 and 28 days duration (see Table 7.7).

Table 7.7: The cumulative number of trips required to undertake baiting and replace degraded or removed baits on the baiting site (on-site) and to purchase fresh bait from the RLPB (off-site) for a baiting campaign (43 bait stations) lasting 7, 14, 21 and 28 days when baits are replaced every 3-4 days. The cumulative prices of the travelling and labour costs and their totals are also shown for comparative purposes. Note: data for day-old chicks are not presented but are identical to wingettes.

		Duration of campaign			
	Bait type	7 days	14 days	21 days	28 days
Cumulative number of trips on-site and [off-site]	Foxoff®	3 [1]	5 [1]	7 [1]	9 [1]
	Wingette	3 [1]	5 [2]	7 [3]	9 [4]
Cumulative labour cost of trips on-site and [off-site]	Foxoff®	$180.50 [$21.66]	$281.58 [$21.66]	$389.88 [$21.66]	$490.96 [$21.66]
	Wingette	$180.50 [$21.66]	$288.80 [$43.32]	$397.10 [$64.98]	$505.40 [$86.64]
Cumulative vehicle cost of trips on-site and [off-site]	Foxoff®	$41.01 [$68.36]	$68.35 [$68.36]	$95.69 [$68.36]	$123.03 [$68.36]
	Wingette	$41.01 [$68.36]	$68.35 [$136.72]	$95.69 [$205.08]	$123.03 [$273.44]
Cumulative labour and vehicle cost on-site, [off-site] and **Total cost**	Foxoff®	$221.51 [$90.02] **$311.53**	$349.93 [$90.02] **$439.95**	$485.57 [$90.02] **$575.59**	$613.99 [$90.02] **$704.01**
	Wingette	$221.51 [$90.02] **$311.53**	$357.15 [$180.04] **$537.19**	$492.79 [$270.06] **$762.85**	$628.43 [$360.08] **$988.51**

The cumulative number of trips required on-site is the same for all bait types for a given campaign duration. For campaigns of up to 7 days duration only one trip off-site to the RLPB is required for all bait types. However, accounting for the need to replace the fresh bait types every 7 days, an additional off-site trip is required to procure this bait every week for campaigns over 7 days duration. This is not required for Foxoff® since it is shelf-stable and may be stored (legally) for up to one month from purchase. Therefore, for campaigns up to 4 weeks duration only one off-site trip is required for Foxoff® compared to four for the wingettes and day-old chicks.

These differences are reflected in the travelling (labour and vehicle) costs. The on-site travelling costs are the same for all bait types. However, the off-site costs increase each week for the fresh bait types with the increase in procurement trips required. These off-site costs for using the fresh bait types therefore represent a 200, 300 and 400% increase over Foxoff® for baiting campaigns lasting 2, 3 or 4 weeks respectively. This is a considerable difference, especially after 4 weeks ($90.02 vs. $360.08 respectively).

The additional time needed to replace the fresh bait type more regularly is reflected in the on-site labour costs for each bait type. For campaigns lasting greater than 7 days, the difference in labour cost indicates the difference between weekly (fresh bait types) and fortnightly (Foxoff®) replacement (see 7.3.2).

7.3.6 Total campaign costs and cost per bait consumed

Considering the cost of purchasing, procuring and distributing/checking/replacing bait, the total cost of undertaking baiting varies with bait type, rate of bait take and duration of the campaign (Table 7.8). For example, 7 day campaigns using wingettes cost a total of $339.91 at 10% bait take but increase to $350.23 at 50% bait take. These costs increase to $593.71 and $611.35 respectively after 14 days, as a function of the number of baits replaced and the additional procurement of fresh baits.

Based on the total campaign cost, it is cheaper to present wingettes and day-old chicks than Foxoff® for campaigns up to 7 days duration. The price of Foxoff® would have to fall by

40%, or alternatively, the price of the fresh bait types would have to increase by 66% for cost of presenting the commercial and fresh bait types to be equal. At all other campaign durations, it is cheaper to present Foxoff®. A substantial increase (>170, >110 and >250%) in the price of Foxoff® would be necessary to make them equally or less efficient at 14, 21 and 28 days respectively than the fresh bait types.

Table 7.8: The cumulative total cost of undertaking baiting for an average baiting campaign (43 baits) lasting 7, 14, 21 and 28 days at 10, 25 and 50% bait uptake rates. Data based on the total cumulative labour and vehicle cost and the cumulative cost of bait required to replace degraded or removed baits during the baiting campaign. Note: data for day-old chicks are not presented but are identical to wingettes.

		Duration of campaign			
	Bait type	7 days	14 days	21 days	28 days
Cumulative total cost at bait uptake rates 10%, {25%}, (50%)	Foxoff®	$358.83 {$365.33} ($376.03)	$495.85 {$515.25} ($547.45)	$671.09 {$ 689.39} ($730.09)	$813.81 {$846.11} ($904.21)
	Wingette	$339.91 {$343.81} ($350.23)	$593.71 {$600.49} ($611.35)	$847.33 {$856.51} ($871.69)	$1100.83 {$1112.11} ($1131.85)

Using the total costs (Table 7.8) and the number of baits of each bait type consumed for given bait uptake rates (Table 7.5) the cost per bait consumed was calculated (see Table 7.9). The results indicate that the cost per bait consumed varies dramatically with the duration of the campaign, the level of bait uptake and the bait type chosen. At all presented campaign durations and bait uptake levels, the fresh bait types are more cost-effective than Foxoff®, although the difference between the fresh and commercial bait types decreases with increased campaign duration.

Table 7.9: The cumulative total cost per bait consumed for an average baiting campaign (43 baits) lasting 7, 14, 21 and 28 days at 10, 25 and 50% bait uptake rates. Data based on the total cumulative labour and vehicle cost, the cumulative cost of bait required to replace degraded or removed baits during the baiting campaign, and the number of baits consumed during the campaign. Note: data for day-old chicks are not presented but are identical to wingettes.

		Duration of campaign			
	Bait type	7 days	14 days	21 days	28 days
Cumulative total cost per bait consumed at bait uptake rates 10%, {25%}, 50%)	Foxoff®	$113.55 {$46.19} ($23.76)	$64.40 {$33.48} ($17.78)	$58.10 {$29.84} ($15.81)	$52.84 {$27.48} ($14.68)
	Wingette	$56.94 {$23.04} ($11.74)	$49.72 {$20.12} ($10.24)	$47.31 {$19.41} ($9.74)	$46.12 {$18.63} ($9.48)

7.3.7 Decision tree analyses

The practical implications of the results derived through the economic analyses are summarised in the decision tree in Figure 7.2. This presents the main considerations for deciding the most appropriate baiting strategy to use based on the longevity, palatability, procurement and distribution costs and *retail* cost of the respective bait types, together with storage and handling considerations associated with using each bait type. The retail cost was used since this better represents the total costs involved in the bait manufacture and also the cost incurred by landholders. The decision of which technique to use will ultimately depend on the replacement strategy used, the duration of the baiting campaign, and handling, non-target and cost-effectiveness considerations. Table 7.10 provides a description and summary of the issues and decisions to be made for each node in the decision tree.

Table 7.10: Description and notation for factors considered important in decision-making for baiting campaigns for foxes on the central tablelands of New South Wales.

Factor	Description	Notation	Details
Campaign duration	The number of days that baits are presented	< 7days; 7-14 days, >7 days; >14 days	As per description in 7.2.3.3
Cost-effectiveness	The cost of baiting per unit of output	Min cost per lethal bait presented	The minimum cost ($) of presenting bait lethal to foxes
		Min cost per bait consumed	The minimum cost ($) of bait required for every bait consumed (from those that are taken)
		Min total cost per bait consumed	The minimum cost per bait consumed considering procurement, usage, and bait presented
Minimum cost criteria	The minimum cost associated with undertaking baiting	Min cost of bait procurement	The minimum cost ($) of procuring bait from RLPB
		Min cost of bait usage	The minimum cost ($) of bait laying, checking and replacing
		Min total cost	The minimum cost of campaign considering procurement, usage, and bait presented
Non-target safety	Issues associated with the susceptibility of non-target species consuming the bait	Min persistence	The shortest period of bait longevity and therefore, withholding period
		Min caching	The bait type/s that are cached in the smallest proportion
		Min uptake	The bait type with reduced uptake by non-target animals
Replacement	Descriptor for whether removed or degraded bait is replaced during campaign	Replacement; No replacement	As per description in 7.2.3.3
Handling	Issues associated with the storage, handling or use of bait	Min number of baits required	The minimum number of baits required during a baiting campaign
		Min replacement	The minimum number of degraded baits to be replaced during a baiting campaign
		Min number of procurements	The minimum number of off-site trips required during a baiting campaign
Longevity	Lethal longevity of bait presented	Longevity	Bait presented remains lethal to foxes for campaign period.

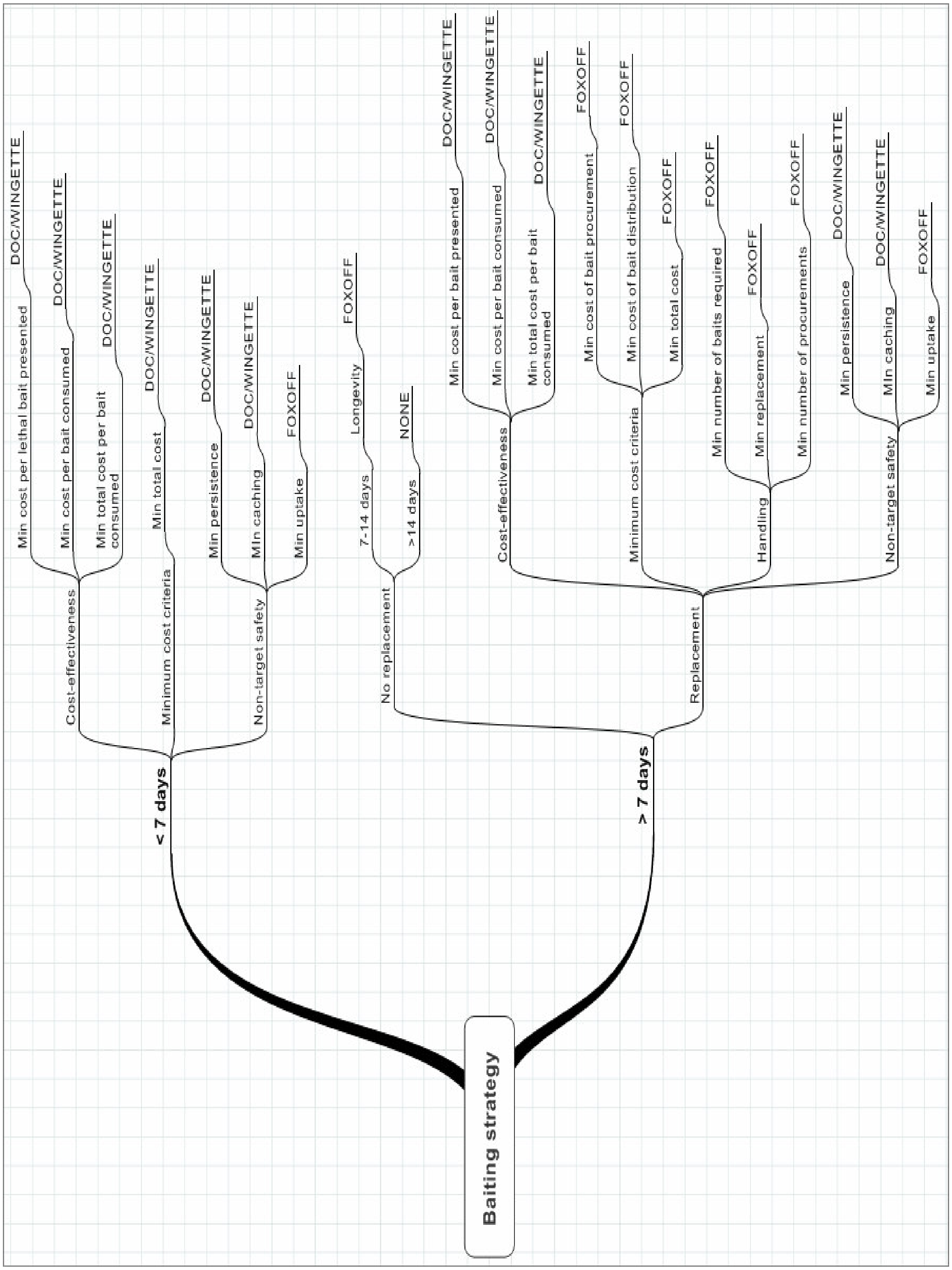

Figure 7.2: Decision tree illustrating the issues and sequence of decisions to be made in choosing the appropriate bait type for a fox baiting campaign. Bait types include DOC = day-old chick, WINGETTE = chicken wingette and FOXOFF = Foxoff®.

The decision tree is unusual in that, at each node, the route to be taken is not always a simple dichotomous choice. Additionally, a choice made at one node may not be mutually exclusive from another decision. This reflects the real life complexity of the issue in that it is often a choice between multiple, unrelated factors that indicates which decision should be made at each branch of the tree. The relative weighing given to each factor by the practitioner will ultimately influence the decision taken.

Given that the decision to undertake fox baiting has already been made, the choice is divided into two main categories depending on the duration of the baiting campaign (<7 days or >7 days). For campaigns lasting less than 7 days the next critical decision is whether cost-effectiveness, minimum cost or non-target safety is more important. Following from these, the relative importance of subsets of each factor to the decision-maker will provide the most appropriate choice of bait type. For campaigns continuing for greater than 7 days the decision to undertake replacement baiting or not (i.e. to replace bait that is removed or degraded) is a critical choice (see section 7.3.2).

It is important to note that not all issues are presented in all scenarios. For example, handling is not considered as an issue for campaigns lasting up to 7 days since both Foxoff® and day-old chicks/wingettes will last at least 7 days before becoming sub-lethal. Therefore there will be no difference in the time and labour associated with either strategy. Other issues are treated in the same manner; where there is no difference between the bait types in the respective strategy, the issue is not presented.

Examples

The optimum bait type to use for a replacement baiting campaign lasting <7 days is reliant upon the goal of the decision-maker. If the most important consideration is to achieve the maximum cost-effectiveness (measured as the minimum cost per lethal bait presented or minimum cost per bait consumed) or minimum total cost then day-old chicks or wingettes should be used. If non-target species safety is the most important consideration, especially to minimise caching, day-old chicks or wingettes should be the bait type chosen. However, if non-target species safety is to be achieved by a reduction of bait uptake, Foxoff® should be preferred.

If handling is the most important issue for baiting campaigns continuing for >7 days, then Foxoff® will have advantages in handling and reduced replacement, and reduced number of procurement trips compared to day-old chicks/wingettes. In contrast, the higher overall cost of purchasing Foxoff® ($1 per bait compared to $0.60) means that it is more cost-efficient to present day-old chicks or wingettes when only the bait cost is considered. If the total cost of bait purchase, procurement and distribution is considered, Foxoff® would be the more cost-efficient on the basis of minimum cost. However, wingettes and day-old chicks would be the more cost-efficient if the total cost of bait purchase, procurement and distribution per bait consumed is considered.

7.4 Discussion

The results of this chapter suggest that the cost of purchasing, procuring and using each bait type, in addition to the palatability and longevity of bait types, should be considered in determining the most appropriate bait type to use in the management of foxes. The results indicate further that the total costs associated with presenting each bait type may not necessarily be the best indication of the most cost-effective bait, especially when the palatability of bait is considered. However, it is also recognised that there may be other considerations more important than simply cost-effectiveness that may influence the decision of which bait type to use.

Considerations not included in the analyses are the costs of bait storage and preparation. The cost of preparing the fresh bait types will be greater than for Foxoff® baits since the commercially manufactured bait is purchased ‘ready to use’ and does not require injection with 1080 (See Chapter 3). Additionally, the product is shelf-stable and may be stored at room temperature for long periods without degradation (Staples *et al.* 1995). The fresh bait substrates may be stored frozen for long periods but should not be re-frozen once prepared (injected with 1080). The use of fresh bait types incurs an additional storage cost associated with freezing (i.e. purchase and use of a -10^0C freezer). These and other costs associated with the injection of bait, including labour, equipment and the disposables required to mix, inject and store the 1080 solution should also be considered, as should the wholesale prices of the commercial and fresh bait types. However, it was assumed that the retail prices best represent the total preparation costs since the difference between the wholesale and retail price of the fresh bait types is proportionally greater than that of Foxoff® to account for these costs (C. Somerset, Molong RLPB, pers. comm. 2003). It is difficult to determine the cost of many items required for injection of 1080 solution given that that many of these items last indefinitely and will have extended lifespans. Therefore, using the retail price to account for these costs was deemed the best compromise.

There are other miscellanous costs associated with undertaking baiting campaigns that will contribute to the total costs that are not included in the analyses. These would include the labour and expenses (e.g. telephone calls) for notifying neighbours of the intention to bait, the cost of purchasing and distributing warning signs and any consumables used during bait laying, and checking and disposal of bait. These will increase the total costs of undertaking baiting campaigns. However, since they are consistent across all bait types used, the costs would be additive and not affect the cost-effectiveness relationships between bait types.

Another cost is not obvious, but probably worth mentioning. This is the 'missed opportunity cost', or the cost of undertaking baiting operations and not other activities. It is difficult to value these costs since they will be influenced by factors including the type of enterprise and workload at the time of baiting, which vary between properties and even between seasons. However, the opportunity costs of undertaking baiting will reflect the relative ranking of the bait type and replacement strategy used, as identified earlier, since the opportunity cost is proportional to the labour component associated with these factors. These costs are additive to the total baiting costs and should be considered when choosing between baiting strategies.

This chapter assesses the relative cost of undertaking different baiting strategies given that the decision to undertake fox baiting has already been made. In many cases foxes may not be causing significant damage and therefore control may not be required. For example, rates of lamb predation are variable and losses to individual producers ranging between 0 and 30%

have been reported (Lugton 1987; Lugton 1993b; Greentree *et al.* 2000; Heydon and Reynolds 2000; White *et al.* 2000; Moberly *et al.* 2003). Ideally, practitioners should undertake a strategic approach, determine if management is required and then develop an appropriate response. The basis of strategic pest management is to define the problem in terms of damage (agricultural or environmental) before developing, implementing and monitoring the progress of an appropriate plan (Braysher 1993; Braysher and Saunders 2003). This approach will ensure that landholders undertake management only if it is required, and the outcomes of management are monitored in terms of damage reduction rather than just the reduction in pest density.

Given the decision to bait has been made, the analyses outlined here seek to identify the minimum cost associated with undertaking each baiting strategy without assessing the potential benefit (i.e. reduced predation) derived from reductions in fox density. The marginal benefit resulting from reductions in fox density is difficult to estimate since the relationship between fox predation, fox density, and fox control has not been reliably assessed (Moberly *et al.* 2004). Additionally, variations in flock size, flock genetics and health, management practices, availability of alternative prey and other factors influencing predation (see Greentree *et al.* 2000; Moberly *et al.* 2003) would affect the practical application of the conclusions in this study. These factors are not considered here, but are recognised as essential considerations to efficiently allocate resources to fox management.

It is important to note, finally, that the preliminary decision tree model determining the appropriate bait choice was developed from studies undertaken on the central tablelands of New South Wales. In other regions, additional or alternative considerations may become important and affect the outcomes of the model. For example, the choice of bait type may be restricted in less altered environments with particular non-target species and specific bait types. Spotted-tailed quolls (*Dasyurus maculatus*) are known to readily consume chicken and are successfully trapped using chicken wings (P. Cremasco, Department of Natural Resources and Mines, pers. comm. 2004). Foxoff® baits appear to be less preferred because their palatability to quolls is low (Kortner *et al.* 2003) and, therefore, would be recommended for use where quolls are present. Such an issue has been included in the decision tree (minimum uptake by non-target animals) even though none are present on the central tablelands area. The application of and conclusions drawn from the preliminary model should, therefore, be restricted to the central tablelands area where it was developed.

7.4.1 Bait longevity - cost per day

Foxoff® baits, on average, retain a lethal dose of 1080 for longer than wingettes, and most probably day-old chicks. Despite the fact that that the retail price per unit of Foxoff® ($1) is greater than that of the fresh bait types (both $0.60), its greater longevity means that it is more cost-efficient at presenting a lethal dose based on retail cost per day (7.1 cents/day) than either day-old chicks or wingettes (8.6 cents/day). Where the main consideration of the baiting campaign is to lay bait once only and at the lowest possible cost per day that it remains lethal, then Foxoff® is more cost-efficient than the fresh bait types.

These figures are based on the average period that baits remain lethal, and given degradation of individual baits is highly variable, there is likely to be considerable overlap between these estimates. For example, the cost/day estimates derived from the 95% confidence intervals range from 2.9 – 14.3 cents for Foxoff®, and 5.0 – 20.0 for day-old chicks and wingettes. This variation in the calculated cost per day would have few implications for actual baiting campaigns, if baits were replaced before any became sub-lethal. However, this is not always practical, and therefore the mean period that they remain lethal was used here to reflect the real life situation.

Using the wholesale purchase price of the bait material, day-old chicks and wingettes (2.5 and 2.6 cents per day respectively) are more cost-efficient than Foxoff® (6.0 cents per day). However, this indicates the cost to the authorised distributor only of purchasing the bait material, whether it is injected with 1080 (Foxoff®) or not (fresh bait types). As mentioned earlier, the additional costs involved in the preparation of the bait (including labour, materials and consumables) are not reflected in this price and should be considered in comparing between wholesale prices.

The cost per day relationship between bait types is reasonably robust to fluctuations in the purchase price of the bait. Retail price rises of at least 20% would be required to equal or improve the mean cost per day of the alternative bait types.

7.4.2 Baiting campaigns – bait uptake and replacement

The need to replace baits before they reach sub-lethal 1080 concentrations depends on the bait type and the duration of the baiting campaign. The most-cost efficient bait type (in terms of presenting toxic bait at the lowest bait purchase cost) alternates between the fresh and commercial bait substrates every 7 day period. For short (up to 7 day) campaigns at bait uptake rates of 10%, day-old chicks and wingettes are cheaper to purchase; it would cost an extra 66% of the fresh bait purchase price to use Foxoff® and does not require any replacement. If baiting campaigns continue for up to 14 days it is only slightly cheaper to purchase Foxoff® (99% of the fresh bait price) since it does not need replacing within this period. Presenting wingettes/day-old chicks for a 21-day campaign will cost only 87% of the price of using Foxoff. For a 4-week campaign it is again slightly more cost-efficient to purchase Foxoff® (98% of the fresh bait price).

As bait uptake increases, the relative cost differences both within and between bait types increase. This is due to the interaction of bait longevity, bait uptake and the replacement strategy on the numbers of baits that need to be replaced. The above examples were calculated using strategies where removed or degraded bait was replaced with fresh bait every 3-4 days and the rates of bait take continued at the same rate (10, 25 and 50%) for the entire campaign period. At higher rates of bait uptake there are more baits being removed by foxes, resulting in proportionally less degraded baits needing to be replaced. Also, as the duration of the campaign increases the cumulative number of baits removed also increases – including an increasing proportion of the 'fresher' baits laid to replace earlier-removed baits. Therefore, the increasing difference between the commercial and the fresh bait types is due to the compounding effect of the number of baits needing to be replaced as a result of bait degradation and removal (see Figure 7.1).

This chapter demonstrates that the replacement baiting strategy can make large differences to the number of baits required, and therefore cost, in baiting campaigns. It also demonstrates that the number of baits to be replaced in campaigns of typical duration (1-4 weeks) varies according to the bait type used. Replacing baits that are removed or degraded may result in a considerably greater number of baits being used in a campaign compared to replacing only degraded baits (Table 7.3 vs Table 7.2, respectively). The additional costs associated with this strategy will also vary with the bait type used. If additional baits are to be laid then the typical costs associated with checking and laying the baits will be the same for both fresh and commercial bait types. Foxoff® bait may be legally stored for up to 4 weeks after purchase of the bait (Environmental Protection Authority 2002), enough for most baiting campaigns. But the fresh bait types can be stored temporarily and only under refrigeration for a few days (<5) before bait spoils. If any additional wingette or day-old chick baits are required throughout the campaign after this period, then these must be purchased. This would require travelling to and from the supplying RLPB; for a 4 week baiting campaign this would mean three additional trips – this could be a large additional cost both in time and travelling costs, as well as in missed opportunity costs.

7.4.3 Bait consumption – relative cost per bait consumed

It is important to have an understanding of the relationship between bait palatability and cost; a relatively inexpensive bait may be either cost-efficient if highly palatable or cost-*in*efficient if unpalatable. Likewise, more expensive bait may be more or less cost-efficient than a lower-priced bait if it is more or less palatable. Analyses of the price of each bait type in comparison to its palatability indicate that Foxoff® has a considerably higher cost per bait consumed, based on the purchase price of bait, than either wingettes or day-old chicks. Based on the retail price, it is greater than 3 times more expensive to achieve the same result with Foxoff® than wingettes or day-old chicks. This increases to an 8-fold difference when the wholesale price is used. Therefore, the use of day-old chicks and wingettes for fox baiting is considerably more cost-efficient than Foxoff® with respect to the cost of the bait type.

The proportion of each bait type consumed from those taken has been translated to the cost per bait eaten. However, given that foxes may find and consume multiple baits within the same night (Chapter 2) the number of baits eaten is not directly proportional to the number of foxes killed. Consequently the real cost per fox killed is likely to be greater than the cost per bait eaten.

This analysis fails to consider other costs that may be associated with using bait with relatively low palatability. For example, it may be necessary to lay additional baits to achieve the same levels of bait consumption as the more palatable bait types. The costs are not only the purchase of additional bait material but the cost of distributing, checking and retrieving the additional baits. Such costs can be considerable (Saunders *et al.* 1997a) and would probably be in excess of those spent on bait material alone. Using Foxoff®, a bait with lower palatability, would therefore add economic costs to baiting practices compared to the more palatable and cheaper day-old chicks or wingettes.

Despite this observation, the strategy of laying additional low palatability baits like Foxoff® to increase consumption to levels of day-old chicks or wingettes may be inherently flawed. Presenting additional baits (‘food’) (by increasing the number of baits available to individual foxes) may result in increased caching as a response to the temporary food surplus (Vander Wall 1990). Therefore caution is needed in interpreting these conclusions.

Not all the additional costs associated with using less palatable bait like Foxoff® are economically quantifiable. For example, the many Foxoff® baits that are cached by foxes may offer a significant hazard to non-target animals, including farm dogs, long after the baiting campaign is finished. The percentage of Foxoff® baits cached is considerably greater than either wingettes or day-old chicks and therefore the associated risk is higher. Additionally, since Foxoff® baits degrade at a slower rate than wingettes (and probably day-old chicks), cached baits will remain toxic for longer, compounding the risk (see Chapter 3). The withholding period would be greater, perhaps restricting the ability to work such areas.

In addition, there may be greater potential for bait aversion to occur through consumption of degraded bait containing sub-lethal doses of 1080 (see Chapter 2). This may affect the efficiency of future baiting practices. Again, this is another potential cost that needs to be considered in comparing bait types.

7.4.4 Bait procurement and distribution costs

The results demonstrate that the travel and labour costs associated with procuring, laying, checking and replacing bait are considerable and constitute a large proportion of the total campaign cost. Although the actual dollar value will fluctuatate with the labour and travel costs, the influence of using the different bait types upon these costs is important. These influences are often unrecognised when choosing an appropriate bait type but may affect the procurement and distribution costs of a baiting campaign.

Bait that degrades rapidly will require replacing at more regular intervals than bait with greater longevity. The costs related to this replacement include an additional purchase, labour and travelling cost involved with procuring fresh bait as well as extra labour time replacing bait on site. Choosing bait with greater longevity will reduce the procurement and labour costs only where the duration of the campaign is greater than the longevity of the alternative bait type. For example, there are no differences in these costs between Foxoff® and the fresh bait types for a 7 day campaign, but for longer campaigns Foxoff® becomes more efficient.

It is important to note that the actual cost difference between using these bait types will increase or decrease with greater or less travelling distance and time respectively. However, the relative need to undertake procurement and bait replacement will remain the same, regardless of the actual costs.

7.4.5 Total campaign costs and cost per bait consumed

When the bait procurement and distribution costs are considered in combination with the cost of purchasing bait, the total cost of the campaign can be estimated. The results demonstrate that the cost of bait purchase may be the most important determinant of the total campaign cost for short-term campaigns. However, where degraded bait must be replaced, the additional costs associated with this replacement far exceed those of purchasing bait with greater longevity. Therefore, the total costs of presenting Foxoff® may exceed those of the fresh bait types for campaigns up to 7 days duration, but not for campaigns of longer duration.

These relationships will change as the number of baits purchased increases. This is noted by the reduced difference between the total costs of using Foxoff® and the fresh bait types at higher rates of bait uptake (Table 7.8).

The relationships also change when the palatability of the bait type presented is considered. The total cost associated with each bait consumed indicates that, at all presented campaign durations and bait uptake levels, the fresh bait types are more cost-effective than Foxoff. The difference between the fresh bait types and Foxoff® is again greater for short campaigns, but decreases with campaign duration.

The total cost per bait consumed is perhaps the most definitive measure of cost-effectiveness since it accounts for the total labour, vehicle and bait purchase cost for every bait consumed. Such an objective measure of performance would be useful for comparing between control programs since it accounts for the total costs involved with achieving a desired outcome. Ideally, future assessments of cost-effectiveness should account for bait palatability, in addition to the costs of presenting the bait for an objective measure of comparing baiting strategies.

7.4.6 Other considerations

The total costs associated with using each bait type or strategy are difficult to estimate. The monetary inputs are relatively straightforward, but other considerations may be equally or more important in deciding which strategy to use. For example, comparing the type of helicopter used for aerial shooting of feral pigs could be made on the basis of cost per hour but this may fail to take into account issues such as operator safety that vary with the type of helicopter chosen (Saunders 1993). Issues such as this may override any cost considerations and could ultimately be the most important determinant in deciding which strategy is more suitable. Thus it should be recognised that practitioners may use particular baiting practices for reasons apart from cost-effectiveness.

7.4.7 Decision tree analyses

The decision tree model is a useful tool to highlight the several factors that may affect choice of bait types. However, it is only a preliminary model and can be modified to encompass advances in knowledge.

The weighting that each particular item is given by the decision-maker will ultimately affect the final decision. If cost is the issue, this can be easily predicted using the above cost-effectiveness modelling. However, the risk from increased caching, in addition to increased longevity for Foxoff®, may prove to be the deciding factor against its use for many landholders who recognise the risk (to domestic dogs and other non-targets) associated with its use.

The results of this study should be useful for further cost-effectiveness analyses given information about the losses suffered from fox predation and the density:damage relationship. For example, if the relationship between fox density and damage is known the benefit from undertaking control can be calculated, as can the likely cost of reducing animal density to required levels.

In addition, not all techniques are available for use by landholders in all areas. Since RLPBs are responsible for overseeing the distribution of bait to landholders within their administrative area (see Chapter 4), decisions made by individual RLPBs may limit the availability of techniques to practitioners. The availability of bait material, storage and handling, and personal preference by the practitioner may all influence the decision of what techniques will be available and/or undertaken by landholders in fox baiting campaigns.

7.5 Conclusion

This chapter has demonstrated the need to consider bait palatability in addition to the total costs associated with presenting bait (including labour and travelling costs) when assessing the cost-effectiveness of baiting operations. It also suggests that other considerations may be equally or more important when choosing an appropriate bait type to use. Additionally, accounting for the palatability of the bait and the total cost associated with presenting bait should also provide a more useful means to compare baiting programs with other forms of control. However, it is important to note that the measures of cost-effectiveness presented in this chapter only represent an initial step in an economic analysis of pest control. For control to be economically worthwhile, the cost of undertaking control should not exceed the benefits derived from undertaking control (Moberly *et al.* 2004). Given that the relationship between pest abundance and damage may not be linear, the cost-effectiveness of control needs to be assessed with respect to reduction in pest damage, not abundance.

CHAPTER 8

GENERAL DISCUSSION

In the preceding chapters several important factors likely to affect the efficiency of fox baiting practices have been examined: the longevity of poison bait in the environment, bait palatability and caching behaviour, the spatial coverage of current baiting practices, and the relative cost-effectiveness of different strategies. In this chapter I first outline the key findings of this study, compare these with previous research, and then discuss the implications of these results for improving the efficiency of fox management. Finally, recommendations for fox management and future research are presented.

8.1 Key findings

In this thesis, I have used a combination of ecological and modelling approaches to assess factors affecting the efficiency of fox baiting practices on the central tablelands of New South Wales. The following conclusions have emerged:

I. The influence of climate and rainfall on degradation of 1080 in bait is not consistent for different bait types. The loss of 1080 from wingettes was independent of the tested rainfall and climate conditions, with wingettes remaining lethal to foxes for, on average, 1.1 weeks. Foxoff® baits remain lethal for longer than wingettes under all tested conditions although their degradation generally increased with increasing rainfall. Bait degradation rates did not change significantly between the central tablelands and western slopes of New South Wales.

II. There may be significant problems with the assay for determining 1080 concentration in fresh meat baits. Despite using a relatively accurate method of injecting 1080 solution into baits (graduated 1 ml syringes), assay results showed significant variation of 1080 concentration for freshly prepared bait. Commercially prepared Foxoff® baits do not suffer from this problem, partly due to the consistency of the substrate between individual baits. Inability to determine 1080 concentration accurately may result in safety, efficiency and effectiveness concerns.

III. Defluorinating micro-organisms are present in soils on the central tablelands and western slopes of New South Wales. A total of thirty-one species of defluorinating micro-organisms was isolated from soil samples. The defluorinating ability of four bacteria, two fungi and two actinomycete species had not previously been recorded. The variety of micro-organisms isolated proves the existence of defluorinators in eastern Australia, supporting arguments that 1080 will not persist in the Australian environment.

IV. Caching intensity is largely dependent on the palatability of the bait presented, reflecting the bait type and the presence of 1080. In the non-toxic trials Foxoff® baits were cached the most (66.9%) compared to wingettes (5.7%) and day-old chicks (4.5%). Higher rates of caching were recorded in the toxic trials, with 74.3% of Foxoff® baits compared to 43.1% of wingettes and 26.2% of day-old chicks being cached. Worryingly, 1080 baits were cached more often and caches are less likely to be retrieved compared to non-toxic baits, suggesting multiple bait uptake by foxes and reduced palatability of 1080 bait. Seasonal differences in caching intensity were inconsistent across sites, but some seasonal peaks occurred within sites, and were possibly related to variations in food availability.

V. The incorporation of an illness-inducing chemical (levamisole) into highly palatable bait can reduce multiple bait consumption by wild foxes. The mechanism driving the reduced consumption appears to be a learned avoidance of levamisole rather than development of a true conditioned aversion to bait. Use of levamisole to reduce multiple bait uptake by individuals may increase the efficiency and cost-effectiveness of baiting operations.

VI. Strategies for the use of conditioned taste aversion in the field (including reducing multiple bait uptake) must consider the dietary diversity of the target animal. Laboratory trials showed that freshly-weaned rats raised on a single food had a stronger and more persistent aversion than those raised on a variety of foods. This indicates the need for caution in extrapolating results from laboratory trials to field situations, particularly for animals with diverse feeding habits such as the fox.

VII. When temporal coordination between landholders and the likely impact on re-colonisation by foxes are taken into account current baiting practices in the Molong Rural Lands Protection Board appear to be largely ineffective at achieving desired objectives. The strategy of encouraging cooperative baiting campaigns to reduce the impact of immigration may be difficult and impractical in production environments where property sizes are small.

VIII. The central tablelands region provides highly suitable fox habitat and supports high density fox populations. In conjunction with published information on group structure, counts of natal dens produces population density estimates comparable with previous studies using different techniques.

IX. The cost-efficiency of baiting practices is dependent upon the length of the baiting campaign and replacement regime in addition to bait palatability, longevity and purchase cost. When measured on a cost per bait consumed basis, the fresh bait types (wingettes and day-old chicks) were more cost-effective for campaigns up to 4 weeks duration. However, it is recognised that other considerations, such as handling time, may be equally or more important in deciding the most appropriate strategy to use.

8.2 Discussion of key findings

The rate of caching in the present study was considerably greater than that reported previously (Saunders *et al.* 1999; Van Polanen Petel *et al.* 2001; Thomson and Kok 2002). Saunders *et al.* (1999) found that 38% of non-toxic and 32% of toxic Foxoff® baits taken by foxes were cached, while Van Polanen Petel *et al.* (2001) found that 41% of non-toxic Foxoff® baits were cached compared to only 12% of deep-fried beef liver baits. Thomson and Kok (2002) trialled non-toxic dried kangaroo meat baits and found that 25% of baits removed by foxes were cached. Given that the largest difference in caching intensity in the current study was a result of the bait type, the differences between the reported caching rates may be due to differences in palatability of the presented baits (Van Polanen Petel *et al.* 2001). However, comparisons may be confounded due to differences in free-feeding techniques, including free-feeding with replacement (Saunders *et al.* 1999; this study), free-feeding without replacement (Van Polanen Petel *et al.* 2001) and no free-feeding (Thomson and Kok 2002). Results from the current study suggest free-feeding can increase caching.

The majority of non-toxic caches appear to be retrieved within a short period. This is supported by the findings of other studies: Thomson and Kok (2002) found that 59% were retrieved and consumed within 10 days, most of these within 3 days; Saunders *et al.* (1999) found that 80% of non-toxic bait caches were retrieved within 10 days. This concurs with the hypothesis that most caches should be retrieved as a means of securing food for later consumption. However, fewer toxic baits were retrieved following caching, probably as a result of the death of the responsible animal (Saunders *et al.* 1999). Scatter hoarders, such as foxes, can recover caches through a variety of mechanisms (see Vander Wall 1982, 1990), most likely through remembering the precise location of cache sites using visual cues. This hypothesis is supported by empirical data (see Macdonald 1976), suggesting that caches are usually retrieved only by the individual responsible for making them. Additionally, foxes usually directly approach the cache site and, if a previously made cache has been moved a short distance, foxes are less likely to retrieve it (Macdonald 1976). This suggests that caches are unlikely to be found and raided by foxes other than the individual responsible for making the cache. This is important for baiting campaigns given that these caches may remain in the environment until consumed or degraded.

The caching of 1080 bait has been recorded in only one other study (Saunders *et al.* 1999). The greater rate of caching of toxic bait compared to non-toxic in the current study is in contrast to Saunders *et al.* (1999), who found that fewer toxic Foxoff® baits were cached compared with non-toxic baits (32% vs. 38%) (current study Foxoff® 74.3% vs. 66.9%). One possible explanation is that Saunders *et al.* (1999) presented only one bait type (Foxoff®) whereas the current study presented three bait types, albeit at different bait stations. Foxoff®

is less palatable than the other bait types, and foxes would have had greater access to bait stations since they were spaced at shorter intervals (minimum of 200 m) than Saunders *et al.* (1999) (400-500 m). It has been noted that food discovered is usually eaten until an animal is satiated, after which it is cached. It may be possible that foxes may have preferred to consume the more palatable, alternative bait types before removing and caching Foxoff®. This suggests that the relationship between food palatability and caching can be confounded by the availability of the food, and may be responsible for the differences between studies. Therefore, the availability of bait, together with presentation of bait of varying palatability, may interact to affect caching intensity.

Previous studies have suggested that caches may not be detrimental to baiting campaigns if they are consumed by immigrating foxes (e.g. Twigg 2001). However, the ability of cached baits to act as a temporal buffer may be limited since it is unlikely that immigrants locate many baits. Additionally, since less than half (43%) of toxic caches are removed before ten days (Saunders *et al.* 1999), they may degrade to sub-lethal levels before being consumed. Consumption of caches may, therefore, have a detrimental effect on baiting campaigns since it may result in consumption of sub-lethal doses of 1080, leading to re-population with bait averse foxes.

Ideally, baiting should be undertaken during periods that increase the probability of foxes consuming bait. Bait uptake and consumption will be affected by relationships between fox density, food abundance, individual nutritional status and energy demands, and seasonal differences in food preference (Saunders and McLeod *in press*). The effectiveness of baiting operations may be improved by undertaking campaigns during periods of peak food demands. Winstanley *et al.* (1999) assessed body fat in different seasons and found that foxes have greater levels of body fat in autumn than spring (especially November), when the predicted high daily food consumption suggests a high daily expenditure of energy in foraging activities. Specific periods of greater foraging activities include August to October for males (reduced feeding during mating and supplying females with food) and September to October for females (increased nutritional demand of lactation). The period August to November, coinciding with the peak whelping and cub-raising period (McIlroy *et al.* 2001) may thus be optimal for baiting since it suggests increased foraging to support lactation and provision of cubs. Considering all factors, November may be the optimal month for baiting since it reflects the period between maximal energy depletion and gain (Winstanley *et al.* 1999; Saunders and McLeod *in press*).

Surprisingly, in view of this, the results from the caching trials indicate no seasonal difference in caching rates between autumn, winter and spring. It is possible that any short-term changes may have been disguised by the testing regime, which, by necessity, was undertaken within the same season rather than the same month. The lack of consistent seasonal variation in caching found in this study supports Thomson and Kok (2002), who also found no difference in caching between winter and spring. The lack of consistent seasonal differences in caching intensity across sites suggests that targeting foxes during any seasonal period may not offer advantages for reducing caching. However, there are likely to be interactions between the availability of food (i.e. bait) and caching behaviour (Vander Wall 1990), suggesting that site-specific peaks in food availability may be more responsible for variation in the intensity of caching than actual seasonal influences.

It is important to recognise that the timing of any campaign may be restricted by its goals and the ability to satisfy these goals. In agricultural enterprises, baiting programs may need to be undertaken only when prey are susceptible, for example prior to and during lambing periods (Balogh *et al.* 2001). Campaigns for nature conservation, though, may require constant management effort for reducing predation pressure on prey. These goals may be equally or more important in deciding appropriate temporal baiting strategies than the biology of the fox.

From the above it could be concluded that the largest variation in caching behaviour identified thus far is due to the type of bait presented. Given that caching is a major determinant of the cost-effectiveness of using a particular bait type, choosing highly palatable bait should assist in improving the cost-effectiveness of control operations and reducing caching-associated problems.

There have been concerns about the effects of 1080 poisoning campaigns on non-target animals, both native and introduced. Apart from the potential to result in non-target deaths, such uptake may reduce the cost-effectiveness of delivering bait to foxes (Twigg 2001). Many studies have reported the removal of bait by non-target species including birds, native rodents, reptiles, cats, dogs, quolls and other marsupial mammals (e.g. McIlroy *et al.* 1986; Allen *et al.* 1989; Calver *et al.* 1989; Fleming 1996; Belcher 1998; Dexter and Meek 1998; Twigg *et al.* 2001; Glen and Dickman 2003; Kortner *et al.* 2003). Many of these studies have used non-toxic bait as a proxy for toxic bait, which may be misleading given that the palatability of 1080 bait may be reduced relative to non-toxic bait (Sinclair and Bird 1984). Additionally, most have assumed non-target susceptibility from baiting campaigns through measuring bait uptake, rather than bait consumption. The variation in the fate of bait once removed from a station in this study confirms the importance of assessing bait consumption rather than just uptake in assessing the impact of baiting. This finding supports Kortner *et al.* (2003), who found that quolls removed many baits but actually consumed very few.

The results of the caching chapter deal with baits removed by foxes only; those removed by other animals or disturbed by weather or stock were excluded from analyses. Over the course of the study, dogs, birds (probably corvids) and unidentified species removed and consumed several baits, both toxic and non-toxic. None were consumed by domestic stock, despite bait stations and baits being frequently disturbed, particularly by cattle. Overall, the level of non-target bait take was very low (<4% of baits presented), and was probably indicative of the lack of non-target species in the study area capable of removing and consuming bait. This is not surprising given that the central tablelands region is a highly modified landscape that has been significantly impacted by agriculture (see Chapter 1). Low levels of non-target impact should assist viability of the buried bait technique on agricultural lands, supporting the continued use of the technique for fox control.

Species of fungi, actinomycetes and bacteria capable of defluorination were isolated from soils on the central tablelands and western slopes (see Chapter 2). This is the first confirmation of their presence in soils from eastern Australia; previous studies have shown that such organisms are present in the soils of central (Twigg and Socha 2001) and Western Australia (Wong *et al.* 1991; King *et al.* 1994). In central Australia (Finke Gorge), soil samples contained a total of 24 species of micro-organisms capable of defluorinating 1080

(Twigg and Socha 2001), while in Western Australia, a total of 20 defluorinating species have been isolated (Wong *et al.* 1991). Since the relative abundance and activity of micro-organisms, and hence probability of isolation, may vary with soil conditions, including moisture and organic matter (Clark 1967), it is likely that the number of species isolated will vary according to seasonal conditions (see Twigg and Socha 2001) in addition to region. This variation in the number of species isolated between these studies is therefore likely to represent the soil conditions at the time of collection in addition to the number of species actually present in each area.

It is not surprising that fluoroacetate-degrading microbes are present in eastern Australian soils. Fluoroacetate-bearing plants are part of the Australian flora (Twigg and King 1991) and it would be expected that micro-organisms capable of detoxifying fluoroacetate would be present in Australian soils. Such organisms also occur on other continents where fluoroacetate-bearing plants may or may not be present (Twigg *et al.* 1996; Cremasco 2002), including New Zealand (Bong *et al.* 1979; Parfitt *et al.* 1994; Walker 1994), South Africa (Meyer 1994), Britain (Kelly 1965) and Japan (Kawasaki *et al.* 1983), supporting the suggestion that the ability to metabolise fluoroacetate may be common amongst many soil micro-organisms (Walker 1994). This would suggest that 1080 will not persist generally in soils. Additionally, a combination of micro-organism activity, uptake from aquatic plants and physical breakdown from ultra-violet radiation and heat will also degrade fluoroacetate, indicating that prolonged persistence in natural waterways should not occur (Parfitt *et al.* 1994). Nevertheless, confirmation of the presence of defluorinators in the soils of eastern Australia provides further evidence to indicate that 1080 will not persist in the environment, one important consideration in support of the continued use of 1080 for pest animal control.

The 1080 content of freshly prepared bait is highly variable. With some baits measured at almost twice the nominal concentration, it is almost inconceivable that all of this variation is due to injection error, given the accuracy of the injected dose and the concentration of the stock solution (Chapter 2). Other studies (published and unpublished data) have also reported, or presented, data showing high variability in 1080 concentration in fresh meat bait (e.g. Korn and Livanos 1986; Kramer and Merrell 1987; McIlroy and Gifford 1988; Fleming and Parker

1991; A. Claridge, Department of Environment and Conservation, unpublished data) despite using a variety of bait substrates, solution concentrations and volumes, and application techniques. The ability of 1080 to bind to meat, amplified by the time lag between injection and analysis means that the percentage recovery of 1080 (relative to the injected dose) is low (Frost *et al.* 1989; Fleming and Parker 1991). Given that 1080 recovery within substrates varies according to the substrate type (Frost *et al.* 1989) and composition (R. Parker, Department of Natural Resources and Mines, pers. comm. 2003), it appears that variation in tissue composition between individual baits may result in variations in the measured concentration. The calculated variation may then be compounded through correcting the (low) measured recovery rate.

The 1080 content of baits prepared experimentally, where great care and attention is undertaken, should be more consistent than that for non-commercial bait prepared for normal usage. An example of this is the accuracy of the insulin syringe technique (this study) compared with the use of a vaccinator gun (Fleming and Parker 1991) more typically used by practitioners to impregnate baits. Given the variability encountered in this study, this is a concern and suggests that the variation in 1080 content of fresh baits used in everyday campaigns is likely to be greater. Furthermore, variation in the physical state of meat baits would be expected due to differences in the preparation techniques and state of the bait when presented in the field. Bait is prepared whilst fresh but, depending on the period and the storage medium (i.e. refrigerated or not) between preparation and presentation, bait may be laid in a condition ranging from fresh to spoiled. This inconsistency is a concern given that safe, effective and efficient strategies for use rely on presenting bait with a known, accurate dosage of 1080 – all determined from freshly prepared bait. These preparation and spoilage issues do not affect Foxoff®; its shelf-stability ensures that the contained dose is consistent, and the bait substrate at presentation is consistent. In fact, Foxoff® baits have the most consistent dose of all fox baits tested to date (R. Parker, Department of Natural Resources and Mines, pers. comm. 2003). Therefore, the superior quality control and shelf stability of Foxoff® provides an important criterion for favouring its use over freshly prepared bait types. It is important to recognise consistency of dose, as it will directly affect issues such as cost and degradation and, in turn, usage strategies (Chapter 7).

The ability to induce a learned aversion to bait may be beneficial to baiting campaigns, particularly those that present non-toxic bait. Each bait used in a poisoning operation contains sufficient poison to kill a fox (McIlroy and King 1990). Following consumption of a single bait, foxes would have only limited opportunity to consume additional baits before succumbing to the effects of the toxin. Therefore, inducing an aversion to bait, may only be of benefit to campaigns that rely on non-toxic bait. Oral vaccination programs, where bait is used as a delivery mechanism for vaccines, should only require consumption of a single bait to provoke an immune response (Linhart *et al.* 1997), although consumption of multiple baits may sometimes be necessary (Artois *et al.* 1993). Recent developments toward an anti-fertility vaccine by the Pest Animal Control CRC (now Australasian Invasive Animal CRC) have shown that consumption of a single non-toxic bait coated with wild-type canine herpesvirus (CHV) results in an immune response in all foxes consuming the bait (Pest Animal Control CRC 2004). In circumstances such as this, where consumption of only one bait is required, incorporation of an aversion-inducing agent such as levamisole would be advantageous. However, where it is necessary for foxes to consume multiple baits, the application of CTA or learned repellency to bait would reduce the probability of this occurring. Additionally, where individuals need to be re-treated over time (e.g. rabies vaccination programs, fertility control agents such as cabergoline or an immunocontraceptive), an aversion may hamper the ability to re-dose the animal. In these circumstances, the persistence of the aversion must be considered relative to the interval required for the re-dosing to be effective.

Perhaps the most important finding of this study is with respect to the perceived effectiveness of current baiting techniques. Commonly used indicators of success in baiting campaigns, such as the number of baits distributed, number of landholders involved and area of land covered may not be necessarily correlated with the actual success of baiting campaigns. The assessment of the spatial coverage of baiting in the Molong Rural Lands Protection Board area suggests that the effectiveness of current baiting operations in eastern Australia is compromised by the ability of foxes to re-colonise baited areas. This is supported by the empirical findings of Greentree *et al.* (2000) and Molsher (1999). Greentree *et al.* (2000)

found that undertaking best practice fox baiting once and three times per year had no significant effect on fox abundance on sheep farms, despite baiting additional buffer zones up to 3 km wide surrounding each site. Immigration was cited as the likely cause of no effect. The immigration problem was confirmed by Molsher (1999) who found that fox abundance did not decline even when baiting was carried out monthly. These studies confirm the findings of the present study, which suggest that immigration into baited areas would be rapid unless they were protected by buffers greater than 9.5 km wide (as estimated from mean recovery distances and home range sizes (Trewhella *et al.* 1988; Saunders *et al.* 2002a- see Chapter 5).

These results suggest that there may be a need to extend baiting practices to cover larger areas. The ease with which bait can be distributed over large areas may make aerial baiting more attractive and potentially more cost-effective than ground-based baiting. Aerial baiting for foxes is undertaken over large tracts of land in Western Australia (Armstrong 1997) and is suggested as an alternative technique to ground baiting in New South Wales. Aerial baiting may be highly effective, with kill rates of up to >95% (Thomson *et al.* 2000) and offers the advantages of uniform bait coverage over all areas, particularly those that are difficult to commute to on the ground. However, there are several differences between conditions in eastern and western Australia that may affect the application of the technique, and would require refinement if aerial baiting were to be considered for eastern Australia.

Thomson *et al.* (2000) reported that although the majority of monitored foxes (~75%) were killed during the first 14 days of a baiting campaign, the remainder perished between 4 and 6 weeks following bait presentation. This is slower than that occurring in ground baiting campaigns; a slower rate of bait uptake in aerial campaigns is probably a function of bait placement and subsequent location by foxes. This slower rate of uptake suggests that bait in an aerial campaign may have to remain lethal for longer to allow all foxes sufficient time to consume bait. Given that bait in higher rainfall agricultural areas will, generally, degrade within 2 weeks (Chapter 2), the success of aerial baiting in these areas is likely to be reduced. To counter this it may be necessary to present bait with greater longevity, continue regular re-baiting to ensure that bait still remains lethal, or increase the bait density to promote faster rates of uptake. Using bait with a greater lethal longevity may be advantageous for targeting foxes (e.g. Twigg 2001) but may be detrimental for non-target safety reasons (see Chapter 2). Similarly, increasing the bait density relative to ground baiting may have non-target implications, since individuals will have increased access to multiple baits (Glen and Dickman 2003). Aerial strategies may thus be detrimental to safety and cost-efficiency in comparison to ground baiting.

In addition to immigration, fox populations may respond through compensatory processes. Foxes are resilient to increases in mortality; populations exposed to control may compensate through increased reproduction or increases in litter size or juvenile survival (Marlow *et al.* submitted). Even without compensatory mechanisms, an estimated population reduction of >65% is required to stop maximum population growth (Hone 1999), a level probably achieved in most 1080 control operations (see Hone 1999) despite occasional lower reductions (50% - Fleming 1997). Such estimates suggest that, without sustained reductions of fox density, fox populations would soon return to pre-control levels regardless of immigration.

It is important to assess the effect of management strategies on the predator, but ultimately the effect on prey needs to be considered to determine the effect of management. Even if current management programs are effective at reducing fox density on a temporary basis, immigration may nullify efforts in the longer term. Regardless, we must assess whether current baiting strategies are effective in terms of the prey response. A major, replicated experiment was undertaken on the southern central tablelands of New South Wales to estimate the benefits associated from undertaking best practice fox baiting operations (Saunders *et al.* 1997a; Greentree 2000; Greentree *et al.* 2000). Fox abundance, lamb production and lamb predation were monitored on two replicate sites at three levels of fox control (once per year, three times per year and no control) over two years. Fox control had no significant effect upon lamb production, most probably due to the inability to significantly reduce fox abundance. Immigration was touted as the most likely cause (Greentree *et al.* 2000).

Similar issues relevant to immigration have occurred in international studies of predation. Conner *et al.* (1998) found that the removal of coyotes was not correlated with sheep losses. Control efforts did not have a lasting effect on coyote density; immigration, reduced mortality of young and compensatory reproduction were likely causes. Reynolds *et al.* (1993) assessed the impact of fox culling on two fox populations in southern England. Study sites consisted of core areas where foxes were deliberately, intensively controlled with 'surround' buffer areas where control efforts were sporadic. Both core and surround areas were recolonised each year due to immigration, although immigration was probably at lower levels in the breeding season compared to the peak dispersal period. However, despite immigration, hen partridges increased in the core area, suggesting the control technique was beneficial for game conservation (Reynolds *et al.* 1993).

The above examples demonstrate the importance of assessing management strategies in terms of the prey response. However, it is important also to consider the benefits of undertaking control in terms of the costs associated with generating the prey response. The cost-effectiveness analyses undertaken in this study (Chapter 7) indicate the cost of undertaking baiting campaigns, including the cost per bait consumed. Measures such as these are useful for comparing alternative control techniques, but alone are not a true measure of cost-effectiveness, or the economic benefit derived from undertaking control. A more appropriate measure of performance may be to determine whether there is a net benefit to agricultural protection or wildlife conservation programs (Twigg 2001). Therefore, the cost of undertaking control should, ideally, be compared to the benefits from undertaking control to assess whether the control is economically worthwhile, or cost-effective.

There have been few assessments of the cost-effectiveness of management strategies for preventing livestock predation, although such an approach has been recently undertaken for foxes (Moberly *et al.* 2004). Moberly *et al.* (2004) completed an economic analysis of fox predation on lambs in Britain through comparing the cost of preventative measures including shed lambing and fox control with predation losses. Their results suggested that the majority of farms would not benefit economically from undertaking additional fox control, and that reducing fox density had only a small effect on expected lamb losses; additional control only influenced the probability of predation occurring.

8.3 Other factors that may affect the efficiency of baiting

Although this study investigated several important factors affecting fox baiting, many other aspects are likely to influence the effectiveness of baiting practices, associated costs of control, and hence, efficiency. In this section these are briefly summarised with examples from previous studies.

Bait density, or the number of baits laid per unit area, will affect the efficiency of the baiting program. The appropriate bait density to effectively target foxes is likely to vary with fox density, home range size and habitat use, and the method of bait presentation (Saunders and McLeod *in press*). Obviously, bait density must exceed fox density to ensure that sufficient baits are presented for each animal. However, laying excessive bait may result in an excessive number of baits being available to each individual, wasting bait, and perhaps encouraging problems such as caching and increased non-target uptake (Thomson and Algar 2000).

A variety of baiting densities has been used in Australia, but comparisons between studies are difficult due to differences in underlying fox density. Thompson and Fleming (1994) suggested that comparisons between baiting rates should be made on the number of baits available per fox rather than the absolute bait density. For example, aerial baiting in Western Australia was successful (>95% kill) using a bait density of between 5-6 baits/km^2 at an estimated fox density of 0.5-1 foxes/km^2 (Thomson *et al.* 2000). This equates to between 5 and 12 baits available per fox. At a similar fox density, aerial baiting at 5 baits/km^2 (5-10 baits per fox) was found to be just as effective as at 10 baits/km^2 (10-20 baits per fox), resulting in a potential population reduction of 79% (range = 63-88%) (Thomson and Algar 2000). Considering these studies, it would be expected that the bait density should be greater in the more productive lands in eastern Australia where fox densities are generally higher. Thompson and Fleming (1994) reported that ground baiting of agricultural lands in New South Wales at a density of 12 baits/km^2 and fox density ranging between 4.6 - 7.2 foxes/km^2, resulted in a 70% reduction of fox numbers. Similarly, a 50% reduction was recorded on farmland at a bait density of 4.4 baits/km^2 for a given fox density of 1.3-1.9 foxes/km^2 (Fleming 1997).

In addition to the number of baits laid in an area, consideration must be given to how baits are distributed within the area, i.e. the bait placement. Ideally bait should be distributed in consideration of fox distribution, including territorial boundaries, to ensure that all foxes within the population will have physical access to bait (Saunders 1992). Increasing bait density without considering the distribution may simply increase the bait availability within fox groups rather than to a greater proportion of fox groups (Thulke *et al.* 2004). For example, uniform distribution of baits is likely to give more individuals access to bait than if they are clustered due to the fact that foxes mainly live in family territories (Hässig 1984 in Linhart *et al.* 1997). However, uniform bait placement is usually achieved only through aerial baiting; ground bait placement may be restricted by such factors as topography and vegetative cover to areas able to be traversed by vehicle. As a result, ground-placed baits are usually laid along roads, fencelines or other features likely to be conducive to fox activity. Such placement would be likely to encourage uptake by foxes (Korn and Lugton 1990) whereas uniform bait placement, as would occur from aerial operations, would probably increase the amount of time before discovery by foxes (Thomson and Algar 2000; Thomson *et al.* 2000). Placement of bait has been shown to affect bait uptake in urban areas (Trewhella *et al.* 1991), suggesting that knowledge of where to lay baits would increase the probability of successful removal by foxes (Saunders *et al.* 1997b). With these factors in consideration, it appears that, despite considerable differences between studies, a lower bait density may be required for ground baiting in comparison to aerial baiting to achieve a similar result due to differences in bait placement (Saunders and McLeod *in press*).

The density, distribution and placement of bait will affect the number and availability of baits to each fox, but how bait is presented may also affect the ability of foxes to locate the bait and additionally, the fate of the bait following discovery. Baits may be either buried or laid on the surface. Conventional baiting programs in eastern Australia bury bait as a means to reduce non-target uptake; in New South Wales baits must be either buried under the surface of the ground, or within mounds of sand (known as mound baiting). Some studies have noted that burying bait appears to decrease the rate of take in comparison to some surface laid bait (Allen *et al.* 1989). A decline in the rate of take by target species from buried bait is generally well regarded. However, in addition to affecting bait uptake, there is evidence that bait presentation may also affect the intensity of caching. Increased caching of buried baits (35.3%) compared to surface-laid baits (21.6%) was reported by Thomson and Kok (2002). There is no obvious reason for the increased caching of buried bait other than it may mimic a cache; since caching is inversely related to food palatability (Van Polanen Petel *et al.* 2001), buried bait may be recognised as less palatable by a raiding fox, and thus more likely to be cached.

The frequency of baiting campaigns is also likely to have an effect on the efficiency of baiting operations. Baiting on agricultural lands is usually undertaken to protect domestic stock, although the importance of fox control for nature conservation appears to be increasingly recognised (Oliver and Walton 2004). Assessment of baiting practices in the Molong RLPB area indicates that most landholders who undertake baiting (>80%) do so only once per year (see Chapter 5). Given that baiting undertaken at this frequency will be rendered ineffective due to fox immigration, which may be almost instantaneous, it is commonly recommended to undertake baiting more regularly to target re-invading foxes. However, baiting more regularly, including three times per year (Greentree *et al.* 2000) and even every month (Molsher 1999) cannot be guaranteed to reduce fox abundance, indicating susceptibility to re-invasion. This suggests that simply applying current strategies more frequently and over a bigger area may not solve the immigration problem.

Behavioural changes, as related to the fox reproductive cycle may also affect our ability to target foxes. In addition to changes in nutritional status that are likely to affect foraging behaviour (Saunders and McLeod *in press*), changes in ranging behaviour may affect the ability of foxes to locate baits. For example, den sites are the focal point of activity during the whelping and cub-raising period. Juveniles may not be targeted by baiting campaigns during this time if these areas are not targeted (Robertson *et al.* 2000).

The timing of the baiting campaign can also influence the uptake of poison baits by non-target species. Soderquist and Serena (1993) suggested that western quolls (*Dasyurus geoffroii*) are more likely to take baits during winter since prey is relatively scarce then. They predicted that January to March was the period that held the least danger to quolls. The large proportion of egg baits (up to 61%), removed by goannas (*Varanus rosenbergi*) during the warmer months (Twigg *et al.* 2001) may be reduced by timing campaigns during periods of reptile inactivity (i.e. cooler months). Goannas are probably not considered at risk due to their high tolerance to 1080, but removal of 60% of baits would reduce the cost-effectiveness of operations (Twigg 2001).

8.4 Management and research implications

Baiting, as part of any fox management program, is a complex issue affected by a plethora of factors that influence whether foxes will locate and consume baits. The costs associated with undertaking baiting will be affected by the methods chosen and used. There are many factors pertinent to these considerations that are affected by current management practices and require further investigation. In the following section I will comment on the applicability of the present study to other areas/situations, and the most appropriate directions for future research on fox baiting that have been highlighted during the course of this study.

The study area around Molong on the central tablelands of New South Wales is broadly representative of highly modified landscapes associated with grazing and mixed farming. Although these represent typical landscapes and enterprises likely to undertake fox baiting, differences between the agricultural lands of the central tablelands and other areas within New South Wales, or indeed Australia, mean that some of my results may not be immediately applicable to other areas (e.g. specific bait degradation rates). Differences in the climate, landuse (e.g. agricultural vs. conservation), amount of natural vegetation retained, presence and diversity of native species and other species capable of consuming bait must be considered before directly applying my results across a variety of habitats. However, baiting practices, as detailed in this study, are undertaken across New South Wales and, indeed, are very similar to those undertaken throughout most of eastern Australia. Therefore, regardless of regional variations in conditions, many implications of the results of this study may be generalised beyond the immediate central tablelands area.

The inability to accurately measure 1080 concentration has serious implications for the use of 1080 baits in the field. Bait must be prepared to contain the approximate dose to be sufficiently toxic to the target species, but not to constitute a non-target threat (McIlroy and King 1990). Quality control is an important means to ensure that prepared baits contain the appropriate amount, and random checks of operators are undertaken currently under the conditions of registration (S. Balogh, NSW Department of Primary Industries, pers. comm. 2003). The inability to accurately measure 1080 concentration and separate operator from measurement error may impede our ability to undertake such assessments and monitor the safety of 1080 programs. Additionally, it is important that bait is presented with a consistent, accurate dose since strategies for field use are formulated with respect to bait longevity.

The difference in palatability between 1080-laced bait and non-toxic bait warrants further investigation. The ability of native species to detect 1080 content has been previously confirmed (Sinclair and Bird 1984), and the reduced palatability recorded in my caching trials suggests the same may be occurring with foxes. This could be further explored by comparing the consumption of toxic and non-toxic bait at each of a number of sites to counter any possible site/regional differences in palatability. Procedural controls (e.g. Coleman and Connell 2001) should also be established for freshly prepared bait types to ensure that it is indeed the presence of 1080 rather than preparation techniques that reduce bait palatability.

Similarly, the potential for reducing multiple bait uptake through inducing conditioned taste aversion appears to be hampered by the detectability of levamisole. It is important for the further development of this technique to determine whether this is due to cues associated with the chemical or the injection process. An experiment could be undertaken using similar methodology to the 1080 trials as mentioned above, making sure to include procedural controls.

Further development of the CTA method may provide a means of testing whether baits are monopolised by individual foxes, and evaluating the extent of the monopolisation. The use of an aversion technique may assist in improving the effectiveness of all baiting operations through allowing additional foxes access to bait (see Chapter 4). This may be evaluated by incorporating a biomarker in bait on sites where CTA has been induced compared to a normal baiting campaign. Sampling for the presence of the biomarker in an unbiased sample of foxes obtained by shooting, trapping and cyanide baiting would then quantify the proportion of foxes consuming bait. Any differences in the proportion of foxes consuming bait between the sites would indicate whether monopolisation by individuals is occurring, and the extent that the monopolisation reduces the population level of bait consumption. This will assist in determining whether monopolisation is significantly deleterious to the cost-effectiveness of baiting campaigns.

The relationship between bait presentation and caching behaviour also warrants further investigation. The widespread practice of burying bait may be detrimental to the efficiency of baiting programs if it increases caching, although this has been observed only for dried meat bait (Thomson and Kok 2002). This may provide further indications of the potential differences between aerial and ground-based baiting campaigns. Such an assessment should also extend to mound baiting, given its increasing use and the considerable differences between it and conventional ground baiting practices. An appropriate testing regime should present bait types of differing palatability either on the ground (surface), under the ground (buried) or in the ground (mound). The fate of these baits should then be monitored through incorporating transmitters in these baits to determine any differences in caching behaviour.

The most important factor influencing caching behaviour that has been identified to date is the palatability of the bait type. Given that palatability was an important determinant of the cost per bait consumed, and hence cost-effectiveness, it may be beneficial to assess the efficiency of baiting programs using different bait types. Pen trials may be useful to rank between bait types but ultimately field-testing should be undertaken to ascertain caching rates under different field conditions.

Since it is likely that caching is a response to the overabundance of food, knowing the relationship between food abundance and caching behaviour may assist in predicting the required baiting intensity (i.e. bait density, spacing and placement) for given fox densities. Additionally, the density, spatial placement and spacing of baits are important determinants of the ability of foxes to locate baits. An experiment to evaluate the food abundance-caching relationship could be undertaken through monitoring bait uptake and caching behaviour at different levels of bait abundance per fox, as determined by the spacing between baits and overall bait density with regard to fox density. Alternatively, supplementary food could be provided to foxes while undertaking baiting to determine the effect of total food availability on caching behaviour. Consideration must be given to the abundance of other food resources, but given that baits are unlikely to be less preferred than naturally occurring prey items, this may not be as important as bait abundance.

Additional trials should be undertaken to assess the degradation of commonly used bait types, particularly fresh meat. Ideally, these trials should be undertaken in a range of environments, especially more arid environments where degradation is likely to be slower. Given the obvious logistical constraints of investigating all likely environmental conditions, it may be more efficient to quantify and model the processes driving degradation. Improved understanding of the effect of and interaction between intrinsic (e.g. bait type, 1080 dosage) and environmental variables (e.g. rainfall, temperature, soil type and decomposer activity) on the rate of 1080 degradation would assist in developing suitable degradation models. This would be an efficient approach since general relationships may then be applied to untested situations.

Perhaps most importantly, the process of undertaking the cost-effectiveness studies has highlighted the importance of incorporating economic analyses in evaluating management strategies. Determining the most cost-effective strategy for reducing fox abundance is useful for cost minimisation, but, ultimately, cost-effectiveness should be measured in the terms of the response of the prey population. The cost-effectiveness of fox management, regardless of the chosen technique, must be evaluated in terms of the response of the prey rather than that of the predator. This has proven difficult, especially in agriculture where impacts of predation can be variable.

Current levels of baiting coordination, and therefore coverage, appear insufficient to have any long-term impact upon fox populations due to the ability of the fox to re-colonise areas following removal. There may be a need to encourage greater coordination of baiting programs among landholders to reduce the potential for re-immigration into baited areas. The basic strategy of undertaking short-term control has been shown to be relatively ineffective at reducing fox predation, and simply applying this technique across the landscape will not result in any dramatic improvements. Fox populations are resilient to control, with some evidence of compensatory processes resulting from reducing fox density.

In the absence of empirical data, it is often assumed that the relationship between pest density and damage is linear. Therefore, much effort is undertaken to improve control techniques to ensure the maximum reduction in pest density. Perhaps greater recognition should be given to reducing pest density to levels of acceptable damage (Hone 1994). This would require the relationship between fox density and fox-associated damage to be refined in regard to the prey species to be protected, especially as different levels of predation upon each prey species will have different effects.

8.5 Specific recommendations for current baiting practices

Changes are required to current best-practice techniques (Saunders *et al.* 1995) to incorporate deficiencies found during this study. Specific recommendations for the management of foxes on agricultural lands with poison baits include the following:

I. Free-feeding should be discouraged unless the presence of susceptible non-target species such as the spotted-tailed quoll, is suspected. Free-feeding has been shown to increase the potential for caching; the resultant additional cost of bait procurement, bait checking and replacement would substantially increase the costs associated with this strategy. Where quolls are suspected, free-feeding in conjunction with track plots is recommended to determine if quolls are present and visiting bait stations (NSW National Parks and Wildlife Service 2001).

II. If replacement baiting is undertaken, the minimum interval between bait uptake and replacement should be 3-4 days. Given that continual replacement of free-feed bait increases the potential for caching, the continual replacement of toxic bait may also encourage caching by increasing the availability of bait to individual foxes. In the current study, removed baits were replaced daily; this may have resulted in learning by resident foxes. The majority of toxic caches that were consumed were retrieved within 4 days of their initial removal from the bait station; this retrieval is likely to be by the fox responsible for making the cache. Therefore, changing the currently recommended replacement interval of 3-4 days to the minimum interval may reduce the potential of individual foxes to access multiple baits. This may assist in reducing the number of baits cached, improving the safety and cost-efficiency of baiting campaigns.

III. Bait stations should be spaced at greater intervals than the minimum 100 m specified (Environment Protection Authority 2002). Distances between stations in this study were 200 m but this still appears insufficient to reduce multiple bait uptake. Distances of 400-500 m may reduce this occurring, but proposing this as the minimum distance may be restrictive for smaller properties, or for areas where prey are clumped (e.g. lambing paddocks). Increasing the minimum distance to 200 m but recommending a 400-500 m interval would be a suitable compromise.

IV. Where possible, the most palatable bait should be presented to reduce the potential for caching and hence, caching-associated problems. Using palatable bait has also been shown to increase the cost-effectiveness of baiting campaigns. However, the most appropriate bait type for baiting campaigns will depend on the campaign duration, replacement strategy, and approach to caching.

8.6 Specific recommendations for future research

1. Several aspects of baiting should be investigated as a priority. These are specifically:
    a. The difference between caching of toxic bait relative to non-toxic bait to determine if it is due to reduced palatability or death of the individual responsible for making the cache. Comparisons between toxic bait and non-toxic bait need to be continued to ensure that addition of 1080 is not reducing palatability.
    b. The influence of presentation method on caching behaviour, specifically testing buried bait (conventional and mound) and surface laid bait.
    c. The influence of resource availability, as determined by bait density, bait placement and bait spacing, and the effect upon caching behaviour.

2. The use of CTA to reduce multiple bait uptake requires refinement to improve its practical application. The most important issue to resolve is the detectability of the conditioning agent. Given that poisoning is likely to continue as an important technique in the management of exotic species, further development of CTA could potentially improve the efficiency and cost-effectiveness of poisoning practices for a range of exotic species. This potential range of applications, and the encouraging trial results to date strongly indicate that research into improving our understanding and practical application of the technique should continue.

3. Aerial baiting should be considered in eastern Australia to improve our ability to cover large areas rapidly. However, a thorough assessment of all the costs and benefits of such a technique, including non-target issues, would be required, given that the rate of bait uptake by foxes is likely to be lower, and bait density would have to be increased relative to ground-baiting.

4. Decision tree modelling should be further developed to encompass a variety of likely scenarios and factors in exotic species management to assist practitioners in choosing between alternative strategies. Given the increasingly pecuniary nature of exotic

species management, such modelling should incorporate economic analyses of management practices.

5. Further investigation and/or consideration of the impact of management strategies on the prey population, in addition to the impact upon the exotic species, is needed to assist in formulating more appropriate exotic species management strategies. This would help to ensure that valuable resources for exotic species management are allocated strategically, where they are needed most. Such an approach is imperative where only limited resources can be allocated to managing the ever-increasing issues associated with exotic species.

APPENDIX 1

PESTICIDE CONTROL (1080 FOX BAIT) ORDER 2002

[Published in Government Gazette No. 225, 22 November 2002, pp 9993 - 10012]

PESTICIDES ACT 1999 – PESTICIDE CONTROL ORDER UNDER SECTION 38

Name

1. This Order is to be known as the Pesticide Control (1080 Fox Bait) Order 2002 .

Commencement

2. This Order commences on 22 November 2002.

Authority for Order

3. This Order is made by the Environment Protection Authority with the approval of the Minister for the Environment under Part 4 of the Pesticides Act 1999.

Revocation of Previous Order

4. The previous Order known as the Pesticide Control (1080 Fox Bait) Order 2000, gazetted on 21 January 2000 is hereby revoked.

Definitions

5. In this Part -

Agvet Code means the provisions applying because of section 5 of the *Agricultural and Veterinary Chemicals (New South Wales) Act 1994.*

Authorised control officer means a person who: –

(a) holds a current:
    (i) certificate of completion issued by NSW Agriculture for the vertebrate pest management course consistent with the current edition of the Vertebrate Pest Control Manual (published by NSW Agriculture); or
    (ii) statement of attainment issued by a Registered Training Provider certifying competency at Australian Qualifications Framework level 4 with respect to the chemical, vertebrate pest and OH&S national units of competency; and
(b) is employed by a Rural Lands Protection Board, NSW Agriculture, Wild Dog Destruction Board, NSW National Parks and Wildlife Service, or other NSW Government Agency or Authority.

NRA means the National Registration Authority for Agricultural and Veterinary Chemicals established by the *Agricultural and Veterinary Chemicals (Administration) Act 1992* of the Commonwealth.

1080 fox bait means –

a) **1080 Poisoned Bait** being bait product prepared by an Authorised Control Officer from fowl heads, fowl eggs, chicken wingettes, boneless red meat, manufactured baits which are dyed blue or green, or pieces of offal such as tongue, kidney or liver and injected with 3 milligrams of 1080 derived from the product RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER (NRA Product Registration Number 33890) per bait; and
b) **Foxoff Fox Bait** (NRA Product Registration Number 40573) containing 3.0mg Sodium Fluoroacetate per bait as its only active constituent; and

c) **Foxoff Econobait** (NRA Product Registration Number 46434) containing 3.0mg Sodium Fluoroacetate per bait as its only active constituent.

Registered training provider means a training provider registered under the Vocational Education and Training Accreditation Act 1990.

Note: It is expected that registered training providers will also be registered training organisations for the purposes of the Australian Qualifications Framework.

Sodium monofluoroacetate is also a reference to sodium fluoroacetate (also known as 1080).

Use includes possess.

Yathong Fox Bait means the registered product Yathong Fox Bait (NRA Product Registration Number 50911) containing 3.0mg sodium fluoroacetate per bait as its only active constituent

Background

Restricted chemical products/restricted pesticides

6. A chemical product containing sodium monofluroacetate (also known as 1080) has been declared to be a "restricted chemical product" under Regulation 45 of the Agricultural and Veterinary Chemicals Code Regulations of the Commonwealth.

   Section 94 of the AgVet Code provides that "A person must not, without reasonable excuse, supply a restricted chemical product, or cause or permit a restricted chemical product to be supplied, to a person who is not authorised to use the product under another law of this jurisdiction."

   In NSW section 4 of the Pesticides Act provides that a "restricted pesticide" means a pesticide that is a restricted chemical product within the meaning of the Agvet Code. Section 17 of the Pesticides Act 1999 provides that a person must not use or possess a restricted pesticide unless authorised to do so by a certificate of competency or a pesticide control order.

Objects

7. The objects of this Order are to –

(a) Authorise those persons described in condition 9(1) to use 1080 fox bait.
(b) Authorise those persons described in condition 9(2) to use **RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER**.
(c) Authorise those persons described in condition 9(3) to use **FOXOFF FOX BAIT** and **FOXOFF ECONOBAIT**.
(d) Authorise those persons described in condition 9(4) to use **YATHONG FOX BAIT**.
(e) Specify the manner in which **1080 POISONED BAIT, RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER, FOXOFF FOX BAIT, FOXOFF ECONOBAIT** and **YATHONG FOX BAIT** may be used in NSW.
(f) Revoke the Pesticide Control (1080 Fox Bait) Order 2000 gazetted on 21 January 2000.

Application

8. This Order authorises the use of **1080 POISONED BAIT**, **RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER, FOXOFF FOX BAIT**, **FOXOFF ECONOBAIT** and **YATHONG FOX BAIT** subject to conditions as specified in this Order.

Persons authorised

9. (1) The following persons are authorised to use, subject to condition 10(1), 1080 fox bait only:-

   (a) Authorised Control Officers and persons directly supervised by Authorised Control Officers; and

(b) Any person who has obtained the 1080 fox bait from an Authorised Control Officer and who is an owner, occupier, manager or authorised agent of the land, property or holding where the 1080 fox bait is to be used.

(2) The following persons are authorised to use, subject to condition 10(2), the product **RENTOKIL A.F. SODIUM MONO-FLOUROACETATE TENATE (1080) BRAND VERMIN DESTROYER** (NRA registration number 33890):

(a) Authorised Control Officers.

(3) The following persons are authorised to use, subject to condition 10(3), **FOXOFF FOX BAIT** (NRA registration number 40573) and **FOXOFF ECONOBAIT** (NRA registration number 46434):

(a) persons who have been appropriately trained or are experienced in the handling or use of 1080 fox baits and are under the control of NSW National Parks and Wildlife Service, Hornsby Shire Council, Ku-ring-gai Municipal Council, Pittwater Council, Ryde City Council, Warringah Council and Willoughby City Council, Taronga Zoo, Parramatta Council, Hunters Hill Council, North Sydney Council, Lane Cove Council, Mosman Council, Macquarie University, Baulkham Hills Council, or State Forests of New South Wales.

(4) The following persons are authorised to use, subject to condition 10(4), **YATHONG FOX BAITS** (NRA registration number 50911):

(a) Authorised Control Officers employed by the National Parks and Wildlife Service and persons directly supervised by the Authorised Control Officers.

Conditions on the use of 1080 fox bait, RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER, FOXOFF FOX BAIT, FOXOFF ECONOBAIT and YATHONG FOX BAIT

10. (1) The person must only use 1080 fox bait in accordance with the permit described as "Permit to allow use of 1080 baits for control of Foxes" PERMIT NUMBER PER2746 issued by the NRA, as set out in Schedule 1 to this Order.

(2) The person must only use **RENTOKIL AF SODIUM MONO-FLUOROACETATE TENATE (1080) BRAND VERMIN DESTROYER** for the purpose of producing 1080 Poisoned Bait in accordance with section 3 of the 4th edition of the Vertebrate Pest Control Manual (published by NSW Agriculture 1996) and in accordance with the permit described as "Permit to allow use of 1080 baits for control of Foxes" PERMIT NUMBER PER2746 issued by the NRA, as set out in Schedule 1 to this Order.

(3) The person must only use **FOXOFF FOX BAIT** or **FOXOFF ECONOBAIT** in accordance with the permit described as "Permit to allow use of 1080 baits for control of Foxes" PERMIT NUMBER PER5448 issued by the NRA , as set out in Schedule 2 to this Order.

(4) The person must only use **YATHONG FOX BAITS** in accordance with the instructions on the NRA approved label for this product and the conditions set out in schedule 3 to this Order.

Notes

Words used in this Order have the same meaning as in the Pesticides Act 1999.

A person must not contravene this Order – maximum penalty $120 000 in the case of a corporation and $60 000 in the case of an individual.

A pesticide control order remains in force until it is revoked by another pesticide control order.
Note: Any permit issued by the NRA which is set out in this Order has effect in NSW until such time as this Order is revoked.

LISA CORBYN
Director-General
Environment Protection Authority

BOB DEBUS MP
Minister for the Environment

Schedule 1

(Condition 10)

PERMIT TO ALLOW USE OF 1080 BAITS FOR CONTROL OF FOXES

PERMIT NUMBER – PER2746

This permit is issued by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) under the Agvet Code scheduled to the *Agricultural and Veterinary Chemicals Code Act 1994* to the permit holder stated above. The holder of the permit must comply with all requirements as specified in the Agvet Code. A summary of the key requirements are that the holder must:

- supply any requested information to the NRA;
- inform the NRA if they become aware of any relevant information concerning the uses dealt with by this permit;
- comply with a lawful direction or requirement of an inspector; and
- provide a copy of the permit to persons who wish to possess and/or use the product for the purpose specified in this permit.

This permit for the reason given below allows any person listed in ***1. Persons*** to possess and use the products listed in ***2. Products*** for the use specified in ***3. DIRECTIONS FOR USE*** in the jurisdictions listed in ***4. States*** according to ***CONDITIONS OF PERMIT.***

Persons who wish to possess and use 1080 baits for the purposes specified in this permit must read, or have explained to them the permit, particularly the information included in ***CONDITIONS OF PERMIT***.

If this permit were not issued possession and use of these products, specified in ***2. Products*** would constitute an offence under the Agvet Codes.

The persons listed in ***1. Persons*** must comply with all conditions listed in ***CONDITIONS OF PERMIT*** to be covered by this permit.

THIS PERMIT IS IN FORCE FROM 1 OCTOBER 1999 TO 1 NOVEMBER 2002♦.
It is in force until it expires or it is cancelled, suspended or surrendered.

Reason for issue of permit:
In NSW supply and use of sodium fluoroacetate (1080) bait is subject to special conditions on use which may from time to time change due to regulatory requirements. NSW Agriculture has published the a Vertebrate Pest Control Manual (currently 4th edition July 1996) which stipulates the manner in which pesticides, among other methods, should be used to control vertebrate pests. This permit is consistent with the manual and places constraints on use of 1080 baits for fox control.

DETAILS OF PERMIT

1. ***Persons***

Persons are owners, occupiers, managers, authorised agents of the land (property or holding), Authorised Control Officers and persons directly supervised by Authorised Control Officers in respect to possession and use of 1080 products listed in 2. ***Products.***

2. ***Products***

(i) 1080 POISONED BAIT

♦ Note – the requirements set out in this permit continue until this Pesticide Control Order is revoked. Please disregard the expiration date stated above.

Containing 3mg SODIUM FLUOROACETATE per bait, as its only active constituent.
For the purposes of this permit "1080 Poisoned Bait" is a bait product prepared from bait material to which is added 3 milligrams of 1080 from the product **RENTOKIL AF SODIUM MONOFLUOROACETATE TENATE 1080 BRAND VERMIN DESTROYER** per bait, to be used for the control of foxes. Only fowl heads, fowl eggs, chicken wingettes, boneless red meat, manufactured baits that are dyed blue or green, or pieces of offal such as tongue, kidney or liver can be used as bait for fox control. With the exception of fowl heads, fowl eggs and chicken wingettes, the baits requiring 1080 injection must weigh about 100g.

(ii) FOXOFF FOX BAIT
Containing 3.0mg SODIUM FLUOROACETATE per bait as its only active constituent.

(iii) FOXOFF ECONOBAIT
Containing 3.0mg SODIUM FLUOROACETATE per bait as its only active constituent.

3. DIRECTIONS FOR USE

Situation	Pest	Rate
RURAL AND BUSHLAND AREAS	FOXES	Refer to the ***CONDITIONS OF PERMIT***

Critical Use Comments:
Refer to instructions in ***CONDITIONS OF PERMIT.***

4. States
NSW

CONDITIONS OF PERMIT

1. POSSESSION OF 1080 POISONED BAIT, FOXOFF FOX BAIT AND FOXOFF ECONOBAIT

1.1 The products 1080 Poisoned Bait, Foxoff Fox Bait and Foxoff Econobait for the purpose of this permit will henceforth be referred to as "1080 baits" except where indicated otherwise.

1.2 This permit allows **Persons,** if they fully comply with ***CONDITIONS OF PERMIT,*** to possess 1080 baits and to claim that 1080 baits can be used for the purposes as outlined in ***3. DIRECTIONS FOR USE.***

1.3 Each person who takes possession of any 1080 baits must first sign an indemnity form.

1.4 A person who owns or occupies more than one property or holding or their authorised agent or manager must complete and provide to the Authorised Control Officer who supplies the 1080 baits, a separate indemnity form in respect of each property or holding before any 1080 baits may be used on a specific property or holding.

1.5 An Authorised Control Officer must only issue 1080 baits to a person who is the owner or occupier of the land on which the 1080 baits are to be used ("landholder"), unless the person to whom the 1080 baits are issued is known by the Authorised Control Officer, to be the manager or authorised agent of the owner or occupier, and in control of the land upon which the 1080 baits are to be used or the person is under the direct supervision of the Authorised Control Officer.

1.6 Persons as stated under ***1. Persons*** may only temporarily possess and store 1080 baits. 1080 baits must be stored in a lockable storage area away from children, animal food, foodstuffs, seed and fertiliser. Where 1080 bait is required to be placed in a refrigerator, the refrigerator must not be concurrently used to store food and must be located in a lockable storage area. All 1080 Poisoned Bait should be used immediately but where this is not possible 1080 Poisoned Bait must be used within 7 days. Foxoff products must be used within 1 month of purchase from the issuing Rural Lands Protection Board. All unused Foxoff or be returned to the issuing Rural Lands Protection Board within 1 month of purchase.

2. DIRECTIONS FOR USE - GENERAL RESTRICTIONS

2.1 A person must not place the 1080 baits in a position accessible to children, livestock, or domestic animals or pets.

2.2 A person must not feed 1080 baits to wild or domestic birds.

2.3 A person must not apply 1080 baits to, or in, crops.

2.4 A person must not allow 1080 baits to contaminate foodstuffs, or feed, for human or non-target animal consumption.

2.5 Containers (including plastic bags) which have held 1080 baits are not to be used for any other purpose and must be disposed of by burning or deep burial.

2.5.1 Burial

Triple rinse or pressure rinse containers before disposal. Dispose of rinsate in a 1 metre deep disposal pit and cover with at least 500mm of soil. The disposal pit must be specifically marked and set up for this purpose and clear of waterways (permanent or ephemeral). Break, crush or puncture and dispose of empty rinsed containers in a local authority landfill. If no landfill is available, bury the containers below 500mm in a 1metre deep disposal pit on the property where the 1080 baits were used.

2.5.2 Burning

Empty containers may be burnt by open fire as prescribed by a notice of approval under the *Clean Air (Control of Burning) Regulation 1995*. Persons using 1080 baits and wishing to dispose of bait packaging are subject to the following conditions:

1. The amount of Bait Packaging to be burnt at any premises on any single day must not exceed 100 bags or 10 kg without the prior written approval of the Environment Protection Authority (EPA).
2. The burning of the Bait Packaging must be conducted in accordance with the public notification requirements in condition 4.1 of this permit.
3. The burning of the Bait Packaging must be carried out at least 500 metres from any human habitation.
4. The burning must be carried out in accordance with any requirement of the *Rural Fires Act 1997* and the *Fire Brigades Act 1989*, as administered by the relevant local authority and the NSW Fire Brigades.
5. The open fire burning must not be carried out on a day subject to a no-burn notice declared by the EPA under provisions of the *Clean Air Act 1961*.
6. The open fire burning must be carried out only in dry weather using such practicable means as may be necessary to minimise visible smoke emissions causing air pollution.

2.6 A person must not contaminate dams, rivers, streams, waterways or drains with 1080 baits or used containers.

2.7 1080 Poisoned Bait must be kept and stored in the labelled (as shown in **attachment 1**) plastic bag in which the 1080 Poisoned Bait is supplied to the landholder. Foxoff Fox Bait and Foxoff Econobait must be kept and stored in the container supplied by the manufacturer and bearing the NRA approved label.

2.8 At the end of a baiting program a person who has received 1080 baits must ensure that all untaken baits at baiting locations are collected and removed. All collected and uneaten 1080 baits must be disposed of, as soon as possible on the property where the 1080 baits were used by burial in a 1 metre deep disposal pit (except for Foxoff products which must be returned to the Rural Lands Protection Board in accordance with condition 1.6), Buried 1080 baits must be covered with at least 500mm of soil. The disposal pit must be clear of waterways (permanent or ephemeral).

2.9 Continuous and ongoing baiting may be necessary in some instances to reduce the impacts of fox predation on native fauna. Such programs may be undertaken only if the risk to non-target species is low (see also 10. Risk to Domestic Animals).

3. DIRECTIONS FOR USE - DISTANCE RESTRICTIONS

3.1. The minimum distances in this permit for the laying of 1080 baits have been set to minimise the risk to people and to non-target animals. 1080 baits must not be laid where they can be washed into or contaminate surface or groundwaters. 1080 baits must not be laid in areas where distance restrictions cannot be met. Other control methods must be used in those areas.

3.2 ***Property Boundary:*** No 1080 baits shall be laid within 5 metres from any property boundary.

3.3 ***Habitation (means the dwelling or other place where any person, other than of the owner/occupier carrying out the baiting, lives):*** No 1080 baits shall be laid within 500 metres of a habitation.

An exemption is permitted in certain cases where a group of adjoining landholders all agree in writing to use 1080 baits as part of a coordinated fox control program. This coordinated fox control program cannot be implemented **UNLESS**:

(i) **ALL** the landholders in the group are made fully aware of the problems associated with 1080 baits in closely settled areas; AND

(ii) **EVERY** landholder in the group signs an agreement that they:
   - (a) have had explained to them the problems associated with 1080 baits in closely settled areas; and
   - (b) understands these problems; and
   - (c) waives the 500 metres distance restriction from their dwelling; and
   - (d) agrees with to allow implementation of the poisoning program; and
   - (e) accepts all responsibility for any problems arising from the program; AND

(iii) **ALL** the landholders of the outermost holdings of the group abide by all the requirements of this permit in relation to adjoining properties not covered by the group activity.

3.4 ***Domestic Water Supply (means the water line or small dams from which water is pumped or the draw-off point from such as wells, bores, etc.):*** No 1080 baits shall be laid within 10 metres of a domestic water supply.

4. PUBLIC NOTIFICATION

4.1 A person shall not lay any 1080 baits or burn plastic bags or containers in which 1080 baits were stored unless the person has first given a minimum of 3 days notice of the date the 1080 baits are to be laid and that plastic bags or containers which contained 1080 baits may be burnt on the property where the 1080 baits were used, to the occupier of every property which has a boundary within one kilometre of a baiting location or in the case of 1080 bait containers, the site where they will be burnt ("notification").

4.2. The notification can be given by telephone or in person, or, where this is not possible, by mail. If neighbours cannot be contacted by telephone, personal contact and mail then notification by advertisement in a local newspaper is permissible but only after all other methods of contacting neighbours have been unsuccessful.

4.3 Baiting may be conducted for longer than 7 days but must commence within 7 days of this notification otherwise further notification of intended baiting is required.

4.4 Where baiting programs are continuous and ongoing (in accordance with condition 2.9) notification must be undertaken at intervals no greater than 6 months.

5. EMERGENCY BAITING

5.1 A person whose stock or poultry are being mauled, killed or harassed may lay up to fifty (50) 1080 baits with approval from an ACO. This is the only occasion where the normal 3 day public notice period is not required. The landholder must however, notify anyone, whose property boundary lies within one kilometre of a baiting location immediately **before** laying the 1080 baits.

6. 1080 POISONING NOTICES

6.1 In every situation where a person lays 1080 baits, they must erect notices immediately before 1080 poisoning operations commence on a property. This also applies before emergency baiting can begin.

These notices must remain up for a minimum of 4 weeks from the last day of baiting. Notices must be placed:

(i) At every entry to the property; and

(ii) At the entrance to the actual baiting location; and

(iii) At the extremities of and at 1 kilometre intervals along the property boundaries where the property fronts a public thoroughfare.

6.2 The Notices may be obtained from the Rural Lands Protection Board, and must specify which animal species is being poisoned, and the date the 1080 baits are first laid or the dates between which 1080 baits will be laid.

7. 1080 GROUND BAITING ON SMALL HOLDINGS

7.1 Where a person lays 1080 baits on a property of less than 100ha, the person must check the 1080 baits not later than the 3rd night after the 1080 baits have been laid, and must collect and destroy all untaken 1080 baits before the 7th night after the 1080 baits were laid. All untaken 1080 baits are to be disposed of in accordance with condition 2.8. This does not preclude replacement baiting for longer than 7 nights where 1080 baits continue to be taken.

7.2 Baiting locations or stations must be a minimum distance of 100 metres apart and only a maximum of ten 1080 baits can be used per kilometre of trail provided the total number of baits used does not exceed one (1) bait per hectare.

8. FOX CONTROL - BAIT NUMBERS AND DISTRIBUTION

8.1 A person who lays 1080 baits must:

(i) Not lay more than ten 1080 baits per kilometre of trail (ie baiting locations or stations must be a minimum distance of 100 metres apart). The only variation permitted is mound baiting provided the total number of baits does not exceed one (1) bait per hectare; and

(ii) Not lay more than fifty (50) 1080 baits on any one property or holding unless the baiting program is planned in conjunction with an Authorised Control Officer; and

(iii) Lay the 1080 baits in such a way that any untaken 1080 baits can be readily found and destroyed in accordance with condition 2.8.

9. BAIT PLACEMENT PROCEDURES

9.1 Bury 1080 baits in a shallow hole dug with a mattock or similar instrument and cover with earth. If practicable, tie 1080 baits to a fence with a cord and mark the burial spot so that 1080 baits can be easily found and replaced and, at the end of the program, picked up and destroyed.

9.2 There is no need to free feed. For small scale ground baiting, 1080 baits must only be laid where untaken 1080 baits can be readily found.

10. RISK TO DOMESTIC ANIMALS

10.1 Precautions must be taken in closely settled areas to avoid poisoning of domestic pets. As 1080 is particularly lethal to domestic dogs, it is advisable to tie up or muzzle dogs during poisoning operations.

10.2 1080 baits must not be laid within close proximity to urban areas unless the baiting program is planned in conjunction with, and has been agreed to by an Authorised Control Officer. Such programs must include strategies for minimising risk to non-target animals. Proposals for baiting in closely settled farming areas or areas within four (4) kilometres of a village or any street with a speed restriction of 70 kilometres per hour or less, fall within this requirement.

11. RISK TO ENVIRONMENT AND WILDLIFE

Routine agricultural activities are effectivelyexempt from provisions of the *Threatened Species Conservation Act 1995* (*TSC Act*) and the *Environment Planning and Assessment Act 1979* (*EP&A Act*) but persons using 1080 baits should be aware that large scale cooperative baiting programs may trigger provisions of the *EP&A Act* and may require an environmental impact statement. NSW Agriculture also holds a general Section 120 licence that requires it to provide notification if it becomes aware of the presence of threatened species. Persons using 1080 baits should pass on this information where it exists, and should carefully choose bait types and placement techniques to minimise the impact on threatened species.

Further information on the *EP&A Act* can be obtained from the Senior Environmental Planner, Department of Urban Affairs and Planning on 02 9391 2343 and in relation to the *TSC Act* from the Manager Threatened Species Unit, National Parks and Wildlife Service on 02 9585 6542.

12. RISK TO HUMANS

12.1 SAFETY DIRECTIONS:

VERY DANGEROUS. Poisonous if swallowed. When opening the container and handling the bait, wear cotton overalls buttoned to the neck and wrist, washable hat and elbow-length PVC or nitrile gloves. If product gets on skin, immediately wash area with soap and water. After use and before eating, drinking or smoking, wash hands, arms and face thoroughly with soap and water. After each day's use, wash contaminated clothing and gloves.

12.2 FIRST AID:

If poisoning occurs, contact a doctor or Poisons Information Centre on 131126 at once. Urgent hospital treatment is likely to be needed. DO NOT induce vomiting. If skin contact occurs, remove contaminated clothing and wash skin thoroughly. Remove from contaminated area. Apply artificial respiration if not breathing. If in eyes, holdeyelids apart and flush the eyes continuously with running water. Continue flushing until advised to stop by the PIC or a doctor.

Issued by

Delegated Officer

ATTACHMENT 1

DANGEROUS POISON S7

KEEP OUT OF REACH OF CHILDREN
READ SAFETY DIRECTIONS BEFORE OPENING OR USING

1080 POISONED BAIT

ACTIVE CONSTITUENT: 0.0025 TO 0.006g of SODIUM MONOFLUOROACETATE (1080) per kg of bait

FOR THE CONTROL OF WILD DOGS OR FOXES

DIRECTIONS FOR USE: TO BE USED ONLY IN ACCORDANCE WITH REGULATIONS FOR WILD DOGS OR FOX CONTROL IN NSW.

NOT TO BE USED FOR ANY PURPOSE OR IN ANY MANNER CONTRARY TO THIS LABEL UNLESS AUTHORISED UNDER APPROPRIATE LEGISLATION.

SAFETY DIRECTIONS:
Very dangerous. Poisonous if swallowed. When opening the bag and handling the bait wear cotton overalls, washable hat elbow-length PVC gloves. If products gets on skin immediately wash area with soap and water. After use and before eating, drinking or smoking, wash hands, arms and face thoroughly with soap and water. After each day's use wash gloves and contaminated clothing.

FIRST AID:
If poisoning occurs, contact a doctor or Poisons Information Centre on 131126 at once. Urgent hospital treatment is likely to be needed. DO NOT induce vomiting. If skin contact occurs, remove contaminated clothing and wash skin thoroughly. Remove person from contaminated area. Apply artificial respiration if not breathing. If in eyes, hold eyelids apart and flush the eyes continuously with running water. Continue flushing until advised to stop by the Poisons Information Centre or a doctor.

PROTECTION OF LIVESTOCK, WILDLIFE AND OTHERS:
Remove all livestock from baited area.
Do not leave baits accessible to domestic animals, children and non-target wildlife.
Do not contaminate streams, rivers or waterways with the product or this plastic bag.

TRANSPORT, STORAGE AND DISPOSAL:
This bait must be kept inside a secure location, away from food after procuring bait from the Rural Lands Protection Board. Store bait only in this approved plastic bag. Bait can only be placed in a refrigerator that is not used to store food. This bait should be used immediately but where this is not possible baits must be used within 7 days of acquiring it from the Rural Lands Protection Board. Do not allow bait to contaminate foodstuff or feed intended for human or animal consumption. Plastic bags which have held bait should not be used for any other purpose. Dispose of this plastic bag and all unused or untaken bait by burying in an approved dump or by burning.

MANUFACTURER'S WARRANTY; EXCLUSION OF LIABILITY:
No responsibility is accepted in respect of this product save those not excludable conditions implied by any Federal and State Legislation.

RURAL LANDS PROTECTION BOARDS **KG NET**

Notes

- *Words used in an Order have the same meaning as in the Pesticides Act 1999.*
- *A person must not contravene a pesticide control order – maximum penalty $120 000 in the case of a corporation and $60 000 in the case of an individual.*
- *A reference to sodium monofluoroacetate is also a reference to sodium fluoroacetate (also known as 1080).*

Schedule 2

(Condition 10)

PERMIT TO ALLOW USE OF 1080 BAITS FOR CONTROL OF FOXES

PERMIT NUMBER – PER5448

This permit is issued by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) under the Agvet Code scheduled to the *Agricultural and Veterinary Chemicals Code Act 1994* to the permit holder stated above. The holder of the permit must comply with all requirements as specified in the Agvet Code. A summary of the key requirements are that the holder must:

- supply any requested information to the NRA;
- inform the NRA if they become aware of any relevant information concerning the uses dealt with by this permit;
- comply with a lawful direction or requirement of an inspector; and
- provide a copy of the permit to persons who wish to possess and/or use the product for the purpose specified in this permit.

This permit for the reason given below allows any person listed in ***1. Persons*** to possess and use the products listed in ***2. Products*** for the use specified in ***3. DIRECTIONS FOR USE*** in the jurisdictions listed in ***4. States*** according to ***CONDITIONS OF PERMIT.***

Persons who wish to possess and use 1080 baits for the purposes specified in this permit must read, or have read to them the permit, particularly the information included in ***CONDITIONS OF PERMIT***.

If this permit were not issued possession and use of these products, specified in ***2. Products*** would constitute an offence under the Agvet Codes.

The persons listed in ***1. Persons*** must comply with all conditions listed in ***CONDITIONS OF PERMIT*** to be covered by this permit.

THIS PERMIT IS IN FORCE FROM 15 MAY 2002 TO 1 NOVEMBER 2002[♦].
It is in force until it expires or it is cancelled, suspended or surrendered.

Reason for issue of permit:
The northern Sydney region contains a green web of interconnecting bushland reserves. This area hosts a diverse range of native fauna including threatened species and requires special management to ensure its long-term integrity. Foxes are a major threat to the on-going survival of many native species within the region. Without this permit there are no effective control techniques for foxes within these urban bushland areas.

This permit allows Foxoff 1080 baits to be used in sensitive bushland areas and lessens the distance restrictions from 500m baiting from habitation to 150m baiting from habitation in the areas specified in this permit. This reduction in the distance restriction will give public Land Managers of urban bushland the opportunity to help protect native wildlife from predation. This reduced distance restriction also creates an extra responsibility for public Land Managers of urban bushland to adequately publicise baiting activities, to liaise with the community, and to address any resulting community concerns. This reduced distance restriction also creates an extra responsibility for public Land Managers of urban bushland to monitor and report the impact of baiting activities.

[♦] Note – the requirements set out in this permit continue until this Pesticide Control Order is revoked. Please disregard the expiration date stated above.

DETAILS OF PERMIT

1. Persons

Persons who have been appropriately trained or are experienced in handling of 1080 baits and who are under the control of NSW National Parks & Wildlife; Hornsby Shire Council; Ku-ring-gai Municipal Council; Pittwater Council; Ryde City Council; Warringah Council; Taronga Zoo, Parramatta Council, Hunters Hill Council, North Sydney Council, Lane Cove Council, Mosman Council, Macquarie University; State Forests; Baulkham Hills Council; OR Willoughby City Council.

2. *Products*

(i) **FOXOFF FOX BAIT**
Containing 3.0mg SODIUM FLUOROACETATE per bait as its only active constituent.

(ii) **FOXOFF ECONOBAIT**
Containing 3.0mg SODIUM FLUOROACETATE per bait as its only active constituent.

3. DIRECTIONS FOR USE

To control FOXES, as specified in the CONDITIONS OF PERMIT, in specified BUSHLAND RESERVES located in the following areas:

NSW NATIONAL PARKS & WILDLIFE SERVICE:
- **Garigal National Park**
- **Sydney Harbour National Park (North Head, Dobroyd Head, Bradley's Head, Nielsen Park & Middle Head)**
- **Lane Cove National Park**
- **Ku-ring-gai Chase National Park (including Barrenjoey Headland)**
- **Muogamarra National Park**
- **Marramarra National Park**
- **Cattai National Park**
- **Scheyville National Park**
- **Pittown Nature Reserve**
- **Windsor Downs Nature Reserve**
- **Castlereagh Nature Reserve**
- **Agnes Banks Nature Reserve**
- **Mulgoa Nature Reserve**
- **Rouse Hill Regional Park**
- **Western Sydney Regional Park**
- **Botany Bay National Park (La Perouse)**

WARRINGAH COUNCIL:
- **Manly Warringah War Memorial Park (Reserve No. 478, 430)**
- **Dee Why Lagoon Wildlife Refuge and the adjacent Long Reef Headland area (Reserve No. 340, 341);**
- **Council managed bushland corridors adjacent to Narrabeen Lakes and Middle Creek (including Jamieson Park and the bushland corridor recreation reserve from Narrabeen Lakes extending along Wakehurst Parkway, Middle Creek and Oxford Creek to Oxford Falls Road West, Meatworks Road and the unnamed and unmade road at the intersection of Morgan Road and Oxford Falls Road West) (Reserve No. 306,180, 1000, 926);**
- **Council managed bushland adjacent to Mona Vale Road and Garigal National Park (including JJ Melbourne Hills Memorial Park, Tumbledown Dick Hill and Kimbriki Waste Recycling centre) (Reserve No. 9054, 618)**
- **Anembo Reserve**
- **Forestville Park (Reserve No. 289, 293).**

HORNSBY SHIRE COUNCIL:
- **Berowra Valley Regional Park**
- **Beecroft Reserve**

PITTWATER COUNCIL:
- **Warriewood Wetlands**
- **Barrenjoey Sandspit**
- **Deep Creek Reserve**
- **Angophora Reserve**
- **Reserve 28 Ingleside Road**

KU-RING-GAI MUNICIPAL COUNCIL:
- **Lovers Jump Creek Reserve (Wahroonga)**
- **Bobbin Head Road Bushland (Turramurra)**
- **Curagul Road Bushland (North Turramurra)**
- **Ku-ring-gai Creek Reserve (St Ives)**
- **Upper Ku-ring-gai Creek Reserve (St Ives)**
- **Cowan Creek Reserve (St Ives)**
- **Clive Evatt (Wahroonga)**
- **Turiban Reserve South (Wahroonga)**
- **Upper Cowan Creek Reserve (Wahroonga)**
- **Governor Phillip Reserve (Gordon)**
- **Bushranger Reserve (Killara)**
- **Illeroy Forest (Killara)**
- **Old She Oak Reserve (Killara)**
- **Seven Little Australians (Killara)**
- **Roseville Bridge Bush (Roseville)**
- **Echo Point Foreshore (Roseville)**
- **Brown's Bush (Wahroonga)**
- **Twin Creek Reserve (Turramurra)**
- **Bradley Reserve (Turramurra)**
- **Sheldon Forest (Turramurra)**
- **Comenarra Bush (Turramurra)**
- **Comenarra Creek Reserve (Turramurra)**
- **Lower Dam Forest (Pymble)**
- **Blackbutt Reserve (Killara)**
- **Lower Blue Gum Creek Bush (Roseville)**
- **Upper Blue Gum Creek Bush (Roseville)**

RYDE CITY COUNCIL:
- **Field of Mars Wildlife Refuge.**
- **Brush Farm Park**

WILLOUGHBY CITY COUNCIL:
- **Explosives Reserve**
- **Harold Reid Reserve**
- **North Escarpment**
- **Rob Reserve**
- **North Arm Reserve**
- **Willis Park**
- **Northbridge Park, Flat Rock Gully**
- **Mowbray Park**
- **Ferndale Park**
- **Blue Gum Park**
- **O.H. Reid Reserve**
- **Clive Park**

TARONGA ZOO
- **Reserve land managed by Taronga Zoo**

PARRAMATTA COUNCIL
- **Vineyard Creek Reserve, Telopea**
- **McCoy Park, Toongabbie**
- **John Curtin Reserve, Northmead**
- **Moxham Park, Northmead**
- **Campbell Hill Pioneer Reserve, Campbell Hill**

- **Lake Parramatta Reserve, North Parramatta**
- **Edna Hunt Sanctuary, Epping**
- **Galaringi Reserve, Carlingford**
- **Coxs park, Carlingford**
- **Duck River Bushland, Granville**

HUNTERS HILL COUNCIL
- **Boronia Park Reserve**
- **Great North Walk from Buffalo Creek Reserve to Boronia Park Reserve**

NORTH SYDNEY COUNCIL
- **Ball Head Reserve**
- **Berry Island Reserve**

LANE COVE COUNCIL
- **Blackman Park north to Stringybark Creek**

MOSMAN COUNCIL
- **Reid Park**
- **Little Ashton Park**
- **Balmoral Park**
- **Larry Plunkett Reserve**
- **Parriwi Park and Parriwi Point**

MACQUARIE UNIVERSITY
- **Macquaqrie University fauna park**

BAULKHAM HILLS COUNCIL
- **Hunts Creek Reserve**
- **Excelsior Reserve**

STATE FORESTS OF NEW SOUTH WALES
- **Cumberland State Forest**
- **Darling Mills State Forest**

4. States
New South Wales ONLY.

CONDITIONS OF PERMIT

1. POSSESSION OF FOXOFF FOX BAITS

1.1 For the purpose of this permit, the products Foxoff Fox Bait and Foxoff Econobait, will henceforth be referred to as "Foxoff 1080 baits" except where otherwise indicated.

1.2 This permit allows **Persons,** if they fully comply with ***CONDITIONS OF PERMIT,*** to undertake the following actions with Foxoff 1080 baits which contains 3 milligrams SODIUM FLUOROACETATE per bait as their only active constituent:

(i) have Foxoff 1080 baits in their possession for the purposes of use;
(ii) claim that Foxoff 1080 baits can be used for the purposes as outlined in ***3. DIRECTIONS FOR USE.***

1.3 FOXOFF 1080 baits must only be purchased from a Rural Lands Protection Board and must be used within 1 month of purchase or be returned to the issuing Rural Lands Protection Board within 1 month of purchase.

1.4 Persons as stated under ***1. Persons*** may only temporarily possess and store 1080 baits. 1080 baits must be stored in a lockable storage area away from children, animal food, foodstuffs, seed and fertiliser. Foxoff products can only be possessed and stored in accordance with condition 1.3.

2. DIRECTIONS FOR USE - GENERAL RESTRICTIONS

2.1 A person must not place Foxoff 1080 baits in a position accessible to children, livestock, or domestic animals or pets.

2.2 A person must not feed Foxoff 1080 baits to wild or domestic birds.

2.3 A person must not allow Foxoff 1080 baits to contaminate foodstuffs, or feed, for human or non-target animal consumption.

2.4 Containers which have held Foxoff 1080 baits must not to be used for any other purpose and must be disposed of by deep burial.
Triple rinse or pressure rinse containers before disposal. Dispose of rinsate in a 1 metre deep disposal pit and cover with at least 500mm of soil. The disposal pit must be specifically marked and set up for this purpose and clear of waterways (permanent or ephemeral). Break crush or puncture and dispose of empty rinsed containers in a local authority landfill. If no landfill is available, dispose of containers in a 1 metre deep disposal pit and cover with at least 500mm of soil on the property where the Foxoff 1080 baits were used.

2.5 A person must not contaminate dams, rivers, streams, waterways or drains with Foxoff 1080 baits or used containers.

2.6 Foxoff Fox Bait and Foxoff Econobait must be kept and stored in the container supplied by the manufacturer and bearing the NRA approved label.

2.7 All unused Foxoff 1080 baits must be returned to the Rural Lands Protection Board in accordance with condition 1.3. At the end of a baiting program a person who has received Foxoff 1080 baits must ensure that all untaken baits at baiting locations are collected and removed. All untaken Foxoff 1080 baits must be disposed of, as soon as possible by burial in a 1 metre deep disposal pit. Buried Foxoff 1080 baits must be covered with at least 500mm of soil. The disposal pit must be clear of waterways (permanent or ephemeral). It is the responsibility of the person who has received Foxoff 1080 baits to ensure that unused Foxoff 1080 baits are returned and untaken Foxoff 1080 baits are properly disposed of.

3. DIRECTIONS FOR USE - DISTANCE RESTRICTIONS

3.1 Foxoff 1080 baits must not be laid where they can be washed into or contaminate surface or groundwaters. Foxoff 1080 baits must not be laid in areas where distance restrictions cannot be met. Other control methods may be used in those areas.

3.2 ***Boundaries and public thoroughfares (public roads and associated footpaths but not internal roads tracks or trails):***

The minimum distance that Foxoff 1080 baits shall be laid from the boundary of a bushland reserve is 5 metres except for boundaries adjoining public thoroughfares.

The minimum distance that Foxoff 1080 baits shall be laid from the boundary of a bushland reserve which adjoins a public thoroughfare is 50 metres for untethered Foxoff 1080 baits, or 20 metres for tethered Foxoff 1080 baits.

The minimum distance that Foxoff 1080 baits shall be laid from any public thoroughfare traversing the bushland reserve is 50 metres for untethered Foxoff 1080 baits, or 20 metres for tethered Foxoff 1080 baits.

3.3 ***Internal roads, tracks and trails other than public thoroughfares traversing bushland reserves:***

The minimum distance that Foxoff 1080 baits shall be laid from internal roads, tracks, trails is 2 metres except for the section of internal road, track or trail between the boundary of the bushland reserve and a position 150 metres into the bushland reserve.

The minimum distance that Foxoff 1080 baits shall be laid from the section of internal road, track or trail between the boundary of the bushland reserve and a position 150 metres into the bushland reserve is 50 metres for untethered Foxoff 1080 baits, or 20 metres for tethered Foxoff 1080 baits.

3.4 ***Habitation (means the dwelling or other place where any person, other than of the owner/occupier carrying out the baiting, lives):***

No Foxoff 1080 baits shall be laid within 150 metres of a habitation.

3.5 ***Domestic Water Supply (means the water line or small dams from which water is pumped or the draw-off point from such as wells, bores, etc.):***
No Foxoff 1080 baits shall be laid within 10 metres of a domestic water supply.

4. PUBLIC NOTIFICATION

4.1. Public notification must include an advertisement in a prominent local area newspaper at least 5 days prior to the commencement of Foxoff 1080 baiting. Public notification may also include notification by telephone or personal contact, or, where this is not possible, by mail. Public notification must include appropriate details of the baiting program and the closure of bushland reserves to dogs.

5. 1080 POISONING NOTICES AND COMMUNITY NOTIFICATION

5.1 In every situation where Foxoff 1080 baits are laid in a bushland reserve specified under this permit, the person responsible for coordinating the use of Foxoff 1080 baits must ensure that 1080 poisoning notices are erected in that bushland reserve at least 5 days prior to the commencement of Foxoff 1080 baiting.

In every situation where Foxoff 1080 baits are laid in a bushland reserve specified under this permit, the person responsible for coordinating the use of Foxoff 1080 baits must ensure that notices banning dogs are erected in that bushland reserve at least 5 days prior to the commencement of Foxoff 1080 baiting.

These notices must remain up for at least a minimum of 4 weeks from the last day of baiting and, Notices must be placed:

(i) At every made entrance to the Bushland Reserve; and
(ii) At the entrance to the baiting location; and
(iii) At the extremities of and at 1 kilometre intervals along the boundaries where the bushland reserve adjoins a public thoroughfare; and
(iv) At the extremities of and at 1 kilometre intervals along any public thoroughfare traversing the bushland reserve but not along internal roads, tracks or trails.

5.2 The Notices, indicating the presence of Foxoff 1080 baits, must specify which animal species is being poisoned, and the date the Foxoff 1080 baits are first laid or the dates between which Foxoff 1080 baits will be laid.

Any Notices banning dogs must clearly indicate that dogs must not be allowed to enter reserves closed to dogs during a baiting program.

5.3 All neighbours immediately adjoining the bushland reserve boundary, within 300 metres of the site where Foxoff 1080 baits will be laid, must be given a minimum of 5 days written notice prior to the commencement of the baiting program.

6. FOX CONTROL -DIRECTION FOR USE - BAIT NUMBERS AND DISTRIBUTION

6.1 A person who lays Foxoff 1080 baits must:

(i) Not use an excessive amount of 1080 baits. Baiting locations must be a minimum distance of 100 metres apart and no more than ten Foxoff 1080 baits can be placed per kilometre per day. The only variation permitted is mound baiting using multiple baits (maximum three (3) Foxoff 1080 baits per mound) provided the total number of Foxoff 1080 baits used does not exceed one (1) bait per hectare; and
(ii) Lay the Foxoff1080 baits in such a way that any untaken Foxoff 1080 baits can be readily found and destroyed in accordance with condition 2.7
(iii) Each bait site will be made up of a sand pad about one metre in diameter. Foxoff 1080 baits must be buried to a depth of 10 centimetres to reduce the access by non-target species.
(iv) Free feeding must be undertaken at all sites for a minimum of 3 days prior to the commencement of 1080 baiting to establish the presence or absence of foxes and to determine

if other non-target animals are visiting the site. The decision to lay 1080 Foxoff baits is determined by the results of free feeding and condition 7.1(ii) if required for dogs.

(v) 1080 baiting must be discontinued during periods of heavy rainfall.

7. RISK TO DOMESTIC ANIMALS

7.1 The following preventative measures must be undertaken to reduce the risks of domestic dogs taking poisoned bait:

(i) Close Bushland Reserves to dogs during the baiting program.

(ii) If regular dog prints are recorded at bait stations during the free feeding period, further community notification and education should take place.

7.2 All untaken baits which are recovered must be destroyed by deep burial as per condition 2.7.

8. MONITORING OF NON-TARGET EFFECTS

8.1 Adverse effects including deaths of wildlife and animals, other than foxes, must be reported to the Pest Management Officer , North Sydney Region, National Parks and Wildlife Service by telephone (02 9472 8953 or fax (02) 9457 8265

9. RISK TO HUMANS

9.1 In addition to taking appropriate steps to inform the community of the baiting program, the following steps must be undertaken:

(i) All Foxoff 1080 baits will be buried in sand pads as per condition 6.1(ii).

(ii) Where possible, inaccessible places will be chosen as baiting locations to reduce the chances of children or adults finding the bait stations.

9.2 SAFETY DIRECTIONS:

VERY DANGEROUS. Poisonous if swallowed. When opening the container and using the baits, wear elbow-length PVC gloves or Nitrile gloves. If product gets on skin, immediately wash area with soap and water. After use and before eating, drinking or smoking, wash hands, arms and face thoroughly with soap and water. After each day's use, wash contaminated clothing and gloves.

9.3 FIRST AID:

If poisoning occurs, contact a doctor or Poisons Information Centre (phone: 13 11 26). Give large quantities of water and induce vomiting. If skin contact occurs, remove contaminated clothing and wash skin thoroughly. Remove from contaminated area. Apply artificial respiration if not breathing. If in eyes, hold eyes open, flood with water for at least 15 minutes and see a doctor.

Issued by

Delegated Officer

Schedule 3

(CONDITION 10)

USE OF YATHONG FOX BAIT

1. Directions for use

Situation	Pest	Rate	Critical Comments
NSW NPWS MANAGED LAND	Fox	Apply up to 5 Yathong Fox Baits per km^2	Apply only by helicopter or fixed wing aircraft

2. State

NSW only

3. *Conditions on use of Yathong Fox Bait*

3.1 NSW National Parks and Wildlife Service must only employ pilots for aerial application of Yathong Fox Bait if they meet the requirements for aerial licences under section 45 of the Pesticides Act 1999.

3.2 An Authorised Control Officer must:

a. Give approval to any proposed aerial baiting programme; and
b. Directly supervise the application of Yathong Fox Baits or be available to give instruction during the aerial application of Yathong Fox Baits

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